Optimised diagnosis in digital flexor tendon sheath pathology in the horse

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“Until one has loved an animal, a part of one’s soul remains unawakened”

A. France

I want to dedicate this work to the horses, the ones inspiring my path in life. En especial a tu Patufet, per tot el que m’has ensenyat i hem compartit.

I la més especial dedicatòria és per tu mama, per creure sempre en mi i estar sempre, incondicionalment, al peu del canó. T’estimo.
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<tr>
<td>bwt</td>
<td>Body weight</td>
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<tr>
<td>CI</td>
<td>Confidence interval</td>
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<tr>
<td>CT</td>
<td>Computed tomography</td>
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<tr>
<td>CV</td>
<td>Coefficient of variability</td>
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<td>DDFT</td>
<td>Deep digital flexor tendon</td>
</tr>
<tr>
<td>DFTS</td>
<td>Digital flexor tendon sheath</td>
</tr>
<tr>
<td>DIP</td>
<td>Distal interphalangeal (joint)</td>
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<tr>
<td>DSLs</td>
<td>Distal sesamoidean ligaments</td>
</tr>
<tr>
<td>EDTA</td>
<td>Ethylenediaminetetraacetic acid</td>
</tr>
<tr>
<td>ELISA</td>
<td>Enzyme-linked immunosorbent assay</td>
</tr>
<tr>
<td>FLASH</td>
<td>Fast low angle shot</td>
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<tr>
<td>i.v.</td>
<td>Intravenously</td>
</tr>
<tr>
<td>MB</td>
<td>Methylene blue</td>
</tr>
<tr>
<td>MCP</td>
<td>Metacarpophalangeal (joint)</td>
</tr>
<tr>
<td>MHz</td>
<td>Megahertz</td>
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<tr>
<td>MNT</td>
<td>Mechanical nociceptive threshold</td>
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<tr>
<td>MRI</td>
<td>Magnetic resonance imaging</td>
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<tr>
<td>MTP</td>
<td>Metatarsophalangeal (joint)</td>
</tr>
<tr>
<td>N</td>
<td>Newton</td>
</tr>
<tr>
<td>NB</td>
<td>Navicular bursa</td>
</tr>
<tr>
<td>OR</td>
<td>Odds ratio</td>
</tr>
<tr>
<td>PAL</td>
<td>Palmar/plantar annular ligament</td>
</tr>
<tr>
<td>PD</td>
<td>Proton density</td>
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<tr>
<td>PIP</td>
<td>Proximal interphalangeal (joint)</td>
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<tr>
<td>PSB</td>
<td>Proximal sesamoid bone</td>
</tr>
<tr>
<td>s.d.</td>
<td>Standard deviation</td>
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<td>SDFT</td>
<td>Superficial digital flexor tendon</td>
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<tr>
<td>STIR</td>
<td>Short $\tau$ inversion recovery sequence</td>
</tr>
<tr>
<td>T2 TSE</td>
<td>T2 turbo spin echos</td>
</tr>
<tr>
<td>UTC</td>
<td>Ultrasound tissue characterisation</td>
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Preface
The digital flexor tendon sheath (DFTS) is an important synovial structure of the equine limb in which pathology can regularly be encountered. Lesions of the DFTS and its related structures often result in lameness, which generates discomfort to the horses hence preventing them from achieving their intended level of work. Orthopaedic examinations are routinely performed to identify the exact origin of pain causing lameness, allowing therefore to provide the most adequate treatment. With the currently available diagnostic methods, diagnostic analgesia remains indispensable during lameness examinations to localise the source of pain causing lameness. Several authors however, have questioned the specificity of DFTS analgesia, but the exact mechanism responsible for this lack of specificity remains unknown. Additionally, endoscopic examination of the DFTS has become routine for diagnosis (and treatment) of DFTS lesions. Although the anatomy of the DFTS has been well described, the digital manica flexoria has been inconsistently mentioned even unrecognised, despite being one of the structures that is visualised during DFTS tenoscopy.
The equine digital flexor tendon sheath

A review of its anatomy and pathophysiology, and the diagnosis, treatment, and prognosis of its most common disorders

Part of this review has been published:

Tenosynovitis of the digital flexor tendon sheath in the horse: diagnosis and treatment

Tenosynovitis van de sesamschede bij het paard: diagnostiek en behandeling

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Adapted from:

SUMMARY

Equine clinicians are often confronted with lame horses presenting distension of the digital flexor tendon sheath. This synovial structure is rather complex and offers several diagnostic and therapeutic challenges. This chapter reviews the anatomy, physiology, and pathophysiology of the digital flexor tendon sheath, and the diagnostic methods, treatment, and prognosis of non-infectious tenosynovitis of this synovial structure in horses.
Lameness is the most common cause of health problems in horses and is a leading cause of poor performance. In the majority of cases, pain originates from the distal part of the extremities (at the level of or distal to the carpus and tarsus), with front limb or hind limb involvement mainly depending on the horses’ sport discipline (Back et al., 1995; Baxter and Stashak, 2011a). For example, carpal or fetlock problems (synovitis or fractures) are commonly encountered in racehorses while foot problems, fetlock osteoarthritis or tenosynovitis are more commonly observed in jumping and dressage horses (Ross, 2010).

The digital flexor tendon sheath (DFTS) is a complex synovial structure that surrounds the digital flexor tendons at their passage along the palmar/plantar aspect of the fetlock joint. Lesions of the tendon sheath and its related structures are often diagnosed in horses as the cause of lameness. Septic and aseptic aetiologies are possible. Due to its localisation, the DFTS is often involved in distal limb lacerations resulting in serious septic tenosynovitis that needs prompt recognition and appropriate treatment. However, this chapter will focus on the non-infectious disorders of the DFTS that cause lameness in sport horses, preventing them from performing at their intended level.
1.1. ANATOMY OF THE EQUINE DIGITAL FLEXOR TENDON SHEATH
AND RELATED STRUCTURES

1.1.1. Gross anatomy

The gross anatomy of the equine extremities has been well described in literature (Sisson and Grossman, 1975; De Lahunta, 1986; Nickel et al., 1986; Denoix, 1994; Barone, 2000; Dyce et al., 2002). Although tendon and ligament anatomy varies between the thoracic and the pelvic limbs, it is quite similar at the level of the digit. Therefore the terms palmar and metacarpal will be used throughout this section, except for specific features in the pelvic limbs where the terms plantar and metatarsal will be used instead.

The DFTS is a thin-walled synovial structure that surrounds both the superficial and deep digital flexor tendons from the distal third of the palmar metacarpal region to the middle third of the middle phalanx, just proximal to the navicular bursa (Bursa podotrochlearis) and the palmar pouch of the distal interphalangeal joint (Figure 1).

The wall of the DFTS is composed of two layers: an inner synovial layer, which produces the constituents of the synovial fluid, and an outer fibrous layer, which provides structural support and vascularity. The palmar wall of the DFTS incorporates three annular ligaments: the palmar annular ligament (PAL), the proximal digital annular ligament, and the distal digital annular ligament. These three ligaments are local thickenings of the fibrous layer of the DFTS wall with a transverse fibre pattern, which stabilise both flexor tendons to the palmar aspect of the digit. The PAL inserts on the palmar border of both proximal sesamoid bones (PSBs) and has a sagittal adhesion to the palmar surface of the superficial digital flexor tendon (SDFT). The proximal digital annular ligament has a quadrilateral shape and its four corners insert to the proximal and distal collateral tubercles.
of the proximal phalanx. The distal digital annular ligament attaches proximally to either side of the middle third of the proximal phalanx, forming a sling across the palmar aspect of the deep digital flexor tendon (DDFT). Distally, there are connections from this ligament to the digital cushion.

**Figure 1.** A) Illustration of the location of the digital flexor tendon sheath (dashed blue line) in the equine distal limb. B) Sagittal anatomical section of a distal limb after methyl methacrylate injection of the synovial structures. Digital flexor tendon sheath (blue); Synovial articular recesses (yellow); Navicular bursa (red).

S: superficial digital flexor tendon; D: deep digital flexor tendon; *: manica flexoria; I: intersesamoidean ligament; Black arrow heads: proximal scutum; DSL: distal sesamoidean ligaments; Green arrow heads: middle scutum.
The dorsal wall of the DFTS is bordered by the proximal scutum, the middle scutum, the distal sesamoidean ligaments (DSLs) and the middle phalanx. The proximal scutum and the middle scutum are strong fibrocartilagenous pads containing transversely oriented collagen fibres that allow sliding of the flexor tendons along the palmar aspect of the fetlock and pastern joints respectively (Figure 1B). The fibrocartilagenous pad of the proximal scutum covers the PSBs and the intersesamoidean ligament (*Ligamenta palmaria*). The fibres of the intersesamoidean ligament and the proximal scutum are continuous with those of the PAL and together they form an inelastic canal around the digital flexor tendons on the palmar aspect of the fetlock, which is commonly known as the fetlock canal. The middle scutum inserts proximally to the palmar aspect of the distal condyles of the proximal phalanx, and distally to the flexor tubercle (*Tuberositas flexoria*) of the middle phalanx. Distal to the fetlock, the DSLs represent the functional continuation of the suspensory ligament (*M. interosseous medius*) in the digit. This complex of ligaments is formed by (from palmar to dorsal): the straight sesamoidean ligament, the oblique sesamoidean ligaments, the cruciate sesamoidean ligaments, and the short sesamoidean ligaments. They all originate from the base of the PSBs and the intersesamoidean ligament (or proximal scutum), but insert on different sites: the straight sesamoidean ligament attaches to the proximopalmar aspect of the middle phalanx, on the middle scutum, together with the distal branches of the SDFT and the palmar ligaments of the proximal interphalangeal joint. The oblique sesamoidean ligaments converge distally in a V-shape and insert on the triangular area on the palmar aspect of the proximal phalanx. The cruciate sesamoidean ligaments cross in an X-shape and insert to the proximopalmar margin of the opposite tuberosity of the proximal phalanx. The short sesamoidean ligaments run from the axial border of the base of each PSB to the abaxial proximal border of the proximal phalanx, between the cruciate sesamoidean ligaments and the palmar...
capsule of the metacarpophalangeal joint. From this group of ligaments, only the straight sesamoidean ligament and the oblique sesamoidean ligaments are directly involved with the dorsal wall of the DFTS.

The DFTS has several synovial recesses (Figure 1B): the proximal recess is located proximal to the manica flexoria and the PAL, mainly dorsal to the DDFT. The collateral recesses are located at the medial and lateral aspects of the pastern, between the flexor tendons and the DSLs, and between the flexor tendons and the proximal digital annular ligament. The distal recess extends between the middle phalanx and the dorsal aspect of the DDFT and presents a palmar pouch, palmar to the DDFT, between the proximal and distal digital annular ligaments (Denoix, 1994).

The superficial and deep digital flexor tendons are the two main structures incorporated in the DFTS. At the proximal level of the DFTS, the cross sectional profile of the SDFT has a half-moon shape with a sharp lateral border and a more rounded medial border. At the level of the fetlock canal, its shape becomes symmetric and wider. Proximal to the PSBs, the medial and lateral borders of the SDFT give rise to the manica flexoria, a tendinous band that surrounds the DDFT, with a free distal border and a proximal border connected to the DFTS wall (Figure 2). At the middle third of the proximal phalanx, the SDFT splits in two distal branches that insert on the palmar side of the distal collateral tubercles of the proximal phalanx and the flexor tubercle of the middle phalanx. A fibro-tendinous communication between these two branches, at the mid-level of the proximal phalanx and dorsal to the DDFT, is observed on gross dissections and tenoscopically (Figure 2). However, this structure has not been consistently described in the veterinary literature and it can be found under different names such as digital or distal manica flexoria (Smith and Wright, 2006; Fiske-Jackson et al., 2013; McIlwraith et al., 2014), distal ring
(Redding, 1993), distal girdle (Neumeier et al., 2004) or deep part of the manica flexoria (Dyce et al., 2002), or synovial fold (Denoix, 1991; 1994; 2000).

The DDFT has a rounded shape at the proximal level of the DFTS and its cross sectional profile becomes wider and elliptical when passing on the palmar aspect of the fetlock. In the pastern region, the tendon becomes bilobed and after passing between the two distal branches of the SDFT it is located very superficially. Distally, the DDFT widens as it glides over the palmar aspect of the navicular bone and the navicular bursa, to insert finally on the facies flexoria of the distal phalanx. The normal tendon tissue of the dorsal aspect of the DDFT is replaced by fibrocartilage in the areas where the tendon passes over joints and bony prominences due to the increased frictional and compressive forces recorded at these points. These fibrocartilage regions are also characterised by a decreased blood supply (Kraus et al., 1995).

Figure 2. Lateral view of the structures within the right digital flexor tendon sheath of a horse. The synovial lining has been removed.

S: superficial digital flexor tendon; D: deep digital flexor tendon; MF: manica flexoria; PS: proximal scutum; SSL: straight sesamoidean ligament; *: digital manica flexoria.
Both digital flexor tendons are intimately related to the synovial lining of the DFTS by mesotenons (medially and laterally) and vincula (sagittally). The mesotenons are the reflection between the visceral and parietal layers of the DFTS wall. The vincula are remnants or vestigial strands resulting from the partial regression of the mesotenons. Both the mesotenons and the vincula contain nerves and blood vessels that contribute to the arterial supply of the intrasynovial part of the tendons (Denoix, 1994; Budras et al., 2008; Schramme and Smith, 2010). However, some authors believe in a supportive function of the vincula rather than the commonly assigned nutrient role, especially in areas of higher movement (Neumeier et al., 2004). Several mesotenons and vincula are encountered in the DFTS. The SDFT has two palmar (and sagittal) vincular attachments: one at the level of the PAL, and another at the level of the proximal digital annular ligament (Figure 3).

**Figure 3.** Vincular attachments of the superficial digital flexor tendon at the level of the palmar annular ligament. Proximal is at the left of the image.

PAL: palmar annular ligament and its vincular attachment (*) to the superficial digital flexor tendon (S); PDAL: proximal digital annular ligament and its vincular attachment (>) to the superficial digital flexor tendon.
The DDFT also has several mesotenon and vincular attachments (Figure 4). At the proximal aspect of the DFTS, proximal to the manica flexoria, the abaxial borders of the DDFT are connected with the DFTS wall, both medially and laterally, by short thick mesotenons (Figure 4A). The lateral mesotenon has been reported to be more substantial and to extend further distally compared to the medial one (Redding, 1993; McIlwraith et al., 2014). At the distal aspect of the DFTS, the DDFT has several sagittal vincular attachments, which can differ in number and in size (Figure 4B and 4C): a vinculum between the palmar DFTS wall (or distal digital annular ligament) and the palmar aspect of the DDFT (“palmar vinculum”), a vinculum connecting the dorsal aspect of the DDFT and the digital manica flexoria (palmar aspect) and/or the dorsal DFTS wall (“intermediate vinculum”), and a vinculum connecting the dorsal aspect of the digital manica flexoria and the dorsal DFTS wall (“dorsal vinculum”).

It is generally accepted that no natural anatomical communication exists between the DFTS and adjacent synovial structures. However, some studies have found communication between the DFTS and the distal interphalangeal joint or the navicular bursa after injection of polymer plastic (latex), dye, or radiographic contrast (Gibson et al., 1990; Bowker et al., 1993; 1997). Similarly, other authors have claimed that this communication could exist, but only in young foals (Calislar and St. Clair, 1969; De Lahunta, 1986). To ascertain this hypothesis, we performed a pilot study on 28 cadaveric limbs of 7 foals younger than 4 weeks of age. In total, 28 DFTSs were injected with 10 ml of methylene blue, at the level of the PSBs, using the technique described by Hassel et al. (2000). The limbs were frozen at -20°C for 24h. Subsequently, sagittal sections where obtained to check for the possible presence of methylene blue in synovial structures other than the DFTS (Figure 5). Only one foal showed a communication between the DFTS and the navicular bursa in one limb (left hind limb; Figure 5B).
Figure 4. Vincular attachments of the deep digital flexor tendon. Proximal is at the top of the images. A) Palmar view of the proximal aspect of the digital flexor tendon sheath (DFTS). B) Medial view of the distal aspect of the DFTS. The palmar wall of the DFTS has been reflected distally. C) Palmar view of the distal aspect of the DFTS. The deep digital flexor tendon has been reflected distally.

S: superficial digital flexor tendon; D: deep digital flexor tendon; MF: manica flexoria; PS: proximal scutum; DDAL: distal digital annular ligament; SSL: straight sesamoidean ligament; DMF: digital manica flexoria; Arrow: proximal lining of the DFTS wall; *: proximal medial mesotenon; +: palmar vinculum; >: intermediate vinculum; #: dorsal vinculum.
This foal was born one week prematurely and during delivery the mare presented a premature placental separation. However, it is unclear whether this was associated with the observed communication. Despite the low number of limbs injected in our study, there is some evidence of possible communication between the DFTS and other synovial structures of the digit in the foal.

Figure 5. Sagittal sections of the left hind limbs of two foals. A) The digital flexor tendon sheath (DFTS) shows no communication with other synovial structures. B) Communication of the DFTS with the navicular bursa.
1.1.2. Innervation and blood supply to the DFTS and digital flexor tendons

The DFTS and flexor tendons receive their nerve supply in the metacarpal region from the medial and lateral palmar nerves and their communicating branch. In the digital region (distal to the fetlock joint), innervation is provided by the medial and lateral palmar digital nerves. Both the palmar and palmar digital nerves are located adjacent to the medial and lateral aspects of the DFTS wall over its entire length (Figure 6).

Figure 6. Lateral view of a right front limb of a horse after removal of the skin. The lateral palmar (digital) nerve (coloured in green) is located palmar to the lateral digital vein (blue) and lateral digital artery (red) along the lateral aspect of the digital flexor tendon sheath (dashed black line).
The common palmar digital artery (direct continuation of the median artery) is the main artery responsible for the blood supply to the structures of the front foot of the horse. Just proximal to the fetlock, this artery divides into the lateral and medial digital arteries, the main arteries responsible for the blood supply of the front digit. In the hind limbs, the lateral and medial digital arteries branch off from the dorsal metatarsal artery III.

The blood supply of the tendons arises proximally from the arteries of the musculo-tendinous junction, and distally from the arteries of the osseous insertion. In these areas, the blood supply provides only local perfusion (Peacock, 1959). Hence, in the area between the origin and insertion, tendons receive blood supply from the intratendinous and extratendinous vessels. The intratendinous blood supply is composed of an interlacing arteriolar network that originates directly from branches of the local arteries and supplies the mid-tendon region (Kraus-Hansen et al., 1992). The extratendinous blood supply arises from the paratenon in extrasynovial areas and from the mesotenon attachments in the intrasynovial areas. The predominance of intratendinous or extratendinous blood supply in the mid-tendon region depends on the species and on the tendon. In the case of the equine SDFT, the main blood supply at the mid-metacarpal area is intratendinous and is provided by two major parallel blood vessels that run longitudinally along and within the lateral and medial borders of the tendon, accompanied by an extensive anastomosing network of vessels (Kraus-Hansen et al., 1992). In the case of the DDFT, the principal blood supply to the intrasynovial part of the tendon is provided by mesotenon vessels (extratendinous blood supply) and has three principal vascular sources: (1) a branch of either the medial palmar artery or medial palmar digital artery, proximal to the fetlock, (2) vessels from the palmar branch of the lateral and medial digital arteries to the proximal phalanx, distal to the fetlock, and finally (3) direct branches of the lateral and medial digital arteries, for the most distal aspect of the intrasynovial part of the DDFT. Furthermore, there are intratendinous
vessels from the extrasynovial portion of the DDFT that supply a small region of the proximal intrasynovial portion of the tendon. All these vessels provide the DDFT with an extensive and uniform intratendinous blood supply, except for the region of the tendon within the fetlock canal. Due to the increased frictional and compressive forces at that location, the dorsal aspect of the tendon is replaced by fibrocartilage, and blood vessels are confined to the palmar surface of the tendon. The most distal fibrocartilagenous areas of the DDFT also show a decreased vascular pattern but this poor vascularisation is not as marked as in the fetlock canal (Kraus et al., 1995).

1.1.3. Function of the DFTS, the synovia and the synovial fluid

The main function of the DFTS is to allow a smooth passage of the flexor tendons through the fetlock canal during metacarpophalangeal and interphalangeal joint flexion and extension (Hago et al., 1990; Schramme and Smith, 2010). This gliding function is mainly provided by the synovial fluid of the DFTS, which is produced by the synovial layer of the DFTS wall. The synovial layer is composed of a diverse population of synoviocytes: tissue macrophage A cells (synoviocytes type A), fibroblast-like B cells (synoviocytes type B), and synoviocytes type C cells (which are intermediate between type A and B forms). The synoviocytes are organised in a discontinuous layer with fenestrated capillaries and extracellular matrix occupying the intercellular gaps. The extracellular matrix contains collagen (types VI, III, I and V) and various molecules including hyaluronic acid, chondroitin sulfate, biglycan, decorin, and fibronectin. The underlying layer of loose connective tissue contains numerous lymph vessels for clearance of transported molecules (McIlwraith and Trotter, 1996a; Steel, 2008).
The synovial fluid is an ultra-filtrate of plasma to which hyaluronic acid, proteoglycan 4, and surface-active phospholipids are added by the cells of the synovial layer (mainly type B cells). These molecules are retained within the synovial fluid by the extracellular matrix of the synovial layer. Filtration of plasma through the synovial layer excludes large proteins and molecules from entering the synovial space. Therefore, the composition of the synovial fluid is almost equal to plasma, with similar glucose and electrolytes concentrations but lower levels of proteins (total protein concentration amounts 25% to 35% of the plasma protein concentration) (McIlwraith and Trotter, 1996a; Steel, 2008). Besides lubrication, the synovial fluid also plays an important role in tendon nutrition.

Macroscopically, the synovial fluid of a normal DFTS is clear, pale yellow and should not clot at room temperature. Characteristics of the equine DFTS synovial fluid have been shown to be similar but not identical to equine tarsal joint fluid (Malark et al., 1991). Similar values have been reported for protein concentrations and cell counts, whereas hyaluronic acid concentration has been reported to be lower in the DFTS than in the normal equine joints (Malark et al., 1991). This might be explained by either a reduced production of hyaluronic acid by the synovial intimal cells or by a lower number of synovial intimal cells in the tendon sheath compared to joints (Malark et al., 1991).

The reported mean volume of synovial fluid encountered in the DFTS is approximately 2 ml (Malark et al., 1991). However, it is not uncommon to find horses with a clinically non-significant fluctuant distension of the DFTS (windpuffs or windgalls). One study found significantly higher volumes of synovial fluid in the DFTS of the hind limbs compared to the front limbs (Malark et al., 1991). The synovial fluid contains low numbers of nucleated cells (< 500-1000 nucleated cells/µl), of which the predominant type are
mononuclear cells (approximately 90%). The remaining cells are polymorphonuclear leukocytes (< 10% in normal synovial fluid). Total protein concentration should be < 2 g/dl. Infected synovial fluid has a turbid and watery appearance with total protein concentrations most often > 4 g/dl and nucleated cell counts > 30000 cells/μl, with > 80% neutrophils (McIlwraith et al., 1996a; Steel, 2008).

1.2. DISORDERS OF THE EQUINE DIGITAL FLEXOR TENDON SHEATH

Synovial distension of the DFTS reflects the presence of tenosynovitis that can be caused by lesions or inflammation of the sheath wall itself (primary tenosynovitis) or any of its related tendons or ligaments (secondary tenosynovitis). Regardless of the cause, digital tenosynovitis can present as an acute or chronic disease.

1.2.1. Primary tenosynovitis

Acute non-infectious tenosynovitis can be caused by repeated low-grade trauma to the synovial capsule or by single traumatic insult that causes overstretching or compression of the DFTS. Injury to other structures within the DFTS such as tearing of the mesotenon or of vincular attachments, core lesions or marginal tears of the digital flexor tendons, or tears of the manica flexoria, PAL or digital annular ligaments, may be present simultaneously and complicate the condition (Smith and Wright, 2006; Schramme and Smith, 2010; Owen et al., 2012). Recently, Crawford et al. (2011) reported synovial ganglion cysts as a cause of digital tenosynovitis. These lesions were observed at the proximal aspect of the DFTS wall. The condition was most commonly accompanied by lameness localised in the DFTS and tenoscopy revealed pathologic lesions of other structures within the DFTS in 3 out of 8 cases.
When untreated, acute tenosynovitis often results in a self-perpetuating cycle of inflammation, repeated tearing and fibrosis of the DFTS wall, ending in the development of chronic tenosynovitis. Tenosynovitis presented along with thickening of the PAL, synovial distension, synovial masses and/or adhesions, is known as complex tenosynovitis (Nixon et al., 1993; Fortier et al., 1999; Nixon, 2002).

1.2.2. Secondary tenosynovitis

Most commonly, DFTS tenosynovitis develops in association with marginal tears of the superficial or deep digital flexor tendons or the manica flexoria. Longitudinal tears of the DDFT are most frequently observed (Wright and McMahon, 1999; Wilderjans et al., 2003; Smith and Wright, 2006; Arensburg et al., 2011). They affect more often the front limbs of jumping horses (88%) (Arensburg et al., 2011), in particular the lateral border of the tendon (75%), although they can also be observed at the medial margin (12%) or, seldom, at the dorsal and palmar margins. Two types of tears have been described according to their length (Smith and Wright, 2006; Arensburg et al., 2011). Long tears (> 7 cm) have been diagnosed more frequently (50-61%) and are reported to extend from the proximal aspect of the DFTS to the fetlock canal or even distal to the PAL, and to be commonly located lateral. In contrast, short tears (< 7 cm) occur most frequently distal to the fetlock canal and without lateral dominance. The depth of the lesions may also vary, with superficial tears (< 5 mm) occurring more frequently than the deep tears (> 5 mm) (58% vs. 42%) (Arensburg et al., 2011). Granulomas of the torn tendon fibres can often be observed at the proximal and/or distal limits of the tears. Adhesions between the torn tendon fibrils or other tendon lesions and the DFTS wall have also been described (Smith and Wright, 2006; Arensburg et al., 2011).
Longitudinal tears of the SDFT occur less often (14-15% of the cases) and are commonly located at the lateral and proximal margins of the tendon, especially in the area of transition with the distal margin of the manica flexoria. However, tears of the medial branch of the SDFT have also been reported (Smith and Wright, 2006).

Tears of the manica flexoria have been reported to occur more often in the hind limbs (74%) (Smith and Wright, 2006), and ponies and cobs seem to be overrepresented (Findley et al., 2012). These tears can cause digital tenosynovitis on their own, but they can also accompany marginal tears of the superficial or deep digital flexor tendons (Smith and Wright, 2006; Arensburg et al., 2011). Most manica flexoria tears occur at the attachment of the manica with the SDFT or just adjacent to this site, affecting most commonly the distal free border and the medial side of the manica flexoria (Findley et al., 2012). However, complete separation of the manica flexoria from the SDFT (usually from one side only) is also frequently observed. Often, the free manica flexoria can be found reflected, on the opposite side of the DFTS, and adhesions with the DFTS wall can be observed.

Desmitis (thickening) of the PAL can also cause digital tenosynovitis. However, it is often difficult to determine whether the desmopathy of this ligament is primary or secondary to DFTS tenosynovitis. In either case, the PAL is generally involved in the self-perpetuating cycle of inflammation and compression of intrasynovial structures of the DFTS, hence the term PAL syndrome has been used (Gerring and Webbon, 1984; Fortier et al., 1999).

Horses with desmitis of the oblique and straight DSLs can present with distension of the DFTS, especially when these injuries are acute (Baxter and Stashak, 2011b) and in communication with the adjacent DFTS (Carstens and Smith, 2014).
Lesions of the intersesamoidean ligament such as desmitis, rupture, avulsion fractures or entesopathy occur less frequently but can also be a cause of DFTS tenosynovitis (Schramme and Smith, 2010).

1.3. DIAGNOSTIC METHODS

1.3.1. Clinic examination

The principal clinical sign accompanying digital tenosynovitis is synovial distension of the DFTS. In cases of mild synovitis, a fluctuating distension can be palpated at the proximal recess of the DFTS (palmar to the suspensory ligament and proximal to the PSBs) or at the distal recess (at the palmar mid-level of the pastern). The distension usually increases with exercise and declines with rest (Nixon, 2002). At this stage, horses are not lame and the synovial distension only represents a cosmetic blemish (windpuffs or windgalls).

However, in cases presenting more severe synovitis or important lesions involving the DFTS or its associated structures, lameness is commonly evident and the distension can be pronounced. Palpation may reveal nodular masses at the proximal recesses of the DFTS and tendon thickening with an associated pain response (Baxter and Stashak, 2011b). Lameness may be of different degrees but it is usually worsened with a lower limb flexion test. Due to the presence of the PAL at the palmar aspect of the fetlock, horses with digital tenosynovitis often have a typical appearance with proximal and distal distension of the DFTS with a notch in the palmar outline of the fetlock region (Figure 7). This clinical picture is often directly attributed to the annular ligament constriction syndrome caused by thickening of the PAL (PAL desmitis). However, the observed notch does not always entail a real constriction of the tendons within the fetlock canal nor a real desmitis of the PAL.
Figure 7. Picture of the distal aspect of the right front limb of a horse with non-infectious digital tenosynovitis, showing proximal and distal distension of the digital flexor tendon sheath (black arrows) with a notch at the palmar aspect of the fetlock, at the level of the palmar annular ligament (open arrow heads).

1.3.2. Diagnostic analgesia

Regional or intrasynovial diagnostic analgesia is routinely performed during lameness examinations to determine the origin of pain causing lameness. Depending on the type and severity of the lesions, horses with DFTS tenosynovitis may respond variably to palmar digital, abaxial sesamoid, or low palmar (or low 4-point) nerve blocks or to intrasynovial analgesia of the DFTS.
Positive responses to DFTS analgesia have been observed in horses suffering from painful digital tenosynovitis, intrasynovial tears of the digital flexor tendons or manica flexoria, tendonitis of the digital portion of the DDFT, desmitis of the oblique and straight DSLs, desmitis of the PAL, and desmitis of the intersesamoidean ligament (Schneider et al., 2003a; 2005; Smith and Wright, 2006; Schramme and Smith, 2010; Findley et al., 2012; king et al., 2012; Fiske-Jackson et al., 2013). However, the specificity of DFTS analgesia has been questioned and some authors have suggested that either backflow or diffusion of local anaesthetic solution after intrasynovial analgesia of the DFTS can lead to desensitisation of structures other than those intended, resulting in an inaccurate localisation of the pain causing lameness (Schneider et al., 2003a; Sampson et al., 2007; Bassage and Ross, 2010). From the observation that perineurally injected contrast medium diffuses along the neurovascular bundle, it has been suggested that desensitisation of structures located more proximally than the site of injection may occur after perineural analgesia (Nagy et al., 2009; 2010; 2012). In general, regional nerve blocks are believed to be less specific than intrasynovial analgesia for the localisation of a DFTS lameness (Fortier, 2005).

Different techniques for synoviocentesis of the DFTS have been described. The choice of technique is determined by the experience and personal preferences of the operator, but it also depends on the presence or absence of synovial distension or clinical conditions that may prevent injection at certain locations. Most commonly, injection of the DFTS is performed at its proximal recess (approximately 1 cm palmar to the suspensory ligament and 1 cm proximal to the lateral -or medial- PSB), or at the distal recess (at the palmar mid-pastern, between the proximal and distal digital annular ligaments). The DFTS may also be approached abaxially, at its outpouching at the base of the PSB, between the distal aspect of the PAL and the proximal aspect of the proximal digital annular ligament.
(Baxter and Stashak, 2011a; Rocconi et al., 2013). These three approaches are easier to perform in the presence of synovial distension. In non-distended DFTS, synoviocentesis using the palmar axial sesamoidean approach can be performed (Hassel et al., 2000). The needle is inserted at the level of the mid-body of the PSB (most often of the lateral PSB in a clinical situation), axially to its palpable palmar border, through the PAL (Figure 8). Due to the absence of synovial villi at this location, aspiration of synovial fluid may be easier and more often successful. This is certainly true in cases of chronic or septic tenosynovitis, when substantial fibrosis, adhesion formation, and/or fibrin accumulation at the proximal recess of the DFTS may prevent fluid aspiration at this site (Honnas et al., 1991; Barr et al., 1995).

![Image of transverse section of a front limb](image.png)

**Figure 8.** Transverse section of a front limb at the level of the mid-body of the proximal sesamoid bones. Red methylmetacrylate based resin (Batson's No. 17) has been injected in the digital flexor tendon sheath (DFTS). The white arrow indicates the place of needle placement for a palmar/plantar axial sesamoidean approach to the DFTS.
To perform DFTS analgesia, 10 to 15 ml (or 1 ml/50 kg bwt) of a 2% mepivacaine hydrochloride solution are injected using a 20 to 22 gauge hypodermal needle. Aseptic skin preparation is mandatory. Protection of the injection site after withdrawal of the needle is recommended in order to avoid contamination but also to avoid possible leakage of local anaesthetic solution to the subcutaneous tissues, through the needle hole (Schmotzer and Timm, 1990).

Results of intrasynovial analgesia should be first evaluated 5 to 10 minutes after injection. Afterwards, regular evaluations are usually performed every 10 to 15 minutes. Absence of immediate response after intrasynovial analgesia should not always be interpreted as a negative result since some injuries or chronic diseases may need longer time to respond to analgesics. Similarly, some injuries will never show a full positive response to DFTS intrasynovial analgesia (Fortier, 2005; Findley et al., 2012; Fiske-Jackson et al., 2013). Fiske-Jackson et al. (2013) for example, reported that horses with DDFT tears were significantly more likely to show a positive response to DFTS analgesia than horses with manica flexoria tears.

1.3.3. Synovial fluid evaluation

Synovial fluid analysis is performed to evaluate the presence and degree of synovitis but it does not reflect the extent of the lesions nor is it of prognostic value (Van Pelt, 1969; Fortier et al., 1999). However, it is essential in the diagnosis of synovial sepsis, to confirm synovial involvement and to allow bacteriologic examination.

The characteristics of the normal and septic synovial fluid have been described earlier in this chapter. In cases of aggressive synovitis, the volume of synovial fluid is generally increased. This fluid is less viscous, presents a higher concentration of total proteins and
higher white blood cell counts, which renders it turbid (McIlwraith and Trotter, 1996b). Most often, it has a darker colour or it can even be haemorrhagic.

### 1.3.4. Ultrasonography

Ultrasonography is the principal diagnostic method for investigation of the soft tissues. Injury to the flexor tendons, manica flexoria, DSLs, or PAL, synovial proliferations, synovial adhesions, synovial masses, or flocculent fluid within the DFTS can be diagnosed (Arensburg et al., 2011; Baxter and Stashak, 2011a).

Good ultrasonographic images of the flexor tendons and DFTS can be obtained with a 7.5 MHz linear transducer, but 10 or 12 MHz probes are generally more efficient. A 5 mm thick stand-off pad may also be required. The hair should be clipped, the skin soaked with hot water and covered with coupling gel. Transverse and longitudinal images should be obtained. Oblique images (in the transverse plane, Figure 9B) are also recommended to be able to examine the borders of tendons and ligaments without edge shadowing artefacts (Edinger et al., 2005), especially because lesions of the manica flexoria and flexor tendons occur more frequently at their lateral border (Barr et al., 1995; Wright and McMahon, 1999; Wilderjans et al., 2003; Edinger et al., 2005). Some authors recommend performing the ultrasonographic examination with the limb in flexion as well. With this technique the wider contact surface may provide a better visualisation of the tendon and ligament borders and the manica flexoria contours (Seignour et al., 2012). Dynamic ultrasonographic examination has also been recommended to evaluate the degree of functional relationship (movement) between the SDFT and DDFT (Denoix et al., 1997; Pasquet et al., 2007; Seignour et al., 2012).
In horses with DFTS tenosynovitis, fluid distension and synovial proliferation are usually visible at the proximal recesses of the tendon sheath. In more severe or chronic cases, villonodular masses or adhesions may also be observed (Figure 9). Mesotenons and vincula are often difficult to image but when thickened, they are readily visualised and should not be confused with adhesions.

Ultrasonographic examination of the PAL can be difficult and is easily misinterpreted. The PAL appears as a poorly defined thin band (< 2 mm) between the subcutaneous tissues and the SDFT (Figure 10). Careful interpretation should be made of the tissues present between the PAL and the epidermis, as it is easy to confuse them with ligament thickening resulting in an incorrect diagnosis of PAL desmitis. Moving the probe abaxially will improve visualisation of the PAL, due to the hypoechogetic synovial lining or fluid present between the SDFT and the PAL at this area. By scanning further medially or laterally, the attachment of the PAL to the palmar border of the PSBs will be visualised, which also helps to identify the PAL (Cauvin and Smith, 2014).

Marginal tears of the flexor tendons appear as an irregular delineation of the tendon borders on ultrasound images. Occasionally, some fibrillation can also be observed at this point (Figure 9). However, many of the marginal tears of the SDFT or DDFT within the DFTS may not be identifiable with ultrasonography due to synovial proliferation or when these lesions are located at the blind ultrasonographic spot beneath the ergot (Schramme and Smith, 2010). Different studies have shown that tears of the DDFT can be predicted using ultrasound with a sensitivity of 63% to 71%, while this is only 38% for manica flexoria tears (Smith and Wright, 2006; Arensburg et al., 2011). Experience in ultrasonography plays an important role on the ability to diagnose marginal tendon tears or manica flexoria lacerations. To help the examiner in the interpretation of ultrasonographic images, it is recommended to always evaluate the contralateral limb, even in the absence of
clinical signs. Measuring the cross-sectional area of the tendons and comparing it with the contralateral limb may help recognise subtle flexor tendon injuries that do not show obvious changes in echogenicity (Schramme and Smith, 2010). Ultrasonographic examination with the limb in a semi-flexed position improves the visualisation of marginal tears of the flexor tendons. With this position, the lower tension sustained by the tendons avoids juxtaposition of the tendon fibres allowing some opening of the tendon cleft (Bertuglia et al., 2014; Cauvin and Smith, 2014).

Recently, Bertugila et al. (2014) reported the use of contrast-enhanced ultrasonography to improve the identification of (surgically created) longitudinal lesions of the intrasynovial part of the DDFT. In their *ex vivo* study, injection of contrast medium containing sulphur microbubbles in the DFTS allowed correct identification of the location and depth of the tendon lesions in 90 to 100% of the cases. If the safe use of this technique could be demonstrated *in vivo*, this seems a promising method to increase the sensitivity of ultrasonography for the diagnosis of intrasynovial marginal tears of the flexor tendons in equine patients.
Figure 9. Transverse ultrasound images, proximal to the fetlock, of a chronic tenosynovitis of the digital flexor tendon sheath (DFTS). Lateral is to the left. A) Distension of the DFTS with anechoic fluid (*) and presence of a hypoechoic mass (white arrow). The wall of the DFTS is thickened (between open arrow heads). B) Transverse ultrasound images with oblique orientation of the probe in the transverse plane to show the palmaromedial and palmarolateral tendon borders. The lateral border of the deep digital flexor tendon (DDFT) is ill defined and shows a hypoechoic lesion (white arrow) whereas the medial border has a normal ultrasound image. A marginal tear of the lateral border of the DDFT was confirmed during tenoscopy.

Figure 10. Transverse ultrasound images of the palmar annular ligament (PAL) at the level of the proximal sesamoid bones, of three different horses with distension of the digital flexor tendon sheath (DFTS). Lateral is to the left. A) Normal PAL (black and white lines). B) Thickening of the DFTS wall (+) with a normal PAL (black and white lines). C) Severe thickening of the DFTS wall (+) and PAL desmitis with lost fibre pattern and thickening of the subcutaneous soft tissues.

1.3.5. Radiography

Although the structures encompassed by the DFTS are not directly visible on plane radiographs, radiographic examination can be indicated to diagnose associated trauma to bony structures, such as sesamoid bone fracture, dystrophic mineralisation of the soft tissue structures around the fetlock, or lysis of the intersesamoidean area (Baxter and Stashak, 2011a).

Contrast tenography can be used in cases of septic digital tenosynovitis to confirm a penetrating tract, but also in cases of non-septic tenosynovitis as a diagnostic aid during lameness examinations for evaluation of certain structures within the DFTS (Figure 11) (Verschooten and De Moor, 1978; Hago and Vaughan, 1986; Verschooten and Picavet, 1986; Fiske-Jackson et al., 2013). Negative contrast air tenograms have been reported useful for the identification of the structures encompassed in the DFTS, but also for the diagnosis of tendinitis of the SDFT and DDFT, and desmitis of the PAL (Verschooten and De Moor 1978; Verschooten and Picavet, 1986). More recently, Fiske-Jackson et al. (2013) reported the use of positive contrast tenograms as a routine exam procedure during their lameness investigations. They injected the DFTS with a combination of local anaesthetic solution (10 ml of mepivacaine hydrochloride 2%) and radiodense contrast medium (5 to 7 ml of sodium meglumine diatrozoate, Urografin 370) and evaluated the structures within the DFTS with lateromedial radiographs of the distal aspect of the limb, within 10 minutes after injection. Tears of the manica flexoria were detected with a sensitivity of 96% and tears of the DDFT with a sensitivity of 57%.
Figure 11. Positive contrast tenograms of the digital flexor tendon sheath (DFTS) of two different horses. **A)** Normal delineation of the DFTS and its related structures. **B)** Closer view showing the normal delineation of the manica flexoria (white arrow). **C)** Horse with tenosynovitis of the DFTS with laceration of the medial attachment of the manica flexoria. The manica flexoria is not visible in the contrast tenogram (white arrow). The diagnosis was confirmed during tenoscopy.
1.3.6. Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is commonly used for the diagnosis of soft tissue and bone injuries when radiographic and ultrasonographic examinations are non-conclusive (King et al., 2012). In relation to the DFTS, MRI has been reported useful for the diagnosis of desmitis of the DSLs (in particular of the oblique and straight DSLs), strain injuries and marginal tears of the SDFT or DDFT, intersesamoidean ligament desmitis, PAL desmitis, and proximal or distal digital annular desmitis (Gonzalez et al., 2010; Dyson and Murray, 2011; King et al., 2012).

DSLs desmitis was the soft tissue injury most frequently diagnosed in two studies evaluating injuries of the metacarpal(tarso)phalangeal region with MRI (Gonzalez et al., 2010; King et al., 2012). The lesions could be located at the origin, body or insertion of the ligaments and appeared as focal or generalised hyperintensities in proton density (PD), T2, and short τ inversion recovery (STIR) images, with or without increased cross-sectional area of the ligaments. Oblique distal sesamoidean ligament injuries were reported to occur more frequently than straight distal sesamoidean ligament injuries in three studies (Schneider et al., 2003b; Sampson et al., 2007; King et al., 2012) whereas straight distal sesamoidean ligament injuries predominated in another study (Gonzalez et al., 2010). Oblique sesamoidean ligament injuries were also reported to occur more often in the hind limbs than in the front limbs (Sampson et al., 2007; King et al., 2012) and quarter horses used for western performance were overrepresented (King et al., 2012).

Acute core lesions of the flexor tendons appear hyperintense in both T1- and T2-weighted images, whereas chronic tendon lesions appear hyperintense in T1-weighted sequences but hypointense in T2-weighted images (Kasashima et al., 2002). More recent studies however, report more optimal visualisation of the DDFT contours and lesions on
fast low angle shot (FLASH) sequences compared to STIR sequences and T2-weighed images (Gonzalez et al., 2010). Longitudinal tears of the flexor tendons are characterised by an irregular tendon contour with a hyperintense area at the abaxial border of the tendon (most often lateral) and partial separation of the tendon margins (Gonzalez et al., 2010; Schramme and Redding, 2011).

Lesions of the proximal and distal digital annular ligaments have been characterised by diffuse or focal thickening of the ligaments, with a variable increased signal intensity in T1- and T2-weighed images (Dyson and Murray, 2011).

Intersesamoidean ligament desmitis appears as a hyperintense (sometimes hypointense) area in the centre of the ligament in T2, PD, and STIR images and it has been reported to occur with concurrent osseous abnormalities of the PSBs (Gonzalez et al., 2010; Schramme and Redding, 2011). Some horses can also present concurrent lesions of the suspensory apparatus (Gonzalez et al., 2010).

1.3.7. Computed Tomography

The use of computed tomography (CT) in combination with contrast enhanced CT (CECT) has proved to be a good alternative to evaluate soft tissue injuries at the level of the equine distal limb, when MRI examination is not available (Puchalski et al., 2009; Anderson and Nelson, 2011; Vallance et al., 2012). Although CT or CECT are more often used for evaluation of soft tissue and bone injuries at the level of the equine foot, these techniques are also useful for monitoring the heeling of tendon lesions (Puchalski et al., 2009).
1.3.8. Tenoscopy

Although ultrasonography is considered the principal diagnostic method for detection of soft tissue injuries within the DFTS, its lack of sensitivity makes tenoscopy an important complementary exam. The introduction of tenoscopy in equine medicine has led to the discovery of different types of lesions within the DFTS that result in chronic synovial distension of the sheath and that formerly remained undiagnosed. In the past, all these cases were treated conservatively with intrasynovial injection of corticosteroids or by blind section of the annular ligament, with variable success obtained depending on the underlying primary lesion.

Although more invasive than ultrasonography, tenoscopy allows a complete examination of the DFTS cavity and its structures, with all the advantages of minimally invasive surgery, including the possibility of immediate treatment of the diagnosed lesions. (Nixon et al., 1993; McIlwraith et al., 2014). However, tenoscopy only provides visualisation of the surface of the tendons but not of the deeper tendon architecture and therefore, some injuries such as core lesions of the flexor tendons cannot be visualised unless they extend to the tendon surface or open into the DFTS (Nixon, 1990).

1.4. TREATMENT

The choice between conservative or surgical management of horses with digital tenosynovitis will depend on the results of the clinical examination and diagnostic imaging.

Horses presenting with acute tenosynovitis and without tendon or ligament abnormalities detected on ultrasound (or contrast tenography) may initially be treated conservatively with supportive local therapy, systemic anti-inflammatory medication and, in some cases, intrasynovial corticosteroids (see later for detailed description).
Horses with chronic tenosynovitis but no obvious primary lesions detected on imaging examination may also be treated conservatively with injection of the DFTS with hyaluronan and corticosteroids. However, these horses are often unresponsive to medical therapy and surgical intervention is therefore recommended. Moreover, in many cases, primary lesions will not have been diagnosed with the conventional non-invasive techniques, and hence tenoscopic evaluation is needed.

In horses with complex tenosynovitis, cases non-responsive to medical therapy, horses with severe or persistent lameness, or cases where ultrasonographic examination reveals obvious tendon or digital sheath pathology, surgical treatment is recommended. Tendon lesions located intrasynovially heal worse than those located extrasynovially due to the rapid growing of a layer of synovial cells over the tendon defect, which prevents further intrinsic debridement and healing of the lesion (Webbon, 1977; Wright and McMahon, 1999). This emphasises the importance of tenoscopic debridement of fibrillated tendon fibres to promote healing.

1.4.1. Conservative treatment

Conservative treatment for horses with acute non-infectious DFTS tenosynovitis consists of stall rest, bandaging, cold hydrotherapy, and topical and systemic anti-inflammatory medication for the first 2 weeks depending on the severity of clinical signs. Afterwards, hand-walking exercise can be resumed for another 2 weeks. If the clinical signs have not resolved after a period of 2 to 3 weeks and no tendon abnormalities are detected during ultrasonographic examination, intrasynovial injection of hyaluronan and corticosteroids can be performed. However, the possibility of a false negative diagnosis of marginal tears of the flexor tendons or a manica flexoria laceration with ultrasonography
should be kept in mind. In these cases exacerbation of the tendon lesions may occur when horses are allowed to resume work under the effects of local corticosteroids.

1.4.2. Surgical treatment: tenoscopy

Compared with the conventional open surgical approaches, tenoscopy allows a better and complete observation of the sheath cavity while offering the advantages of the minimally invasive surgical techniques: smaller incisions, less risk of wound dehiscence and synovial fistulation, and the possibility of early return to exercise during revalidation, which helps preventing adhesion formation (Nixon, 1990; Nixon et al., 1993; McIlwraith et al., 2014).

Tenoscopy has been used successfully in equine patients to treat a variety of disorders of the DFTS. Tenosynovial masses and adhesions can be resected either with motorised synovial resectors or by division at their basis with biopsy cutting forceps and subsequent removal with grasping forceps. Similarly, in cases with linear clefts (or longitudinal tears) of the DDFT or SDFT, the fibrillated tendon edges can be debrided with biopsy punch rongeurs and motorised resectors (Figure 12). Suturing of long and deep longitudinal tendon tears is not possible tenoscopically and requires an invasive open approach. It is therefore nearly never performed. When tears of the manica flexoria are present, either a partial or full excision of the manica can be performed using arthroscopic scissors, knives, or motorised resectors (Figure 13) (Findley et al., 2012).

Desmotomy of the PAL is performed in cases of (ultrasonographically confirmed) PAL desmitis, but a normal PAL can also be transected when restricted movement of the arthroscope through the fetlock canal is experienced by the surgeon, especially in cases of complex tenosynovitis. It also improves tenoscopic visualisation of the DFTS thus
facilitating removal of adhesions and synovial masses (Fortier et al., 1999; Wilderjans et al., 2003; Smith and Wright., 2006).

**Figure 12.** Intraoperative tenoscopic images of the digital flexor tendon sheath (DFTS). The scope is inserted at the base of the lateral proximal sesamoid bone and is directed proximally. **A)** Image of a normal DFTS with normal deep digital flexor tendon (DDFT) and superficial digital flexor tendon. **B)** DFTS with a longitudinal tear of the lateral border of the DDFT (black arrows). **C)** Excision of the torn fibres of the DDFT. **D)** Motorised debridement of fibrillated tendon fibres of the DDFT.

S: superficial digital flexor tendon; D: deep digital flexor tendon.
Figure 13. Intraoperative tenoscopic images of the digital flexor tendon sheath (DFTS). The scope is inserted at the base of the lateral proximal sesamoid bone and is directed proximally. A) Image of a normal DFTS and manica flexoria. B) Tear of the medial border of the manica flexoria (black arrow). C) Proximal reflexion of the torn part of the manica flexoria during its excision. D) Tenoscopic image after partial excision of the torn manica flexoria.

S: superficial digital flexor tendon; D: deep digital flexor tendon; MF: manica flexoria.
Post-operatively, systemic anti-inflammatory drugs are administered for the first 7 to 10 days. Antibiotics can be used at the discretion of the surgeon. Limbs are protected with supporting bandages that will be changed regularly, during a period of 3 to 4 weeks. Hand-walking exercise can be started 3 to 4 days after surgery. Early return to controlled exercise has been recommended to decrease the chance of adhesion formation (Fortier et al., 1999; Wilderjans et al., 2003). Similarly, intrasynovial injection of hyaluronan (20-40 mg) has been shown to reduce the formation of tendon adhesions in the sheath area and to enhance intrinsic tendon healing (Amiel et al., 1989; Gaughan et al., 1991; Moro-oka et al., 2000). In chronic cases, when distension of the DFTS persists, intra-articular administration of corticoids, 3 to 4 weeks after surgery, can also be performed. Return to work will mainly depend on the original tendon lesion or injuries found during tenoscopy. Horses with complex tenosynovitis can usually return to work 4 to 6 months after surgery. This period is a bit longer in cases of severe tendon lesions (6 to 12 months).

Ultrasonographic evaluation is often recommended during the re-education period. However, ultrasonography may not be the best method to evaluate tendon healing since a major part of the ultrastructural events during tendon repair occur below the limits of ultrasound resolution (van Schie and Bakker, 1996; 2000; van Schie et al., 2001). Moreover, ultrasonography cannot assess the functional capacity of the healing tendon and horses may sometimes be allowed to resume work prematurely with the corresponding increased risk of re-injury (van Schie and Bakker, 1996; 2000; van Schie et al., 1999; 2000). Hence, ultrasound tissue characterisation (UTC) has been suggested to be a more optimal method to evaluate structural integrity of the healing tendons as it provides quantitative information about histopathological changes of the tendon tissues (van Schie et al., 2000; 2001). This method has already been used to evaluate the healing of lesions of the equine SDFT (Bosch et al., 2011; Docking et al., 2012). However, both the natural
shape and the anatomy of the palmar side of the fetlock region prevent obtaining optimal images of a significant distance of the intrasynovial part of the DDFT to assess healing of intrasynovial lesions (e.g. marginal tears) of the DDFT (personal observation).

MRI has been increasingly used for evaluation of the equine soft tissues, but also to assess tendon injuries and to monitor tendon healing (Crass et al., 1992; Kasashima et al., 2002; Shalabi, 2004; Dyson et al., 2005; Schramme et al., 2010). However, careful interpretation of the MR images needs to be performed to avoid premature diagnosis of tendon healing and precipitate return to training. Therefore, comparison between T1- and T2-weighted images has been recommended, as acute lesions have increased signal intensity in both T1- and T2-weighted images whereas healing lesions appear hyperintense on T1-weighted images but hypointense on T2-weighted sequences (Kasashima et al., 2002; Schramme et al., 2010).

1.5. PROGNOSIS

It is difficult to give a global prognosis for a non-infectious digital tenosynovitis because the reported numbers vary considerably. Smith and Wright (2006) reported 68% of horses with digital tenosynovitis returning to soundness and 54% returning to previous working levels. In contrast, Arensburg et al. (2011) reported only 38% of horses going back to previous level of work after tenoscopic treatment. It seems that the prognosis highly depends on the underlying lesions. When longitudinal tendon tears are present at the level of the DDFT, the prognosis becomes more guarded, even after arthroscopic debridement, with reported outcomes of 42% of horses returning to their previous level of work (Smith and Wright, 2006). However, the prognosis is more favourable for horses with tears of the manica flexoria, with 67% to 79% of horses going back to previous level of work (Smith and Wright, 2006; Findley et al., 2012). The length of the tear in the DDFT has a negative
effect on the prognosis. Likewise, there is a negative relationship between the duration of clinical signs and the degree of preoperative DFTS distension with outcome, supporting early intervention. The prognosis for cosmetic improvement is also guarded, with complete resolution of the distension reported in only 12 to 33% of cases (Smith and Wright, 2006; Arensberg et al., 2011).
References


CHAPTER 1 · The equine digital flexor tendon sheath


Scientific aims
The digital flexor tendon sheath (DFTS) is an important synovial structure of the equine limb. Tenoscopic examination of this synovial cavity is routinely performed in horses for diagnosis and treatment of disorders of the DFTS or its related tendons and ligaments. During tenoscopic examination of the distal aspect of the DFTS, the digital manica flexoria can be observed. Since this structure has been inconsistently described and variably named in the veterinary literature, the first objective of this PhD was to describe the existence and anatomical variation of the digital manica flexoria in the equine foot.

Although identification and treatment of DFTS lesions has improved considerably since tenoscopy has become routine, diagnostic analgesia still remains an indispensable procedure during orthopaedic examinations to accurately localise the source of pain causing lameness. However, controversy exists over the specificity of the results obtained with this technique. Some authors attribute the lack of specificity of DFTS analgesia to the leakage of local anaesthetic solution through the needle injection hole into the subcutaneous tissues, with subsequent desensitisation of the palmar/plantar (digital) nerves. Moreover, since the DFTS can be injected at different locations, it has also been hypothesised that the results of DFTS analgesia could vary depending on the injection technique used. Other authors believe that non-specific desensitisation after DFTS analgesia can be due to diffusion of local anaesthetic solution through the synovial membranes. Hence, the second objective of this PhD was to assess the reliability of DFTS analgesia and to determine the possible reasons for the inadvertent desensitisation of adjacent structures.
Therefore, to assess the previously described objectives several studies were set up:

- A cadaveric anatomical study to unravel the presence and configuration of the digital manica flexoria in equine front and hind limbs.
- A cadaveric study to compare the 4 most commonly used techniques for synoviocentesis of the DFTS regarding their accuracy and ease of performing, while concurrently assessing the risk of influencing the palmar/plantar (digital) nerves.
- An *in vivo* study to assess the influence of DFTS analgesia on distal limb desensitisation evaluating the possible differences between the 4 most commonly used injection techniques.
- An *in vivo* study to assess the degree of diffusion of local anaesthetic solution injected in the DFTS to adjacent synovial structures.
Anatomical description of the presence and variability of the digital manica flexoria in the equine digital flexor tendon sheath

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Adapted from:
SUMMARY

During tenoscopy of the distal aspect of the equine digital flexor tendon sheath, the digital manica flexoria can be visualised connecting the distal branches of the superficial digital flexor tendon. However, this structure has been inconsistently described and variably named in the veterinary literature. The objectives of this study were to describe the presence, configuration and variability of the digital manica flexoria in the equine foot. Dissection of 144 equine cadaveric limbs revealed the presence of this structure in all the feet, though different types and configurations were identified. Two main types of digital manica flexoria (membranous and tendinous) were defined. Within each type, three subtypes were distinguished: “synovial bridge”, “fibrous bridge”, and “broad synovial fold” in the membranous type and “symmetric X-crossing”, “asymmetric X-crossing”, and “oblique-crossing” in the tendinous type. Three types of intermediate vinculum were defined: “axial”, “lateral and medial abaxial”, and “wide”. In the front limbs, the membranous digital manica flexoria predominated (94%; P < 0.001), in particular the synovial bridge type (83%; P < 0.001) which was significantly associated with a lateral and medial abaxial vinculum (P = 0.001). In the hind limbs, the tendinous digital manica flexoria predominated (93%; P < 0.001), in particular the oblique-crossing of tendinous bundles (61%; P < 0.001) which was significantly associated with an axial vinculum (P < 0.001). Passage dorsal to the digital manica flexoria towards the distal digital flexor tendon sheath was only possible in 22 of the 144 limbs, all front limbs. Clinicians should be aware of the intra- and inter-individual anatomical variations of the digital manica flexoria to avoid misinterpretation during ultrasonographic and tenoscopic examinations of the digital flexor tendon sheath.
INTRODUCTION

The digital flexor tendon sheath (DFTS) is an important synovial structure of the equine foot encircling the flexor tendons at their passage over the palmar/plantar aspect of the fetlock joint. Tenoscopy of the DFTS is often performed in horses for diagnosis and treatment of various lesions that may affect this synovial cavity and its internal structures (McIlwraith et al., 2006; Smith and Wright, 2006; Schramme and Smith, 2010; Findley et al., 2012). During tenoscopic examination of the DFTS, the superficial and deep digital flexor tendons are visualised from the distal part of the metacarpus/metatarsus to the distal aspect of the pastern. Proximally in the DFTS, the deep digital flexor tendon (DDFT) is embraced by the manica flexoria, a tendinous ring inserting on the medial and lateral borders of the superficial digital flexor tendon (SDFT) (Figure 1a). In the distal part of the DFTS, at the mid-level of the proximal phalanx, a similar structure connecting the distal branches of the SDFT is visible at the dorsal aspect of the DDFT and palmar/plantar to the distal sesamoidean ligaments (DSLs) (Figure 1b-1d). However, this structure has not been described consistently in the veterinary literature. Some authors have not recognised (Sisson and Grossman, 1975; Wissdorf, 2002; Schaller et al., 2007) or have even denied (Barone, 2000) its existence, whereas others have mentioned its presence though using different names. Nickel et al. (1986) named it the distal cuff of the SDFT around the DDFT. Nixon (1990) reported the tenoscopic visualisation of this structure and referred to it as the insertion of the SDFT encircling the DDFT in the distal part of the tendon sheath. Redding (1993) identified this structure on dissected cadaver limbs and on ultrasonographic images and referred to it as the distal ring of the manica flexoria. Dyce et al. (2002) defined it as the deep part of the sleeve present halfway the proximal phalanx, with the sleeve being the manica flexoria around the DDFT. Neumeier et al. (2004) named it the distal girdle of the manica flexoria. McIlwraith et al. (2006) described a small encircling component of the
SDFT stabilising the tendons at the end of the DFTS and named it the digital manica flexoria. Smith and Wright (2006) and Fiske-Jackson et al. (2013) used a very similar term, the digital manica. In contrast, Denoix (1991; 1994; 2000) defined this structure as a synovial fold extending between the distal branches of the SDFT, with no relation to the more proximally located manica flexoria. In this article, we will further refer to this structure as the digital manica flexoria.

**Figure 1:** Tenoscopic images of the equine digital flexor tendon sheath with the scope portal located at the base of the lateral proximal sesamoid bone and the scope directed proximally (a) to visualise the manica flexoria, and distally (b, c, and d) to visualise the digital manica flexoria.

Besides this lack of consensus on the nomenclature, to the authors’ knowledge, no detailed and large scale anatomical studies on the composition and variation of the digital manica flexoria have been published so far. Therefore, the objectives of the present study were (1) to describe the prevalence of this structure in the DFTS of horses, and (2) to describe and document its variability.

MATERIALS AND METHODS

Anatomical dissections

A total of 144 isolated equine cadaver limbs were dissected (72 front and 72 hind limbs, 36 right limbs and 36 left limbs in each group). One hundred limbs from horses of different breeds, gender, and age were obtained from a local abattoir. Additionally, the 4 limbs of 11 horses euthanised at the Veterinary Hospital of Ghent University for reasons unrelated to this study were dissected. Front limbs were amputated at the mediocarpal joint (Articulatio mediocarpea) and hind limbs at the proximal intertarsal joint (Articulatio talocalcaneocentralis). Specimens with macroscopically visible lesions or other gross abnormalities were discarded. Dissection started with skinning of the limbs down to the coronary band. Subsequently, two palmar/plantar parallel vertical incisions (approximately 0.5 cm lateral and medial to the axial plane) were made through the palmar/plantar annular ligament and the SDFT, over the entire length of the DFTS. After removing the entire axial piece of the SDFT, the DDFT was transected proximal to the proximal sesamoid bones and was either reflected distally or partially removed after performing a second transverse section at the level of the pastern (Figure 2). This exposed the dorsal aspect of the DDFT, the manica flexoria, the two distal branches of the SDFT, the dorsal wall of the DFTS with the DSLs, the digital manica flexoria, and the distal vincula. The distal vincula were
represented by dorsal vincula (mesotenon remnants connecting the dorsal wall of the DFTS with the dorsal aspect of the digital manica flexoria), and intermediate vincula (mesotenon remnants emerging either from the distal border of the digital manica flexoria or from the straight sesamoidean ligament, distal to the digital manica flexoria, and inserting on the dorsal aspect of the DDFT) (Figure 2b-2d).

For each limb, several characteristics of the digital manica flexoria and its associated intermediate vinculum were recorded: the presence or absence of the digital manica flexoria, the type and configuration of the fibers forming the digital manica flexoria, the type and configuration of the intermediate vinculum, and the possibility to reach the distal part of the DFTS by probing along the dorsal aspect of the digital manica flexoria. Digital photographs were obtained for each limb.

**Data analysis**

Statistical analysis was performed using SPSS 22 (IBM Corporation, Armonk, New York, USA) with statistical significance set at P < 0.05. Chi-square analysis and Fisher's exact test, with Bonferroni adjustment for the individual contrasts were used to examine the associations between (1) the types of digital manica flexoria or intermediate vinculum, and limb (front/hind); (2) the types of digital manica flexoria or intermediate vinculum, and side (left/right); (3) the types of digital manica flexoria and types of intermediate vinculum.
Figure 2: Palmar view of 4 dissected equine limbs. The axial part of the superficial digital flexor tendon has been removed. The central part of the deep digital flexor tendon has also been removed (a and c) or the tendon has been reflected distally (b and d). Dorsal vincula (asterisk) and intermediate vincula (open arrowhead) are present in the distal aspect of the digital flexor tendon sheath (b, c and d).

S: superficial digital flexor tendon; D: deep digital flexor tendon; MF: manica flexoria; PS: proximal scutum; SSL: straight sesamoidean ligament; DMF: digital manica flexoria.
RESULTS

The digital manica flexoria was observed in all dissected limbs (n=144), always between the DDFT and the dorsal wall of the DFTS, connecting the two distal branches of the SDFT, at the middle third of the proximal phalanx. The dorsal and intermediate vincula were also observed in all limbs. The intermediate vinculum emerged either from the distal border of the digital manica flexoria or distal to it, from the straight sesamoidean ligament or the area between this ligament and the distal branch of the SDFT, and inserted on the dorsal aspect of the DDFT.

The digital manica flexoria had a quite variable appearance and therefore, a classification system was established. A tendinous and a membranous type of digital manica flexoria were defined, based on the presence or absence of tendinous fibers in the synovial sheet spanning the two terminal branches of the SDFT (Figure 3). In a further subdivision of the membranous type, three different configurations were distinguished: in the first subtype, a simple bridge of synovial tissue spanned between the distal branches of the SDFT leaving distally a window to the DSLs (“synovial bridge”); in the second subtype, this bridge was reinforced by some small, horizontally oriented fibrous strands (“fibrous bridge”); in the third subtype, the distal edge of the bridge was fused with the intermediate vinculum, resulting in a broad synovial fold spanning all the space between the intermediate vinculum and the two terminal branches of the SDFT, without a distal window to the DSLs (“broad synovial fold”). Similarly, within the tendinous type, three different configurations were defined: an X-shape crossing of tendinous fibers with bundles of equal size (“symmetric X-crossing”), an X-shape crossing of tendinous fibers with predominant bundles crossing from a proximomedial to a distolateral direction (“asymmetric X-crossing”), and tendinous fibers crossing obliquely from one side in a proximomedial to distolateral direction (“oblique-crossing”).
**Figure 3:** Palmar/plantar views of the different types and configurations of the equine digital manica flexoria. Proximal is at the top of the images (L: lateral; M: medial). The deep digital flexor tendon has been reflected distally.
The intermediate vinculum also had different configurations which were classified according to Neumeier et al. (2004) by considering the type of insertion of the vinculum on the DDFT. Three main types of intermediate vinculum were defined (Figure 4): in the first subtype, the vinculum inserted on the axial and dorsal aspect of the DDFT (“axial vinculum”); in the second subtype, two abaxial strands inserted on the dorsal lateral and medial (abaxial) aspects of the DDFT (“lateral and medial abaxial vinculum”); and in the third subtype, the vinculum originated over the complete distal margin of the digital manica flexoria and inserted over a wide area on the dorsal aspect of the DDFT (“wide vinculum”).

**Figure 4:** Palmar/plantar views of the different types of intermediate vinculum. Proximal is at the top of the images (L: lateral; M: medial). The deep digital flexor tendon has been reflected distally.
Table 1 summarises the prevalence of the different types and configurations of the digital manica flexoria in all limbs. In the front limbs, there was a significantly higher proportion of the membranous type of digital manica flexoria (94%; P < 0.001), in particular the synovial bridge (83%; P < 0.001), as compared to the other types. In contrast, the tendinous type of digital manica flexoria predominated in the hind limbs (93%; P < 0.001), in particular the oblique-crossing of tendinous bundles (61%; P < 0.001), as compared to the other types. There were no significant differences in the proportion of different types of digital manica flexoria between left and right limbs (P = 0.4).

Table 2 shows the prevalence of the different types and configurations of the intermediate vinculum in all limbs. In the front limbs, there was a significantly larger proportion of the lateral and medial abaxial type of intermediate vinculum (71%; P < 0.001), whereas in the hind limbs the axial type predominated (92%; P < 0.001). There were no significant differences in types of intermediate vinculum between left and right limbs (P = 0.9).

The presence of a digital manica flexoria of synovial bridge type was significantly associated with a lateral and medial abaxial intermediate vinculum (P = 0.001), and the presence of a digital manica flexoria of oblique-crossing type was significantly associated with an axial intermediate vinculum (P < 0.001).

In the majority of limbs (122/144; 85%), passage dorsal to the digital manica flexoria towards the distal end of the DFTS was not possible due to the attachment of the distal border of the digital manica flexoria to the dorsal wall of the DFTS. Dorsal passage was only possible in 22 of the 144 limbs (15%), all of which were front limbs. Table 3 presents the prevalence and site of passage along the dorsal aspect of the digital manica flexoria towards the distal aspect of the DFTS in the front and the hind limbs.
Table 1: Prevalence of the different types and configurations of the equine digital manica flexoria.

<table>
<thead>
<tr>
<th>Type and configuration</th>
<th>Front limbs Left</th>
<th>Total front limbs</th>
<th>Hind limbs Left</th>
<th>Total hind limbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membranous type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synovial bridge</td>
<td>28</td>
<td>32</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Fibrous bridge</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Broad synovial fold</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tendinous type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symmetric X-crossing</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Asymmetric X-crossing</td>
<td>0</td>
<td>1</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Oblique-crossing</td>
<td>2</td>
<td>0</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>Total (n=144)</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
</tbody>
</table>

Table 2: Prevalence of the different types and configurations of the intermediate vinculum, according to its insertion on the deep digital flexor tendon.

<table>
<thead>
<tr>
<th>Vinculum type and configuration</th>
<th>Front limbs</th>
<th>Total</th>
<th>Hind limbs</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial vinculum</td>
<td>4</td>
<td>6 (8%)</td>
<td>33</td>
<td>66 (92%)</td>
</tr>
<tr>
<td>Lateral &amp; medial abaxial vinculum</td>
<td>25</td>
<td>51 (71%)</td>
<td>0</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>Wide vinculum</td>
<td>7</td>
<td>15 (21%)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Total (n=144)</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
</tbody>
</table>

Table 3: Prevalence of passage along the dorsal aspect of the equine digital manica flexoria towards the distal aspect of the digital flexor tendon sheath.

<table>
<thead>
<tr>
<th>Possibility of passage and location</th>
<th>Front limbs</th>
<th>Hind limbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not possible (n=122)</td>
<td>50</td>
<td>72</td>
</tr>
<tr>
<td>Possible (n=22)</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>Medially and laterally</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Only medially</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Only laterally</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Axially</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Over entire width</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
In 10 of the 11 horses (90%) of which all 4 limbs were dissected, the front limbs consistently presented a membranous type of digital manica flexoria, and the hind limbs consistently presented one of tendinous type. In the majority of these horses (8/11, 73%), there were no contralateral differences in type of digital manica flexoria and intermediate vinculum. One horse had intermediate vincula patterns that differed between the two front limbs. Two horses had contralateral differences in the type of the digital manica flexoria (one horse only in the hind limbs, the other horse in both the front and hind limbs), while the intermediate vincula patterns were the same. Passage dorsal to the digital manica flexoria was present in only 3 of these 11 horses (always in the front limbs) and the site of passage was consistently the same in the left and right front limbs.

DISCUSSION

In this study, a large number of equine cadaver limbs was dissected to unravel the presence and structure of the digital manica flexoria in the DFTS. Our data show that the digital manica flexoria is consistently present in the equine distal limb. However, its configuration is variable and is strongly dependent on its location, with a membranous type of digital manica flexoria predominating in the front limbs and a tendinous type in the hind limbs. Such differences between horses and between front and hind limbs have not been reported for the more proximal manica flexoria, where only a variation of length (longer in the front limbs) has been described, without differences in structural composition (Findley et al., 2014). Nevertheless, various authors have shown that anatomical and morphological differences can exist in other structures of the equine limb. For example, Muylle et al. (2010) reported 6 different patterns of the accessory ligament of the DDFT in the equine
hind limbs, and Wilson et al. (1991) demonstrated breed-, limb- and exercise-related differences in muscular composition of the origin of the suspensory ligament. Furthermore, the variability of the digital manica flexoria observed in the horse is in line with the situation in man, where different types and configurations of tendinous chiasmata (crossing of tendinous fibers between the two distal branches of the SFDT, dorsal to the DDFT) have been identified in the fingers (Schmidt et al., 1994). In other domestic animal species, the presence of a digital manica flexoria or a similar structure has also been reported, and some differences between the various species have been described (Sisson and Gossman, 1975; Nickel et al., 1986; Barone, 2000; Dyce et al., 2002; Wissdorf et al., 2002; Schaller et al., 2007). However, to the authors’ knowledge, detailed descriptive and comparative anatomical studies have not been published so far.

It could be possible that the differences in structure and configuration of the digital manica flexoria observed between the front and the hind limbs of horses are due to differences in function. Redding (1993) suggested that the function of both the manica flexoria and the digital manica in the horse was to maintain the DDFT centrally positioned in the DFTS, but he did not mention that this function could be different between the front and hind limbs. In humans, three functions have been attributed to the tendinous chiasma of the fingers: providing a pathway to the DDFT, increasing the stability and balance of the proximal interphalangeal joint, and preventing hyperextension of this joint (Schmidt et al., 1994). To the authors’ knowledge, there are no objective studies evaluating the physiology of the manica flexoria and digital manica in the horse. Conformation and kinematic studies of the distal portion of the equine limbs have shown that the front limbs sustain higher vertical loads than the hind limbs. However, the fetlock joints of the hind limbs tend to have a higher degree of extension (Holmström et al. 1990; Back et al., 1995). Therefore, it could be hypothesised that the predominant tendinous type of digital manica flexoria found
in the hind limbs has a stabilising function of the digital flexor tendons and the proximal interphalangeal joint, as these structures experience greater degrees of movement in the equine hind foot. However, further investigation is necessary to confirm this hypothesis.

Based on their microscopic observation that the connective tissue of the vinculum is rich in collagenous and elastic fibers, Neumeier et al. (2004) also claimed a stabilising function of the intermediate vinculum (in both the front and hind limbs) rather than the supplying role that has commonly been attributed to the mesotenons and vincula. In the same study, different configurations of the intermediate vinculum were also found and the distribution of those between the front and hind limbs was in accordance with our results. Moreover, we found significant associations between the specific types of digital manica flexoria and intermediate vinculum which, as previously suggested, could be functionally determined.

Pathology related to the digital manica flexoria has up to now hardly been recognised or reported. To the authors’ knowledge, there is only one study reporting 2 torn digital manica within 77 tenoscopically examined DFTS (Smith and Wright, 2006). In contrast, tears of the proximal manica flexoria are frequently diagnosed as a cause of digital tenosynovitis and lameness, and they can be demonstrated ultrasonographically, by contrast radiography, and tenoscopically (Arensburg et al., 2011; Findley et al., 2012; Fiske-Jackson et al., 2013). However, this does not compromise the clinical relevance of our findings as clinicians should be aware of the intra- and inter-individual anatomical variations of the digital manica flexoria and its vincula to avoid misinterpretation during ultrasonographic and tenoscopic examinations of the DFTS and to avoid damage to the intrathecal structures when examining the distal part of the DFTS during tenoscopy.
The digital manica flexoria does not appear in the Nomina Anatomica Veterinaria (N.A.V.) as a recognised structure of the equine distal limb (World Association of Veterinary Anatomists, 2012). Moreover, it can be found in the veterinary literature with different names, which can be confusing for the readers (Nixon, 1990; Denoix, 1991; 1994; 2000; Redding, 1993; Dyce et al., 2002; Neumeier et al., 2004; McIlwraith et al., 2006; Smith and Wright, 2006; Fiske-Jackson et al., 2013). Therefore, the accordance of a consensual name to define this structure and to allow proper and clear reference in the future, was considered necessary. The use of the term tendinous chiasma adopted from human anatomical terminology (Camper, 1760; Schmidt et al., 1994) could be an option to indicate this homologous structure in the horse. However, this term was considered suboptimal because it specifically describes the decussation of tendinous fibers of the SDFT branches and, as we could observe, in the majority of equine front limbs the digital manica flexoria was reduced to a simple synovial fold or bridge. On the other hand, and despite the macroscopic structural differences between the manica flexoria and the digital manica, we still consider both structures closely related as both arise from the medial and lateral borders of the SDFT and both encircle the DDFT completely. Therefore, the term digital manica flexoria was considered more adequate because it can be easily associated to its homologue manica flexoria, it has instructive and descriptive value for the location of this structure in the digit, and it is in accordance with the nomenclatory principles of the N.A.V. (World Association of Veterinary Anatomists, 2012).

In conclusion, the present study has demonstrated that the digital manica flexoria is consistently present in the equine foot, with rather large intra- and inter-individual variation but with characteristic types and configurations predominating in the front and hind limbs. However, the exact function of this structure remains to be studied. The term digital manica flexoria is proposed to name this structure in order to facilitate communication in the future.
References


CHAPTER 4

Comparison of four techniques for synoviocentesis
of the equine digital flexor tendon sheath: a
cadaveric study

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four techniques for synoviocentesis of the equine digital flexor tendon sheath: a cadaveric
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SUMMARY

Synoviocentesis of the digital flexor tendon sheath (DFTS) is often performed in horses and different techniques of injection have been described. The objective of the present study was to compare 4 different techniques for synoviocentesis of the DFTS. Fifteen inexperienced operators performed each of the following injection techniques on 2 cadaver limbs: Proximal (at the proximolateral recess of the DFTS), Axial (axial to the lateral proximal sesamoid bone), Base (at the base of the lateral proximal sesamoid bone), and Distal (at the palmar/plantar mid-pastern). The number of attempts needed before the needle was assumed to be correctly positioned into the DFTS was recorded and 10 ml of methylene blue was injected. Subsequently, the limbs were systematically dissected and the following parameters were recorded and compared between techniques: the presence of methylene blue in the DFTS, the distance between the needle entrance point and the lateral palmar/plantar (digital) nerve (D_N), the degree of subcutaneous leakage, and the distance between the border of the leakage zone and the lateral palmar/plantar (digital) nerve (D_LN). The Axial and Distal approaches had the highest numbers of successful injections (29/30 and 25/30, respectively). The median number of attempts was highest for the Axial approach (3 attempts). Although not significant, the median leakage score was lower for the Axial technique (score 1 on a 3 degree scale). The distances from the injection point (D_N) and from the border of the leakage zone (D_LN) to the lateral palmar/plantar (digital) nerve were longer for the Distal (D_N 30 mm, D_LN 10 mm) and Axial (D_N 23 mm, D_LN 18 mm) approaches. In the hands of inexperienced operators the Axial approach was the most successful technique for injection of the equine DFTS. Sparse subcutaneous leakage and larger distance to the nerve when using this technique might decrease the risk of inadvertent palmar/plantar (digital) nerve desensitisation when performing DFTS analgesia.
INTRODUCTION

Synoviocentesis of the digital flexor tendon sheath (DFTS) is commonly performed in horses for both diagnostic and therapeutic purposes. Indications for DFTS synoviocentesis include synovial fluid analysis in septic and aseptic tenosynovitis, analgesia during lameness investigations, intrasynovial contrast radiography, distension of the DFTS for tenoscopy, through-and-through needle lavage, or therapeutic injection of anti-inflammatory agents.

Due to its anatomical localisation, the DFTS is frequently involved in lacerations of the equine distal limb hence being the most commonly affected synovial sheath (Jackman et al., 1989; Honnas et al., 1991). Early and prompt identification of DFTS involvement is crucial in order to establish appropriate treatment. Therefore, reliable access to the DFTS is mandatory for either synovial fluid sampling or confirming communication between the DFTS and a laceration. Aseptic digital tenosynovitis can also affect the DFTS. It can have several aetiopathogeneses, but is mostly secondary to longitudinal tears of the digital flexor tendons, tears of the manica flexoria, desmitis of the palmar/plantar annular ligament (PAL), tendonitis of the superficial and deep digital flexor tendons, rupture of the DFTS, or chronic synovitis of the DFTS of unknown origin (Gerring and Webbon, 1984; Dik et al., 1991; Barr et al., 1995; Dyson and Denoix, 1995; Wright and McMahon, 1999; McIlwraith, 2002).

Intrasynovial analgesia has become a routine procedure in confirming lameness of the DFTS. Accurate access to the synovial sheath is also mandatory in these cases to obtain reliable results of the diagnostic analgesia. Nevertheless, some controversy exists concerning the specificity of the DFTS analgesia and some authors have suggested that desensitisation of structures other than those intended may occur (Schneider et al., 2003;
Bassage and Ross, 2010). Schneider et al. (2003) reported desensitisation of the foot after DFTS analgesia, probably related to the proximity of the palmar/plantar (digital) nerve to the injection site and to the size of the needle allowing subcutaneous leakage. In contrast, Harper et al. (2007) found no influence of DFTS analgesia on lameness caused by pain within the navicular bursa, distal interphalangeal joint, or the sole (dorsal margin or heel region). However, inadvertent skin desensitisation at the level of the heel bulbs was not assessed in their study.

Different techniques for synoviocentesis of the DFTS have been described. The most commonly used approaches are at the proximal recess of the DFTS and at the distal palmar/plantar aspect of the pastern between the proximal and distal digital annular ligaments (Bassage and Ross, 2010; Baxter and Stashak, 2011). The DFTS may also be approached abaxially, at its outpouching at the base of the proximal sesamoid bone (PSB), between the distal aspect of the PAL and the proximal aspect of the proximal digital annular ligament (Bassage and Ross, 2010). Hassel et al. (2000) described a palmar/plantar axial sesamoidean approach, at the level of the mid-body of the lateral PSB, axially to the palpable palmar/plantar border of the lateral PSB, through the PAL. The choice of technique is determined by the experience and personal preferences of the operator. However the absence of synovial distension, the presence of a wound at the site of synoviocentesis, or a compromised state of the surrounding tissues may prevent the use of a specific technique. In any case, the injection technique should be easy to perform and ensure an accurate access to the DFTS.

To our knowledge, there is no study that compared objectively the 4 most commonly used techniques for intrasynovial injection of the DFTS. Therefore, the goals of the present study were: 1) To compare the accuracy and the ease of performing of the 4 above
mentioned synoviocentesis techniques and 2) To assess the risk of inadvertently influencing the palmar/plantar (digital) nerves by measuring the degree of subcutaneous leakage and the distance to the palmar/plantar (digital) nerve.

**MATERIALS AND METHODS**

**Specimens**

A cadaveric study was performed using a total of 120 distal equine limbs (60 front and 60 hind limbs) from horses of different breeds, sizes and ages, collected at the slaughterhouse. Limbs were amputated at the level of the mediocarpal or proximal intertarsal joints and were examined to exclude the presence of any gross anatomical abnormalities or damage produced during the cutting process. The specimens were used fresh and the hair was clipped.

**Injection techniques**

Table 1 provides a detailed description of the 4 injection techniques, as presented to the operators. Figure 1 illustrates the site of injection for each of the 4 previously mentioned injection techniques. All synoviocenteses were performed using a 20 gauge, 25 mm hypodermic needle. The position of the needle bevel was left to the discretion of each operator. For the Proximal and Axial injection techniques the limbs were held in flexion in a proximal-distal orientation. For the Base and Distal techniques, each limb was lying flat on a table with the palmar/plantar aspect facing upwards (simulating a limb that is held up, parallel to the ground). Limbs were always held by the same person (main investigator).
Table 1: Description of the 4 synoviocentesis techniques.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Position</th>
<th>Insertion</th>
<th>Direction</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximal: Proximo-lateral approach</strong></td>
<td>Fetlock joint slightly in flexion</td>
<td>Needle inserted 1 cm proximal to the PAL and 1 cm palmar/plantar to the lateral branch of the suspensory ligament</td>
<td>Needle directed slightly distal</td>
<td>Approximately 15 mm</td>
</tr>
<tr>
<td><strong>Axial: Palmar-plantar axial sesamoidean approach</strong></td>
<td>Fetlock joint flexed to a 225° angle dorsally</td>
<td>Needle inserted at the level of the mid-body of the lateral PSB, through the PAL, and 3 mm axial to the palpable palmar/plantar border of the lateral PSB</td>
<td>Needle inserted in the transverse plane and directed 45° from the sagittal plane, angled toward the central intersesamoidean region</td>
<td>Approximately 15 to 20 mm</td>
</tr>
<tr>
<td><strong>Base: Base of the proximal sesamoid bone approach</strong></td>
<td>Fetlock joint in a straight dorsal line</td>
<td>Needle inserted in palpable indentation just distal to the lateral PSB, between the distal aspect of the PAL and proximal aspect of the proximal digital annular ligament, palmar/plantar to the neurovascular bundle</td>
<td>Needle inserted in the transverse plane or slightly proximal (approximately 20°), perpendicular to the skin</td>
<td>Approximately 5 mm</td>
</tr>
<tr>
<td><strong>Distal: Palmar/plantar pastern approach</strong></td>
<td>Fetlock joint in a straight dorsal line</td>
<td>Needle inserted in the palmar/plantar aspect of the pastern region, in the outpouching of the DFTS located between the proximal and distal digital annular ligaments</td>
<td>Needle directed in the sagittal plane, perpendicular to the skin</td>
<td>Approximately 5 mm</td>
</tr>
</tbody>
</table>

PAL: palmar/plantar annular ligament; PSB: proximal sesamoid bone.
Figure 1: Cadaver limb illustrating the needle position for each of the four different injection techniques of the digital flexor tendon sheath. For detailed description of the injection technique see Table 1.
Experimental design

Fifteen inexperienced operators (final year veterinary students) were included in this study. The operators were provided with some anatomic slides and a written protocol for each of the 4 synoviocentesis techniques (Table 1). A video film demonstrating each technique was shown at the start of the experiment. Each operator performed each injection technique on 2 cadaver limbs (one front and one hind limb). The order of limb and technique were randomly assigned. As each technique was performed, the main investigator recorded the number of attempts needed before the needle was assumed to be correctly positioned into the DFTS. Any redirection of the needle was considered an attempt, even if the needle was not completely removed from the limb. There was no limit to the number of attempts allowed. When the operator considered the needle to be successfully inserted in the DFTS, 10 ml of methylene blue dye (MB) was injected. Criteria used by the operators for assuming correct placement of the needle in the synovial space were adherence to the anatomical landmarks and protocol definition, palpable evidence of entrance into a potential space, obtaining synovial fluid into the needle hub, and/or lack of resistance to fluid injection. The limbs were systematically dissected between 1-3 hours after the injection. The following parameters were recorded and compared between techniques: presence of MB in the DFTS confirming correct intrasynovial injection and/or presence of MB in the metacarpo- or metatarsophalangeal joint indicating inadvertent intra-articular injection, the distance between the needle entrance point and the lateral palmar/plantar (digital) nerve ($D_N$), the degree of subcutaneous leakage (1 = minimal, with a MB spot $< 5$ mm; 2 = moderate, with a MB spot 5 to 15 mm; 3 = severe, with a MB spot $> 15$ mm), and the distance between the border of the MB leakage zone and the lateral palmar/plantar (digital) nerve ($D_{LN}$) (Figure 2).
CHAPTER 4 - Comparison of 4 techniques for synoviocentesis of the DFTS

Figure 2: Photographs of the limbs during anatomical dissection illustrating the different subcutaneous leakage scores (black arrows). A) Score 1 = minimal subcutaneous leakage with a methylene blue (MB) spot < 5 mm. B) Score 2 = moderate subcutaneous leakage with a MB spot 5 to 15 mm. C) Score 3 = severe subcutaneous leakage with a MB spot > 15 mm. Note the proximal outpouchings of the digital flexor tendon sheath (white arrows) which should not be interpreted as subcutaneous leakage.
Statistical analysis

Statistical analysis was performed using SPSS 17.0 (IBM Corporation, New York) with statistical significance set at \( P < 0.05 \). As data were not normally distributed (Kolmogorov-Smirnov test and QQ-plot) and this could not be adequately resolved by transformation, non-parametric analyses were performed. The association between the different techniques and the number of successful injections was examined using Chi-square analysis with Bonferroni adjustment for the individual contrasts. Front and hind limb values (attempts, score) were compared using Mann-Whitney rank sum test. The number of attempts, leakage score and distance between the injection point and the border of the leakage zone to the lateral palmar/plantar (digital) nerve were all compared using Kruskal-Wallis test with pairwise comparison using Dunn’s test. Only limbs with correct intrathecal injection were included for subcutaneous leakage scoring and distances to the lateral palmar/plantar (digital) nerve. Data are presented as median values (range).

RESULTS

Tables 2 and 3 summarise the results for the different parameters.

The highest numbers of successful injections were recorded for the Axial (29/30) and Distal (25/30) approaches. The Axial approach was significantly more successful than the Proximal (OR 22.2, 95% CI [2.7-184.9]) and Base techniques (OR 16.8, 95% CI [2.0-141.0]) (\( P < 0.01 \)). No significant differences were observed between front and hind limbs. On only two occasions MB was observed in the metacarpo- or metatarsophalangeal joint indicating inadvertent injection of this synovial structure. This occurred in one front and one hind limb, with different operators, both when using the Proximal approach.
Table 2: Comparison of 4 different techniques for synoviocentesis of the digital flexor tendon sheath in 120 equine cadaver limbs (30 limbs for each technique) for accuracy and ease of performing.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Number successful injections in DFTS</th>
<th>Number attempts Median [range]</th>
<th>Penetration MCP/MTP joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal</td>
<td>17 out of 30 (56%) b</td>
<td>2 [1-8] a</td>
<td>2 out of 30 (6%)</td>
</tr>
<tr>
<td>Axial</td>
<td>29 out of 30 (96%) a</td>
<td>3 [1-9] a</td>
<td>0 out of 30 (0%)</td>
</tr>
<tr>
<td>Base</td>
<td>19 out of 30 (63%) b</td>
<td>1 [1-4] b</td>
<td>0 out of 30 (0%)</td>
</tr>
<tr>
<td>Distal</td>
<td>25 out of 30 (83%) a</td>
<td>1 [1-6] b</td>
<td>0 out of 30 (0%)</td>
</tr>
</tbody>
</table>

DFTS: digital flexor tendon sheath; MCP/MTP: metacarpophalangeal/metatarsophalangeal joint.

For the description of Proximal, Axial, Base, and Distal see Table 1. Values in the same column with different superscript letters are significantly different (P < 0.05).

Table 3: Comparison of 4 different techniques for synoviocentesis of the digital flexor tendon sheath in 120 equine cadaver limbs (30 limbs for each technique) for subcutaneous leakage and distance to the lateral palmar/plantar (digital) nerve.

<table>
<thead>
<tr>
<th>Technique</th>
<th>D_N (mm) Median [range]</th>
<th>Leakage score Median [range]</th>
<th>D_LN (mm) Median [range]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal</td>
<td>5 [0-25] b</td>
<td>2 [1-3]</td>
<td>0 [0-5] b</td>
</tr>
<tr>
<td>Base</td>
<td>15 [0-35] b</td>
<td>2 [1-3]</td>
<td>0 [0-20] b</td>
</tr>
</tbody>
</table>

D_N= distance from needle insertion point to the lateral palmar/plantar (digital) nerve; D_LN= distance from border of methylene blue (MB) leakage zone to the lateral palmar/plantar (digital) nerve. Leakage score: 1 = minimal, with a MB spot < 5 mm; 2 = moderate, with a MB spot 5 to 15 mm; 3 = severe, with a MB spot > 15 mm. For the description of Proximal, Axial, Base, and Distal see Table 1. Values in the same column with different superscript letters are significantly different (P < 0.05).
The median number of attempts was highest for the Axial approach (3 attempts) with significant difference compared to the Base (P < 0.01) and Distal (P < 0.001) techniques (both 1 attempt). The Base technique required significantly more attempts in the front limbs (median 2, range 1-4) compared to the hind limbs (median 1, range 1-4) (P < 0.05).

When analysing the distance from the injection point to the lateral palmar/plantar (digital) nerve (DN), Distal and Axial injections occurred significantly further away from the nerve compared to Proximal and Base approaches (P < 0.001 for all comparisons except for Axial to Base: P < 0.01). The median leakage score was lower for the Axial technique compared to the other three approaches but these differences did not reach statistical significance. Only for the Distal approach was the leakage score number significantly higher in the front limbs (median 3, range 1-3) compared to the hind limbs (median 1, range 1-3) (P < 0.01). When analysing the distance from the border of the MB leakage zone to the lateral palmar/plantar (digital) nerve (DLN) similar results were observed as for DN: MB leakage spots observed after Axial and Distal injection were significantly further away from the palmar/plantar (digital) nerve than those obtained with the Proximal and Base techniques except for the comparison of Distal to Base (P < 0.001 for Axial to Proximal; P < 0.01 for Axial to Base and P < 0.05 for Distal to Proximal). No significant differences between front and hind limbs could be identified for DLN.
DISCUSSION

In the hands of inexperienced operators, the Axial and Distal techniques were superior compared to the Proximal and Base approaches in terms of accuracy of injection. Although the Axial approach took the highest number of attempts, there was only one non-successful injection with this technique. In clinical cases with distension of the DFTS, synoviocentesis at one of the synovial recesses of the DFTS (Proximal, Base and Distal techniques) becomes easier to perform as the presence of synovial fluid in the needle hub confirms correct needle location. It is therefore likely that in these clinical situations the rate of successful injection of the Proximal and Base techniques would have been higher compared to the results obtained in this study. However, clinicians should be able to inject the DFTS under any circumstance, even when the DFTS is not distended and the presence of synovial fluid in the needle hub cannot be used as a landmark to confirm accurate positioning of the needle. Since the Axial technique is not performed at one of the outpouchings of the DFTS, this might be the most suitable technique in case of absence of DFTS distension.

The inadvertent penetrations of the metacarpo- or metatarsophalangeal joint (only 2 out of 120 limbs) with the Proximal technique may possibly be explained by the close anatomic proximity of the palmar/plantar recess of the joint capsule to the proximolateral synovial pouch of the DFTS. Although the chance of inadvertent penetration of the metacarpo- or metatarsophalangeal joint is small, unintended intrasynovial analgesia or iatrogenic spread of infection when dealing with septic tenosynovitis may result. Placing the needle plantar to the neurovascular bundle should theoretically reduce the risk of inadvertent penetration of the metacarpo- or metatarsophalangeal joint.
Although the median number of attempts was acceptable, in individual cases many attempts were needed to reach the DFTS. In our opinion, a lack of familiarity of the inexperienced operators with the anatomy of the area, together with the disadvantage of working with cadaver limbs could have played a role. Nevertheless, a large number of attempts increases the likelihood of inducing intrasynovial haemorrhage (Misheff and Stover, 1991) and damage to the tendons. Indeed, needle marks on the flexor tendons (SDFT, DDFT or both) were frequently observed with any of the 4 described techniques during anatomical dissection but substantial needle-induced trauma was not identified during gross dissection of the limbs. Hassel et al. (2000) already suggested that damage to the abaxial region of the flexor tendons may occur when using the Axial technique.

Unfortunately, and similar to the study of Hassel et al. (2000), no detailed recording of iatrogenic damage to the soft tissue and flexor tendons was performed in the present study. Theoretically, one can expect a lower risk of tendon damage when using the Proximal, Base, or Distal techniques compared to the Axial technique as with the latter there is very little free space between the flexor tendons, the PAL, and the PSB in the fetlock canal. On the other hand, in many clinical situations where distension of the DFTS is present, the appearance of synovial fluid in the needle hub as a sign of correct needle placement into the DFTS would no longer result in further needle advancement with less chance of tendon damage. Nevertheless, further investigation should be performed in order to establish the degree of flexor tendon damage for each of the different injection techniques.

The difference in leakage score between the Axial and the other three techniques was not significant, but this might have been due to the lack of power. For the Axial technique, the injection is performed obliquely and through the hard fibrous PAL, and we speculate that this may inhibit subcutaneous leakage of the injected fluid. Furthermore, the Axial and Distal techniques are performed in a more axial position which places the needle further
away from the palmar/plantar (digital) nerve compared to the Proximal and Base techniques, both performed more abaxially and thus closer to the neurovascular bundle. As suggested by Harper et al. (2007), with the Axial technique the combination of injecting further away from the palmar/plantar (digital) nerve together with a lower degree of subcutaneous leakage is likely to result in a reduced risk of inadvertent desensitisation of the palmar/plantar (digital) nerves when performing diagnostic analgesia. Nevertheless, this hypothesis should be confirmed in an in vivo study comparing the different techniques since in a clinical situation other elements may also play a role, like the compression that is routinely applied following injection over the site of needle entrance in order to avoid subcutaneous leakage. Also differences in tissue characteristics of the distal limb between cadavers and patients may influence the degree of subcutaneous leakage.

In conclusion, the results of the present study demonstrate that, in the hands of inexperienced operators, the palmar/plantar axial sesamoidean approach described by Hassel et al. (2000) is the most successful technique for injection of the equine DFTS in an ex vivo situation even though it requires the highest number of attempts to achieve correct needle placement. The sparse subcutaneous leakage together with a relatively larger distance from the injection point to the nerve, suggest a smaller likelihood of inadvertent desensitisation of the palmar/plantar (digital) nerves when performing analgesia of the DFTS during lameness examination.
References


CHAPTER 5

Distal limb desensitisation following analgesia of the digital flexor tendon sheath in horses using four different techniques

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²Department of Comparative Physiology and Biometrics, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, 9820 Merelbeke, Belgium.

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Adapted from:

SUMMARY

Controversy exists about the desensitisation obtained after diagnostic analgesia of the digital flexor tendon sheath (DFTS) during lameness examinations. The objective of this study was to determine whether DFTS analgesia results in inadvertent desensitisation of the palmar/plantar (digital) nerves and whether this depends on the injection technique used. Therefore, the DFTSs of 9 horses were injected with local anaesthetic solution and radiodense contrast medium using one of the following techniques: Proximal (at the proximolateral recess of the DFTS), Axial (axial to the lateral proximal sesamoid bone), Base (at the base of the lateral proximal sesamoid bone), and Distal (at the palmar/plantar mid-pastern). In total, 72 injections were performed. Skin desensitisation at the heel bulb was tested with a dynamometer before injection and at 15, 30, 90, and 120 minutes after injection. Overall, complete desensitisation of a heel bulb at one or more time points after injection occurred in 22 limbs (30.6%). An additional 7 limbs showed partial desensitisation. Complete skin desensitisation occurred in 10, 3, 4 and 5 limbs using the Proximal, Axial, Base, and Distal techniques respectively. Significant differences between techniques were only found at T30. The probability of skin desensitisation at the heel bulbs was 4 times higher when using the Proximal compared to the Axial and Base techniques in the front limbs, and 3 times higher compared to the Axial and Distal techniques in the hind limbs. Skin desensitisation nearly always occurred exclusively on the lateral heel bulb. Only in 5 limbs biaxial desensitisation occurred. Anaesthesia of the palmar/plantar (digital) nerve with distal limb desensitisation often occurs after DFTS analgesia. A higher chance of desensitisation exists when injecting the proximal DFTS recess. It is advisable to verify skin sensitivity at the heel bulbs after DFTS analgesia to avoid false interpretations about the origin of pain causing lameness.
INTRODUCTION

Analgesia of the digital flexor tendon sheath (DFTS) has been documented to be useful in the diagnosis of painful digital tenosynovitis, intrasynovial tears of the digital flexor tendons, tenonitis of the digital portion of the deep digital flexor tendon (DDFT), desmitis of the oblique and straight distal sesamoidean ligaments, and desmitis of the palmar annular ligament (PAL) (Schneider et al., 2003; 2005; Smith and Wright, 2006; Schramme and Smith, 2010). Nevertheless, it has been suggested that diffusion of local anaesthetic solution after intrasynovial analgesia of the DFTS can lead to desensitisation of structures other than those intended, which can result in inaccurate conclusions regarding the origin of pain causing lameness (Schneider et al., 2003; Sampson et al., 2007; Bassage and Ross, 2010). Possible explanations for desensitisation of structures other than the DFTS include diffusion of local anaesthetic solution from the DFTS to adjacent structures or around the palmar/plantar (digital) nerves, but also backflow of local anaesthetic solution from the needle puncture site to the area of the palmar/plantar (digital) nerve.

Schneider et al. (2003) reported desensitisation of the foot after injecting local anaesthetic solution into the DFTS at the level of the lateral collateral recess, just distal to the PAL, and suggested therefore that skin sensation at the level of the heel bulbs should always be tested after performing DFTS analgesia. In contrast, Harper et al. (2007) reported no or very little influence of intrasynovial analgesia of the DFTS on lameness caused by pain within the navicular bursa, distal interphalangeal joint, or the sole when using the palmar axial sesamoidean approach (Hassel et al., 2000). However, skin sensation at the level of the heel bulbs was not assessed in their study. It was hypothesised that these discrepancies could be explained by the use of different injection techniques (needle size and injection site) in these studies.
Synoviocentesis of the DFTS can be performed at several locations. A recent study comparing the 4 most commonly used techniques for injection of the DFTS (1: at the proximolateral recess of the DFTS, 2: axial to the lateral proximal sesamoid bone [PSB], 3: at the base of the lateral PSB, and 4: at the distal recess of the DFTS in the mid-pastern region) showed that the most successful technique in cadaver limbs was the axial sesamoidean approach (Jordana et al., 2012). Furthermore, this technique resulted in only sparse subcutaneous leakage with a relatively large distance from the border of the leakage zone to the palmar/plantar (digital) nerve, suggesting a small likelihood to inadvertently desensitise the digital nerves when performing analgesia of the DFTS during lameness examination (Jordana et al., 2012). These results however, need to be confirmed in vivo.

There is no evidence-based study that demonstrates the potential influence of DFTS analgesia on the palmar/plantar (digital) nerves and, in consequence, of the distal aspect of the limb, and/or that compared the accuracy of different injection techniques in vivo. Therefore, the aims of this study were to evaluate inadvertent desensitisation of the palmar/plantar (digital) nerves after DFTS analgesia and to determine whether this desensitisation was dependent on the injection technique used. We hypothesised that analgesia of the DFTS would occasionally lead to desensitisation of the palmar/plantar (digital) nerves, resulting in loss of skin sensation at the level of the heel bulbs, and that the incidence and degree of palmar/plantar (digital) nerve desensitisation would differ between techniques.
MATERIALS AND METHODS

Subjects

Nine horses belonging to the group of experimental animals of the Faculty of Veterinary Medicine of Ghent University were included in the study: 4 Warmblood horses, 3 Standardbreds, one cross-bred, and one pony (5 females and 4 geldings), mean age 12.5 years (range 8-20 years, s.d. ± 3.7 years) and mean body weight 566.1 kg (range 385-690 kg, s.d. ± 89.8 kg). All horses were evaluated clinically to exclude any lameness or musculoskeletal abnormalities at the level of the distal limbs. The study was approved by the Ethical Committee of Ghent University (EC 2010/044).

Protocol

The study was organized in 4 sessions with a 6 days wash-out period in between them. During a session, the DFTSs of one front limb and one hind limb of each horse were injected with one of the 4 different techniques described in Table 1. The technique to be used and the limbs to be injected were randomly assigned. The non-injected contralateral limbs were used as controls. The experimental sessions were always performed in the same environment, under the same circumstances. At the end of the 4 sessions, each technique had been performed in both a front limb and a hind limb of the 9 different horses.
Table 1: Description of the techniques for injection of the digital flexor tendon sheath in the standing horse. All injections were performed with the limbs held off the ground.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Position*</th>
<th>Insertion</th>
<th>Direction</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROXIMAL: Proximal Approach</strong></td>
<td>Fetlock joint slightly in flexion</td>
<td>Needle inserted 1 cm proximal to the PAL and 1 cm palmar/plantar to the lateral branch of the suspensory ligament</td>
<td>Needle directed slightly distal</td>
<td>Approximately 15 mm</td>
</tr>
<tr>
<td><strong>AXIAL: Palmar/Plantar Axial Sesamoidean Approach</strong></td>
<td>Fetlock joint flexed approximately to a 225° angle dorsally</td>
<td>Needle inserted at the level of the mid-body of the lateral PSB, through the PAL, and 3 mm axial to the palpable palmar/plantar border of the lateral PSB</td>
<td>Needle inserted in the transverse plane and directed 45° from the sagittal plane, angled toward the central inter-sesamoidean region</td>
<td>Approximately 15 to 20 mm</td>
</tr>
<tr>
<td><strong>BASE: Base Of Proximal Sesamoid Bone Approach</strong></td>
<td>Fetlock joint in a straight dorsal line</td>
<td>Needle inserted in palpable indentation just distal to the lateral PSB, between the distal aspect of the PAL and proximal aspect of the proximal digital annular ligament, palmar/plantar to the neurovascular bundle</td>
<td>Needle inserted in the transverse plane or slightly proximal (ca. 20°), perpendicular to the skin</td>
<td>Approximately 5 mm</td>
</tr>
<tr>
<td><strong>DISTAL: Palmar/Plantar Pastern Approach</strong></td>
<td>Fetlock joint in a straight dorsal line</td>
<td>Needle inserted in the palmar/plantar aspect of the pastern region, in the outpouching of the DFTS located between the proximal and distal digital annular ligaments</td>
<td>Needle directed in the sagittal plane, perpendicular to the skin</td>
<td>Approximately 5 mm</td>
</tr>
</tbody>
</table>

PAL= palmar/plantar annular ligament; PSB= proximal sesamoid bone.

*Due to the reciprocal apparatus, the degree of flexion was always a little more pronounced in the hind limbs compared to the front limbs.

For an indicative illustration of the injection techniques, see Chapter 4, Figure 1.
Objective evaluation of skin sensitivity at the heel bulbs

To evaluate the presence or absence of inadvertent palmar/plantar (digital) nerve desensitisation, skin sensitivity was measured at the lateral and medial heel bulbs by determining the mechanical nociceptive threshold (MNT). The MNT was measured in Newton’s (N) with a force measuring device (PCE-FM 200) attached to a long stick (Figure 1). Pressure to the heel bulb was applied with a 3 mm diameter blunt pin. When the horse moved or lifted the limb, pressure was stopped and the peak MNT was automatically recorded by the device. When no reaction was encountered, the maximal force applied was recorded (180 N or lower if there was a risk for wounding the horse). MNT measurements were performed at 5 different time points: prior to analgesia of the DFTS (T0) and 15 (T15), 30 (T30), 90 (T90), and 120 minutes (T120) thereafter. At each time point, 3 measurements per heel bulb of both the injected and the non-injected (contralateral) limb were performed. The order between measurements was alternated to avoid an adaptation effect.

Figure 1. Measurement of the mechanical nociceptive threshold at the heel bulbs with a force measuring device (PCE-FM 200, PCE Ibérica S.L., Tobarra, Spain) attached to a long stick.
Horses were classified into 3 groups, depending on their responses to the pressure applied on the heel bulbs by the dynamometer and on the MNT values recorded: Absence of skin desensitisation: horses showing a normal withdrawal reflex and with MNT values less than twice the control MNT value obtained at the same time point at the homolog heel bulb of the contralateral limb. Partial skin desensitisation: horses showing a withdrawal reflex after a longer time and with MNT values between 2 to 4 times the control MNT value obtained at the same time point at the homolog heel bulb of the contralateral limb. Complete skin desensitisation: horses showing no withdrawal reflex and with MNT values higher than 4 times the MNT value obtained at the same time point at the homolog heel bulb of the contralateral limb.

Intrathecal analgesia

After recording the T0 measurements, the injection site was aseptically prepared and analgesia of the DFTS of one front limb was performed with a 25 mm, 20 gauge hypodermic needle using one of the 4 injection techniques described in Table 1. All Proximal, Axial, and Base techniques were performed laterally. A mixture of the radiodense contrast medium iodixanol (Visipaque 320 mg I/ml) and the local anaesthetic solution mepivacaine hydrochloride 2% (Scandicaine) were injected at a total volume of 1.1 ml/50 kg bwt (0.2 ml/50 kg bwt of radiodense contrast medium and 0.9 ml/50 kg bwt of local anaesthetic solution). All injections were performed by the same clinician (M.J.). Retrieval of synovial fluid was not mandatory but injection had to be performed with no resistance. After withdrawal of the needle, the injection site was immediately protected with a sterile gauze fixed with tape around the limb for 15 minutes. Horses were not walked between measurements. Approximately one hour later, the same procedure was repeated in a hind limb.
Radiological study

Radiographs of the distal aspect of the limb were obtained immediately after the intrasynovial injection to determine whether the injection was successful (presence of contrast medium in the DFTS on lateromedial view) and at T30 to evaluate for the presence of the local anaesthetic solution and radiodense contrast medium mixture in the subcutaneous tissues (lateromedial when the distal technique had been performed, and lateromedial and dorso 45° lateral-palmaromedial oblique views for the 3 other injection techniques). Radiographs were analysed by a board-certified radiologist (J.S.) and an ECVDI-resident-in-training (K.V.). The occurrence of leakage of contrast medium, defined as the presence of contrast medium outside the DFTS at the level of the injection site, was assessed qualitatively (presence of contrast medium yes or no) (Figure 2). For an accurate interpretation, contrast tenograms of the same tendon sheath but injected by different techniques were compared.

Statistical analysis

Due to the presence of right censoring (maximal pressure of 180 N or lower if there was a risk of wounding the horse), statistical analysis was based on the Cox model with applied power to obtain “reaction” as the response variable, “horse” as the frailty term, and “technique” as a categorical fixed effect. The Proximal technique was set as the reference category. Statistical significance was set at $P < 0.05$. The parameter estimate is given as a hazard ratio of having a reaction for a particular pressure applied.

The association between the radiologically evaluated leakage, distal limb desensitisation, and the different injection techniques was examined using chi-square analysis, with Bonferroni adjustment for the individual contrasts, with statistical significance set at $P < 0.05$.d
Figure 2. Contrast tenogram obtained 30 minutes after injection of the digital flexor tendon sheath (DFTS) with the Base technique. Contrast medium is present in the subcutaneous tissues at the injection site (white arrow) palmar to the normal delineation of the DFTS (3 open arrow heads).
RESULTS

A total of 72 injections of the DFTS was performed (each technique 9 times on a front limb and 9 times on a hind limb) and 198 radiographic images and 4320 MNT measurements were obtained. Radiographs obtained immediately after injection confirmed that all DFTS injections were successful, except one of the Base injections (subcutaneous distribution of contrast medium). In the latter case, the injection was successfully repeated 6 hours later.

There was no significant influence of horse, front or hind limb, and left or right limb in the incidence of skin desensitisation. The mean ± s.d. MNT value of all limbs prior to DFTS anaesthesia (T0) was 28 ± 18.4 N. The mean MNT value for the partially desensitised limbs was 83 ± 24.8 N, which is 2.7 times higher compared with the contralateral homolog heel bulb (29 ± 15.7 N). The mean MNT value for the totally desensitised limbs was 130 ± 22.5 N, which is 5.6 times higher compared with the contralateral homolog heel bulb (23 ± 18.1 N).

Table 2 summarises per time-point, for the 4 different injection techniques, the number of limbs in which the lateral and/or medial heel bulb was partially or completely desensitised. The observed differences in incidence of skin desensitisation between techniques were only statistically significant at T30. At T30, the hazard ratio for skin desensitisation at the heel bulbs of the front limbs was significantly higher when using the Proximal technique compared with the Axial (OR 4, P = 0.02) and Base (OR 3.8, P = 0.019) techniques. For the hind limbs, the hazard ratio for skin desensitisation at the heel bulbs was significantly higher when using the Proximal compared with the Axial (OR 3.6, P = 0.023) and Distal (OR 3.1, P = 0.042) techniques.
Table 2: Number of limbs with partial and complete skin desensitisation at the lateral and medial heel bulbs at different time points after analgesia of the digital flexor tendon sheath using 4 different techniques, each technique performed 18 times thus a total of 72 times across the techniques.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Partial skin desensitisation</th>
<th>Complete skin desensitisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T15 Lat</td>
<td>Med</td>
</tr>
<tr>
<td>Proximal</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Axial</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Base</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Distal</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total (%)</td>
<td>3 (4%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Proximal</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Axial</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Base</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Distal</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total (%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

T15, T30, T90, T120: recording of skin sensitivity at the heel bulbs respectively 15, 30, 90, and 120 minutes after analgesia of the digital flexor tendon sheath. Lat: lateral heel bulb; Med: medial heel bulb.
Figure 3 illustrates the total number of limbs in which either partial or complete skin desensitisation after DFTS analgesia was recorded, grouped per technique. Overall, inadvertent desensitisation of heel bulbs occurred after 29 of the 72 (40.3%) DFTS injections. In 7 of 29 limbs distal desensitisation was partial and never evolved to complete desensitisation during the 2 hour evaluation period. In 22 of 29 limbs complete desensitisation was recorded at some stage. Skin desensitisation occurred predominantly at the lateral heel bulb only (24/29 limbs, 82.8%), seldom at both the medial and the lateral heel bulbs (5/29 limbs, 17.2%), and never at the medial heel bulb only.

**Figure 3.** Total numbers of digital flexor tendon sheath analgesia’s after which palmar/plantar (digital) nerve desensitisation occurred (partial and complete), presented per technique.
Evaluation of radiographs obtained immediately after injection revealed the presence of contrast medium in the subcutaneous tissues for 29 of the 72 injections (40.3%). At T30, contrast medium was observed in the subcutaneous tissues in an additional 8 limbs while one limb that was positive for leakage on the radiographs obtained immediately after injection, became negative at T30. In total, 36 limbs (50%) had radiologically detectable contrast medium in the subcutaneous tissues at T30. Table 3 summarises for each technique the number of injections with radiologically detectable subcutaneous leakage and whether this was associated with distal desensitisation (T30). There were no significant differences between techniques for the degree of radiologically observed subcutaneous leakage. Similarly, no statistically significant association was found between subcutaneous leakage of contrast medium as observed on T30 radiographs and heel bulb desensitisation.

Table 3: Distal desensitisation in the presence or absence of radiologically detected subcutaneous leakage at T30, presented per technique, each of which was performed 18 times.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Proximal</th>
<th>Axial</th>
<th>Base</th>
<th>Distal</th>
<th>All techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leakage</td>
<td>Distal limb desensitisation</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Yes</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>No</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Yes: Occurrence of distal limb desensitisation and/or presence of radiologically detected subcutaneous leakage; No: Absence of distal limb desensitisation and/or absence of radiologically detected subcutaneous leakage.
DISCUSSION

Regional or local diagnostic analgesia is used frequently during lameness investigations in horses and can provide useful information as to the source of pain. However, reliable information is only obtained when the regional or local anaesthesia is performed correctly and the clinician is aware of the extent of desensitisation it can cause. The more specific the area of desensitisation, the more useful the techniques are in localising the source of pain causing lameness. Nevertheless, ‘local effects’ of the local anaesthetic solution can never be excluded. As previously indicated, intrathecal analgesia of the DFTS can also influence pain associated with injuries of the distal sesamoidean ligaments and the palmar annular ligament (Schneider et al., 2003; 2005; Schramme and Smith, 2010).

The risk of inadvertent desensitisation of the palmar/plantar (digital) nerves after DFTS analgesia has been previously suggested (Schneider et al., 2003; Sampson et al., 2007; Bassage and Ross, 2010), but neither exact numbers nor correlation with the injection technique have been investigated. Our results show that DFTS analgesia influences the palmar/plantar (digital) nerves frequently because the present study recorded desensitisation of the heel bulbs in more than one third of the limbs (40.3%) following DFTS analgesia. Furthermore, it was found that the frequency of distal limb desensitisation differs for the 4 injection techniques with the Proximal technique carrying at least 3 times more risk of desensitisation compared with the other injection techniques. Harper et al. (2007) suggested that the risk of inadvertent palmar/plantar (digital) nerve desensitisation is minimal when using the axial approach. This corresponds with the results of a recent cadaver study comparing different DFTS injection techniques, where it was found that the Axial technique had the lowest leakage score with the border of the leakage zone being situated at a large distance from the palmar/plantar (digital) nerve (Jordana et al., 2012).
However, the current *in vivo* study did not confirm that the Axial technique leads significantly less frequently to inadvertent distal limb desensitisation compared with the Base or Distal techniques. Even though desensitisation occurs most frequently when using the Proximal technique, it was recorded with all 4 techniques. Therefore, in a clinical situation, it seems essential to always check for skin desensitisation prior to interpretation of the result of DFTS analgesia.

The present study could not reveal the exact mechanism by which the distal limb becomes desensitised. Theoretically, the local anaesthetic solution can reach the palmar/plantar (digital) nerve either by diffusion through the sheath wall or by subcutaneous leakage at the injection site. A recent cadaver study exploring 4 different techniques for injection of the DFTS, showed that backflow through the puncture hole is common, with methylene blue leakage spots larger than 5 mm in diameter being observed in 62.5% of limbs (Jordana *et al.*, 2012). In the present study, contrast tenograms at T30 showed the presence of contrast medium outside the DFTS within the subcutaneous tissues in 50% of the limbs. This observation together with other findings of the present study, favours the hypothesis that subcutaneous leakage of local anaesthetic solution is at least partially responsible for palmar/plantar (digital) nerve desensitisation. Most importantly, heel bulb desensitisation was predominantly observed laterally, hence ipsilateral to the site of injection (Proximal, Axial, and Base injections were all performed laterally). Furthermore, different techniques seem to have different odds for inadvertent distal limb desensitisation, which is expected with leakage but not with diffusion. At T30, a significantly higher frequency of desensitisation was observed for the Proximal approach. In a study investigating the “low 4-point nerve block”, Nagy *et al.* (2010) found relevant numbers of inadvertent DFTS penetration after perineural injection of the palmar nerve at the junction of the proximal three-quarters and distal quarter of the metacarpal region.
Furthermore, in a single cadaver specimen they deliberately injected the DFTS at the lateral aspect of its proximal pouch, after which contrast medium was detected radiologically in the ipsilateral neurovascular bundle. Dissection revealed the absence of connective tissue between the fascia of the neurovascular bundle and the wall of the DFTS at this level. According to Nagy et al. (2010), this not only explains why inadvertent DFTS penetration can easily occur following palmar nerve anaesthesia, but also why backflow of local anaesthetic solution after proximolateral injection of the DFTS may result in palmar/plantar (digital) nerve desensitisation.

By contrast, in the current study there was a minority of limbs in which both the lateral and medial heel bulb were desensitised and in our opinion, this cannot be explained by the leakage hypothesis, but probably results from diffusion of local anaesthetic solution through the DFTS wall. Furthermore, no statistically significant associations were found between the radiological detection of leakage at T30 and heel bulb desensitisation and, most notably, the distal aspect of 12 limbs were partially desensitised in the absence of visible leakage on the T30 contrast tenograms. Although the latter findings do not seem compatible with the leakage hypothesis, one should realise that one single contrast tenogram during the 2 hours evaluation period may have low sensitivity for the detection of leakage. Furthermore, not every leakage observed on a contrast tenogram is clinically relevant since there is no information on the extent of the leakage zone and the distance to the closest palmar/plantar (digital) nerve. Therefore, it is not surprising to have 19 limbs without distal desensitisation despite the presence of leakage on the contrast tenograms.

In our horses, inadvertent desensitisation of the palmar/plantar (digital) nerves was recorded mainly from 30 minutes post injection onwards, with the incidence of desensitisation peaking at T90 and being still observable at T120. Hence, in a complex
lameness case with multiple nerve blocks or intrasynovial analgesia, interpretation of lameness can be influenced by the effects of a DFTS analgesia 1.5 to 2 hours after injection. Fortunately, the incidence of desensitisation of the distal aspect of the limb at T15 is low (4% of the injections) and this is a time at which many clinicians will assess the effect of intrathecal analgesia on pre-existing lameness. Considering that backflow of local anaesthetic solution may be responsible for palmar/plantar (digital) nerve desensitisation, it is possible that the incidence of distal limb desensitisation at T15 would have been higher if the injection site had not been taped until then. Likewise, in a clinical situation, it seems advisable to leave the tape over the injection site until re-evaluation of lameness. There is no general consensus on the optimal time for evaluation of intrasynovial analgesia, with recommendations ranging from 5 to 30 minutes post-injection (Baxter and Stashak, 2011). Therefore, clinicians may prefer to evaluate their blocks already at 5 or 10 minutes post-injection, depending on personal preferences. Although at first instance it may seem a limitation of the present study that the first evaluation was performed at 15 minutes post-injection, the authors speculate that the incidence of inadvertent palmar/plantar (digital) nerve desensitisation at 5 or 10 minutes post-injection would have been even less than the 4% observed at T15.

In conclusion, the present study confirms that inadvertent distal limb desensitisation frequently accompanies DFTS analgesia. Both leakage of local anaesthetic solution from the puncture hole in the DFTS and diffusion of local anaesthetic solution through the DFTS wall may be responsible. When performing a lameness examination with multiple blocks, inadvertent distal limb desensitisation as a result of DFTS analgesia can hinder a reliable interpretation of these blocks for at least 1.5 to 2 hours after the intrathecal injection. Ideally, heel bulb skin sensitivity should be regularly evaluated during this kind of examinations. On the other hand, the incidence of palmar/plantar (digital) nerve
desensitisation seems low as long as the horse is evaluated within 15 minutes after DFTS injection. As desensitisation was observed most frequently after injection in the proximolateral outpouching of the sheath, Axial, Base, or Distal injections should be preferred.

Manufacturers’ addresses

a PCE Ibérica S.L., Tobarra, Spain.

b Amersham Health, Wemmel, Belgium.

c AstraZeneca S.A., Brussels, Belgium.

References


Diffusion of mepivacaine to adjacent synovial structures after intrasynovial analgesia of the digital flexor tendon sheath in the horse

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Adapted from:

CHAPTER 6 · Diffusion of mepivacaine to adjacent synovial structures after DFTS analgesia

SUMMARY

Controversy exists about the specificity of diagnostic analgesia of the digital flexor tendon sheath (DFTS) in horses. The objective of this study was to evaluate the degree of diffusion of mepivacaine from the equine DFTS to adjacent synovial structures. Under general anaesthesia, the DFTSs of one front and one hind limb of 8 horses were injected simultaneously with mepivacaine, using the Axial technique. Synovial fluid samples of the injected DFTS, the adjacent metacarpo-/metatarsophalangeal (MCP/MTP) joint, proximal interphalangeal (PIP) joint, distal interphalangeal (DIP) joint, navicular bursa (NB), and contralateral MCP/MTP joint were collected 15 minutes post-injection (T15) for one of the injected limbs and 60 minutes post-injection (T60) for the other limb. Venous blood samples were obtained at T0, T15, and T60 to check for systemic distribution of mepivacaine. After a 2-week washout period, the procedure was repeated using the same limbs but reversing the time of sampling (front vs. hind limbs). Concentration of mepivacaine in the different samples was measured with a commercial ELISA kit. Mepivacaine concentrations in the DFTS samples, both at T15 (5077 mg/l) and T60 (3503 mg/l), exceeded by far those estimated sufficient to produce synovial analgesia (100 mg/l or 300 mg/l). Mepivacaine was found in all synovial structures adjacent to the injected DFTS and in the contralateral MCP/MTP joints, but concentrations were low, with a maximum value of only 3.2 mg/l. Except for the NB samples, the mepivacaine concentrations in the adjacent synovial structures were significantly higher at T60 compared to T15 (P < 0.03). Significantly higher mepivacaine concentrations were found in the ipsilateral compared to the contralateral MCP/MTP joints at T60 (P < 0.001). Blood samples showed significantly higher mepivacaine concentrations at T15 and T60 compared to T0 (P < 0.001). It was concluded that mepivacaine injected into the DFTS of horses diffuses towards adjacent synovial structures but without achieving clinically relevant concentrations.
INTRODUCTION

Analgesia of the digital flexor tendon sheath (DFTS) is performed routinely during orthopaedic examinations in horses to localise the source of pain causing lameness. Painful digital tenosynovitis, intrasynovial tears of the digital flexor tendons, tendinopathy of the digital portion of the deep digital flexor tendon (DDFT), desmitis of the oblique and straight distal sesamoidean ligaments, and desmitis of the palmar annular ligament, have all been reported to respond to intrasynovial analgesia of the DFTS (Schneider et al., 2003; 2005; Smith and Wright, 2006; Schramme and Smith, 2010). Nevertheless, some controversy exists about the specificity of this technique. Harper et al. (2007) reported a high specificity of DFTS analgesia, whereas other authors have suggested that diffusion of local anaesthetic solution can desensitise structures other than those intended, leading to inaccurate localisation of the lameness (Schneider et al., 2003; Sampson et al., 2007; Bassage and Ross, 2010). Moreover, recent studies have shown that backflow of local anaesthetic solution to the subcutaneous tissues through the needle puncture hole could affect the palmar digital nerves desensitising additional structures in the digit (Jordana et al., 2012; 2014).

Mepivacaine hydrochloride 2% and lidocaine hydrochloride 2% are the two local anaesthetic solutions most frequently used in horses. However, due to its longer lasting activity and lower tissue irritation, mepivacaine is often the product of choice for local, regional or intrasynovial analgesia (Specht et al., 1988; Baxter and Stashak, 2011). Mepivacaine has a small molecular weight and size, and hence, easy diffusion through the tissues or between synovial structures could be expected. Limited information is available regarding the relative activity of local anaesthetics in the horse and the amount required for successful analgesia (Schmotzer and Timm, 1990). Wintzer et al. (1981) indicated
concentrations > 100 mg/l mepivacaine being sufficient for analgesia of the equine tarsocrural joint. Similarly, Keegan et al. (1996) reported concentrations > 300 mg/kg bwt being sufficient for analgesia of the navicular bone and synovial membrane (equivalent to concentrations > 300 mg/l when considering a wet tissue density of 1 mg/ml). Other studies have demonstrated diffusion of mepivacaine between synovial structures in the equine foot (Gough et al., 2002a). However, to the authors’ knowledge, no study has evaluated the possible diffusion of mepivacaine from the DFTS to adjacent synovial structures.

Therefore, the goals of this study were to evaluate (1) whether diffusion of mepivacaine hydrochloride from the DFTS to adjacent synovial structures of the distal limb of the horse occurs and (2) whether this results in clinically relevant concentrations.

MATERIALS AND METHODS

Subjects

Eight horses belonging to the teaching herd of the Faculty of Veterinary Medicine of Ghent University were included in the study. There were 4 Standardbreds and 4 Warmblood horses (7 females and 1 gelding). The mean age of the horses was 11.5 years (range 4-22 years, s.d. 5.3 years) and the mean body weight 545.6 kg (range 470-650 kg, s.d. 54.8 kg). All horses were clinically sound and were free of relevant radiographic abnormalities of their distal limbs. The study was approved by the Ethical Committee of Ghent University (EC 2013/163).
Study Design

The study was organized in 2 sessions with a 2-week washout period in between them. For each session, horses were placed under general anaesthesia in lateral recumbency (4 horses in left and 4 horses in right lateral recumbency, randomly determined). All 4 limbs were circumferentially clipped from the coronary band to the proximal aspect of the third metacarpus/metatarsus. The hoofs were draped and the skin was aseptically prepared. Synoviocentesis of the DFTS of the uppermost front and hind limbs was performed in each horse with a 25 mm, 20 gauge hypodermic needle through a palmar/plantar axial sesamoidean approach (Hassel et al., 2000) by 2 of the 3 different operators (M.J., A.M. and F.P.; randomly assigned). A maximum of 2 ml of synovial fluid was aspirated (DFTS sample T0) and simultaneously, a venous blood sample from the upper jugular vein (approximately 10 ml) was collected by the anaesthetist (blood sample T0). Subsequently, a standard dose of mepivacaine hydrochloride 2% (Scandicaine®; 1 ml/50 kg bwt) was injected in both DFTSs. Criteria for correct injection in the DFTS were the possibility of synovial fluid aspiration, absence of resistance during injection, and visible filling of the DFTS outpouchings while injecting the local anaesthetic solution. After removal of the needle, the injection site was protected with a sterile gauze held by hand and the distal limb was flexed and extended 25 times. Synovial fluid samples from the injected DFTS, the ipsilateral metacarpo-/metatarsophalangeal (MCP/MTP) joint, proximal interphalangeal (PIP) joint, distal interphalangeal (DIP) joint, navicular bursa (NB), and the contralateral MCP/MTP joint were obtained 15 minutes after DFTS analgesia (T15) for the front limbs and 60 minutes after DFTS analgesia (T60) for the hind limbs or vice-versa, depending on the predetermined random sampling protocol. The synovial structures to be sampled by each operator were also randomly assigned. In the second session (two weeks later) the same ipsilateral limbs were injected (left or right) but the time at which samples were
obtained (T15 and T60) was reversed between front and hind limbs. Synoviocentesis was performed with a 40 mm, 19 gauge hypodermic needle for all the joints and DFTS (except at T0) and with a 90 mm, 19 gauge spinal needle for the NB. Fluoroscopic guidance was used for all NB and for some PIP and DIP joint synoviocentesis. A dorsal or proximopalmar/plantar approach was used for the MCP/MTP joints, a dorsolateral approach for the PIP and DIP joints, and an abaxial distal palmar/plantar approach to the navicular position was used for the NB (Schramme et al., 2000; Baxter and Stashak, 2011). When no or insufficient (< 200 µl) synovial fluid was retrieved by aspiration, sterile 0.9% saline solution was injected into the synovial space and re-aspirated immediately to obtain a diluted sample. Additional blood samples from the upper jugular vein were obtained at T15 and T60 to check for possible systemic distribution of mepicavaine and to measure plasma urea concentrations in case diluted synovial samples were obtained. At the end of each session horses received prophylactic antibiotics (Natrium Benzyl Penicillin; 20000 IU/kg bwt i.v.) and limbs were protected with bandages. Horses were monitored daily for signs of local pain or discomfort.

During each session, a total of 17 samples was collected per horse: 14 synovial and 3 blood samples. Synovial fluid samples were transferred into 3 ml EDTA sprayed tubes to which 50 IU of hyaluronidase had been added. They were centrifuged at 1000g for 15 minutes, were aliquotted and stored frozen at -20°C. Blood samples were transferred into 10 ml lithium heparin tubes, centrifuged at 3000g for 20 minutes, aliquotted and stored frozen at -20°C.
Mepivacaine assay

Evaluation of the mepivacaine concentration in the samples was performed using a commercial ELISA kit able to detect mepivacaine concentrations ranging from 5 to 150 µg/l (Racing ELISA for mepivacaine; kit 102710). A standard curve was included in the plates to obtain semi-quantitative values of the mepivacaine concentrations. Samples were thawed at room temperature and were batch assayed (all samples run in duplicates). The DFTS samples of T15 and T60 were run at 1:100000 dilution as very high mepivacaine concentrations were expected. The rest of the samples were run undiluted for the first time. Samples falling outside the regression line due to a too high mepivacaine concentration were re-analysed at different dilutions (1:2, 1:10, 1:30, 1:50, 1:100 or 1:1000, depending on the samples). If the coefficient of variability (CV) between duplicates was higher than 10%, the assay was repeated.

Urea assay

To allow calculation of actual mepivacaine concentrations in diluted synovial samples, the dilution factor of these samples was determined by comparing the plasma and synovial fluid urea concentrations (Gough et al., 2002b), measured with a commercial enzymatic assay kit (Urea assay kit, MAK006). All urea assays were performed in fresh samples (no freezing-thawing) and in duplicate. If the CV between duplicates was higher than 10%, the assay was repeated. Afterwards, the mepivacaine concentrations of the diluted samples obtained with the ELISA test were corrected by the dilution factors.
Data analysis

Two samples (one NB and one MCP joint) from different horses were excluded from the statistical analysis due to suspicion of DFTS penetration during sample collection.

Descriptive statistics were performed and results are presented as mean plus or minus standard deviation. Three separate mixed models were fitted using SPSS statistics 21 with statistical significance set at $P < 0.05$. A first model was fitted to check for local diffusion of mepivacaine to other adjacent synovial structures. Therefore, mepivacaine concentrations in the different adjacent synovial structures were compared including “location” (MCP/MTP joint, PIP joint, DIP joint, and NB), “limb” (left front, right front, left hind, or right hind), “session” (first or second testing round), “time” (T15 or T60) and the interaction between “location” and “time” as fixed effects factors, and “horse” (test subject 1 to 8) as a random effects factor. To evaluate the possible distribution of mepivacaine in the bloodstream, a second model was fitted comparing the mepivacaine concentrations in the venous blood samples at the three different time points (T0, T15, or T60) including “session” (first or second testing round) and “time” as fixed effects factors, and “horse” (test subject 1 to 8) as random effects factor. To evaluate a possible distribution of mepivacaine to other synovial structures via systemic circulation, a third model was fitted comparing the mepivacaine concentrations of the ipsilateral MCP/MTP joints with the contralateral MCP/MTP joints including “limb” (left front, right front, left hind, or right hind), “side” (ipsilateral or contralateral to the injected DFTS), “session” (first or second testing round) and “time” (T15 or T60) as fixed effects factors, and “horse” (test subject 1 to 8) as random effects factor. An interaction between “side” and “time” was also taken into account.
CHAPTER 6: Diffusion of mepivacaine to adjacent synovial structures after DFTS analgesia

RESULTS

A total of 224 synovial fluid and 48 venous blood samples were obtained. Overall, the synovial fluid sampling was straightforward, except for 6 of the 32 NB, where aspiration of a sample was only possible after injection of 3 ml of sterile 0.9% saline solution. The mean dilution factor obtained for these samples was 6.3 (range 5.2-7.6, s.d. 0.9), with a mean urea concentration in the diluted synovial fluid samples of 0.7 mmol/l (range 0.4-0.9 mmol/l, s.d. 0.2 mmol/l), and in the serum samples of 4.5 mmol/l (range 3.02-6.1 mmol/l, s.d. 1.2 mmol/l). Blood contamination occurred in some synovial samples during collection. However, after centrifugation and aliquoting, clear synovial samples were obtained indicating very limited contamination. No relevant complications were encountered during or after the experiment. However, after the first session, 4 horses had a fluctuant non-painful distension of one or both injected DFTS (n=6) compared to the non-injected limb, but without associated pain or lameness.

Table 1 summarises the mean mepivacaine concentrations measured in the different samples at different time points. The mean T0 values for the blood and DFTS samples were under the detection limit of the ELISA kit (5 µg/l). The ELISA results also showed that all DFTS injections were performed successfully, resulting both at T15 and T60 in synovial fluid mepivacaine concentrations that exceeded by far those estimated sufficient for synovial analgesia (Figure 1) and that were detectable only at the same high dilution (1:100000).
Mepivacaine was found in all the samples from the synovial structures adjacent to the injected DFTS, the contralateral MCP/MTP joints, and blood. However, mepivacaine concentrations were very low, with the maximum recorded value of 3.2 mg/l being far from the concentrations considered clinically relevant (Figure 1). For all horses, the mepivacaine concentrations in the different synovial structures adjacent to the injected DFTS were significantly higher at T60 compared to T15 (P < 0.03), except for the NB samples (P = 0.8). However, no significant differences in mepivacaine concentrations were observed between adjacent synovial structures at T15 (P = 0.4) and at T60 (P = 0.2). Statistical analysis showed no significant effect of “limb” and “session” on the mepivacaine concentrations for any of the three statistical models.
Figure 1: Box plot illustrating the mepivacaine concentrations in the different synovial structures and blood, at the different time points (T0: blue; T15: green and T60: yellow). Values are expressed on a logarithmic scale. The box represents the interquartile range, the line represents the median of the values, and the whiskers represent the minimal and the maximal values excluding outliers (circles) and extreme values (asterisk).

DFTS: digital flexor tendon sheath; MCP/MTP: metacarpo-/metatarsophalangeal joint; PIP: proximal interphalangeal joint; DIP: distal interphalangeal joint; NB: navicular bursa; JV: jugular-vein blood; Cont MCP/MTP: contralateral metacarpo-/metatarsophalangeal joint.

Clinically relevant mepivacaine concentrations: ····100 mg/l; ---- 300 mg/l.
Blood samples showed higher mepivacaine concentrations at T15 and T60 compared to T0 (P < 0.001). No significant differences were found between T15 and T60 plasma concentrations (P = 1). When comparing mepivacaine concentrations of the MCP/MTP joints ipsilateral and contralateral to the injected DFTS, a significant effect of “time”, “side” and their interaction was found (P = 0.01, P = 0.004 and P = 0.02 respectively). Post-hoc testing revealed no differences in mepivacaine concentrations between the ipsilateral and the contralateral MCP/MTP joints at T15 (P = 0.7). However, at T60, significantly higher concentrations were found in the ipsilateral MCP/MTP joints compared to the contralateral MCP/MTP joints (P < 0.001). Unlike the ipsilateral MCP/MTP joints, mepivacaine concentrations in the contralateral MCP/MTP joints did not differ significantly between T15 and T60 (P = 0.9).

DISCUSSION

The results of our study show that diffusion of mepivacaine from the DFTS to adjacent synovial structures does occur, but to a very low degree. Indeed, none of the synovial samples other than the injected DFTS ever showed mepivacaine concentrations above those estimated sufficient for synovial analgesia (Winzter et al., 1981; Keegan et al., 1996). This would support the findings of Harper et al. (2007) that reported DFTS analgesia to have almost no effect on pain originating from the sole, DIP joint, or NB. However, clinical evaluation of pain was not performed in our study as horses were under general anaesthesia. On the other hand, our findings contrast with the results of the diffusion studies between other synovial structures in the equine digit, where 32% of NB samples and 44% of DIP joint samples had mepivacaine concentrations greater than 300 mg/l after DIP joint and NB injection,
respectively (Gough et al., 2002a). The different anatomical relationship between the DIPJ and the NB on one hand, and between the DFTS and the adjacent synovial structures that we tested on the other hand, could explain these differences. Moreover, the differences in volume of local anaesthetic used in both studies could also play a role. Gough et al. (2002a) injected 5 ml of a 2% mepivacaine hydrochloride solution in the NB or DIP joint (which are small synovial cavities) representing a much higher relative volume compared to the approximately 10 ml injected in the DFTS (a much larger synovial cavity) used in our study. Hence, it could be hypothesised that a lower intrasynovial pressure in the DFTS in our study could have influenced the degree of local diffusion. The dose-volume of local anaesthetic used in our study is the same used in clinical situations to provide analgesia during lameness examinations (Harper et al., 2007; Schramme and Smith, 2010; Jordana et al., 2014) and did not result in a marked distension of the DFTS outpouchings. However, in a clinical situation the DFTS is often already distended when intrasynovial anaesthesia is performed, which may possibly result in a different intrasynovial pressure compared to the present study. Further studies comparing different volumes of local anaesthetic solution injected into the DFTS would be necessary to confirm this hypothesis.

Local anaesthetics, once administered in a synovial cavity, are cleared from the synovial fluid by the lymphatic vessels, redistributed to the cardiovascular system and subsequently transported to every part of the body (Gerwin et al., 2006; Stanley, 2013). However, local diffusion through the synovial membrane and soft tissues (Bowker et al., 1993; Keegan et al., 1996) and leakage through the needle entrance point into the subcutaneous tissues (Jordana et al., 2012; 2014) are other possible ways of redistribution of local anaesthetic solutions. In our study, mepivacaine concentrations in the synovial fluid of the ipsilateral MCP/MTP joints were
significantly higher than in the contralateral MCP/MTP joints 60 minutes after DFTS analgesia. Moreover, mepivacaine concentrations in the venous blood samples were lower than in the ipsilateral MCP/MTP joints but higher than the contralateral ones. This would suggest that absorption of mepivacaine through the synovial membrane to the systemic circulation occurs, but the low bloodstream concentrations achieved are insufficient to result in relevant diffusion of mepivacaine to other synovial structures in the body. Therefore, local diffusion rather than systemic distribution, seems most likely responsible for the mepivacaine concentrations obtained in the ipsilateral synovial structures.

Clearly, the present study only evaluated the presence of mepivacaine in synovial compartments and not in the soft tissues or surrounding nerves. As demonstrated previously, non-specific desensitisation of the distal limb may occur as a result of leakage of anaesthetic from the puncture hole in the DFTS and/or diffusion of anaesthetic through the DFTS wall (Jordana et al., 2012; 2014). Further studies measuring mepivacaine concentrations in the synovial lining and in the tissues surrounding the DFTS would be necessary to determine the exact pathway of diffusion of mepivacaine from the DFTS to the nearby structures (Keegan et al., 1996).

The mean mepivacaine concentrations measured in the DFTS samples obtained 15 minutes after intrasynovial analgesia were approximately 17 times higher than those considered clinically relevant and remained very high even 60 minutes post-injection. Local anaesthetics are cytotoxic and the degree of tissue irritation they produce correlates with their anaesthetic potency (Schmotzer and Timm, 1990; Harkins et al., 1999). Four horses in this study also showed moderate distension of the DFTS after the first synoviocentesis. Hence, it would be tempting to decrease the dose
of mepivacaine used for DFTS analgesia during lameness investigations, eventually maintaining the final volume (Harkins et al., 1995). However, it has been demonstrated that some lameness caused by pathology localised within the DFTS may respond only partially to DFTS analgesia performed with a standard dose of mepivacaine (Fiske-Jackson et al., 2013). Therefore, further studies would be necessary before the optimal dose for DFTS analgesia could be established.

In conclusion, the results of the present study show that diffusion of mepivacaine to adjacent synovial structures at the level of the digit after analgesia of the equine DFTS occurs. However, mepivacaine in the MCP/MTP joint, PIP joint, DIP joint, and NB never reached concentrations above those estimated sufficient for synovial analgesia. The presence of mepivacaine in those adjacent synovial structures seems rather the result of local diffusion than of systemic distribution.

Manufacturers’ details

\(^{a}\)AstraZeneca S.A., Brussels, Belgium.

\(^{b}\)KELA Pharma nv, St. Niklaas, Belgium.

\(^{c}\)Sigma Aldrich, St. Louis, MO, USA.

\(^{d}\)Neogen Corporation, Lexington, USA.

\(^{e}\)Sigma Aldrich, St. Louis, Missouri, USA.

\(^{f}\)IBM Corporation, Armonk, New York, USA.
References


CHAPTER 6 · Diffusion of mepivacaine to adjacent synovial structures after DFTS analgesia


General discussion
This work focused on optimising different aspects of the diagnostic methods currently available to identify or localise digital flexor tendon sheath (DFTS) disorders. In the course of this study we realised that the digital manica flexoria, a structure which is visualised during tenoscopic examination of the DFTS, had been inconsistently described and not documented in depth. A study was performed to fill this gap and to report on the anatomical characteristics of the digital manica flexoria. The obtained results are discussed in the first section of this chapter.

The second part of this PhD addresses the specificity of the diagnostic analgesia of the DFTS. Indeed, discrepancy exists about the results obtained after DFTS analgesia during lameness investigations and therefore, the second part of this research was aimed to find out possible mechanisms that could be responsible for this lack of specificity. A detailed discussion on the results of these studies is provided in section 2 of this chapter.

1. **Anatomical description of the digital manica flexoria**

   Although the anatomy of the equine extremities has been well described in the veterinary literature (Sisson and Grossman, 1975; De Lahunta, 1986; Nickel et al., 1986; Denoix, 1994; Barone, 2000), the presence of the digital manica flexoria in the distal aspect of the DFTS has been inconsistently mentioned. Since the more widespread use of tenoscopy for the diagnosis and treatment of DFTS disorders, this structure has become visually apparent for equine surgeons and is now referred to in surgical handbooks (McIlwraith et al., 2014). Nevertheless, its existence is currently not recognised by the Nomina Anatomica Veterinaria (World Association of Veterinary Anatomists, 2012), and in-depth and large-scale studies on this structure in the equine digit are missing. The study presented in chapter 3 was performed to address this gap. Dissection of 144 distal equine
limbs revealed the presence of the digital manica flexoria in all equine feet, connecting the two distal branches of the superficial digital flexor tendon (SDFT) at the distal aspect of the DFTS. However, various types and configurations of digital manica flexoria were identified with significant differences between the front and the hind limbs. In the front limbs, a membranous type of digital manica flexoria predominated, especially the synovial bridge type, whereas in the hind limbs, a tendinous type of digital manica flexoria predominated, especially the type with the oblique-crossing tendinous fibers. Interestingly, differences in configuration between the front and the hind limbs have not been described for its homologue and more proximally located manica flexoria (Findley et al., 2014). We hypothesised that the morphological differences observed for the digital manica flexoria between the front and the hind limbs could be linked to the reported biomechanical differences in the digit of the front compared to the hind limbs (Holmström et al., 1990; Back et al., 1995). Redding (1993) suggested that the function of both the manica flexoria and the digital manica is to maintain the deep digital flexor tendon (DDFT) in a central position within the DFTS, but he did not mention any differences in function or configuration between the front and the hind limbs. As far as we know, studies evaluating the function of the digital manica flexoria have not been published and unfortunately, the biomechanics and function of this structure have also not been evaluated in our study. Therefore, further investigation would be necessary to confirm our hypothesis.

Pathology of the digital manica flexoria has not yet been reported as a cause of lameness (Schramme and Smith, 2010; Arensburg et al., 2011; McIlwraith et al., 2014). Only one study has reported the diagnosis of 2 digital manica flexoria tears during tenoscopic examination of 77 DFTS (Smith and Wright, 2006). In our study, pathology of the digital manica flexoria has not been assessed. Nevertheless, our findings still remain clinically relevant as the inter- and intra-individual variations of the digital manica flexoria
should be taken into consideration during ultrasonographic and tenoscopic examinations of the DFTS. Furthermore, it is possible that identification of lesions of the digital manica flexoria, which have remained largely undiscovered until now, will increase thanks to the recognition of this structure and also due to the established use of tenoscopy, similar to what happened with the diagnosis of tears of the intrasynovial part of the digital flexor tendons or the manica flexoria, which mainly became evident after the introduction of tenoscopy.

2. Analgesia of the digital flexor tendon sheath during lameness examinations

Diagnostic analgesia has been used for many years in horses to accurately determine the site(s) of pain causing lameness. Hence, analgesia of the DFTS is routinely performed during orthopaedic examinations to confirm pathology localised in the DFTS. However, several authors have suggested that desensitisation of other structures may occur (Schneider et al., 2003; Schumacher et al., 2003; Sampson et al., 2007; Bassage and Ross, 2010; Baxter and Stashak, 2011). Although several hypotheses have been suggested, the exact mechanism leading to this lack of specificity has not been elucidated yet. Therefore, the second part of this PhD work was aimed at determining the specificity of DFTS analgesia and unravel the possible mechanisms responsible for the desensitisation of structures other than those intended.

Desensitisation of structures other than the DFTS (and the tendons and ligaments encircled by this sheath) after DFTS analgesia could happen in different ways. One possibility is that the local anaesthetic solution injected in the DFTS would reach the adjacent soft tissues or synovial cavities, which could as a result become desensitised. Another possibility is that the local anaesthetic solution injected in the DFTS could reach
the surrounding palmar/plantar (digital) nerves, desensitising therefore a larger area of the distal limb (Schneider et al., 2003; Sampson et al., 2007; Baxter and Stashak, 2011). In either case, the local anaesthetic solution could reach any of these non-intended structures either by diffusion through the synovial membranes (Bowker et al., 1993; Keegan et al., 1996; Schumacher et al., 2003; Bassage and Ross, 2010) or by backflow through the needle entrance hole (Wintzer et al., 1981; Schneider et al., 2003; Sampson et al., 2007; Baxter and Stashak, 2011).

Diffusion or redistribution of local anaesthetic solution after intrasynovial anaesthesia has been investigated in the equine foot (Keegan et al., 1996; Gough et al., 2002a) but also for more proximal synovial structures of the equine limb (Gough et al., 2002a; 2002b). Other studies have also evaluated the degree of local anaesthetic diffusion after regional anaesthesia of the equine digit (Seabaugh et al., 2011). However, none of these studies included the DFTS. Harper et al. (2007) evaluated the clinical effects of DFTS analgesia on pain originating from different structures in the equine foot, but no sampling was performed to trace the local anaesthetic solution in those structures. To our knowledge, at the start of this PhD there were no studies that objectively evaluated redistribution of local anaesthetic solution to the adjacent tissues or synovial cavities after DFTS analgesia.

The studies presented in chapters 4 and 5 of this thesis were performed to assess the effects that DFTS analgesia could have on other structures of the digit. More specifically, it was investigated to what degree the palmar/plantar (digital) nerves could be affected by the local anaesthetic solution resulting in distal limb desensitisation. Schneider et al. (2003) indeed suggested that different results could be obtained after DFTS analgesia depending on the location where the injection was performed and on the size of the needle.
used for synoviocentesis. Therefore, we compared the four most commonly used injection techniques of the DFTS in both a cadaveric (chapter 4) and an *in vivo* (chapter 5) study. In chapter 4, the four injection techniques were compared regarding their accuracy, ease of performing, degree of subcutaneous leakage of injected solution and distance of the leakage spot to the adjacent palmar/plantar (digital) nerves. In chapter 5, DFTS analgesia was performed in live horses with the four previously evaluated injection techniques, assessing the degree of subcutaneous leakage radiologically (by visualisation of subcutaneous radiodense contrast medium) and evaluating its effect on distal limb desensitisation (by testing skin sensation objectively with a dynamometer).

The results of the cadaveric study showed that the Axial and Distal techniques were the most accurate in the hands of inexperienced operators. However, the Axial technique required the highest number of attempts. Probably, identification of anatomical landmarks at the palmar/plantar aspect of the fetlock (where the Axial technique is performed) was more difficult for inexperienced operators compared with the other 3 techniques in which the injection is performed into a synovial outpouching. Although synovial distension was not present in the specimens used in our study, clinicians often rely on the feeling of the needle being positioned loosely in a synovial space to confirm correct intrasynovial positioning. It is possible that the lack of this feeling when using the Axial technique resulted in repeated attempts to reposition the needle compared to the other 3 techniques. Within the fetlock canal there is indeed little free synovial space and the needle may often feel caught by the fibrous nature of the palmar/plantar annular ligament (PAL). It is also possible that the tip of the needle reached tendinous tissue in the fetlock canal, which would give the feeling of extrasynovial positioning (resistance) when trying to inject fluid and the operator would consequently abort a misidentified successful attempt. In the *in vivo* study (chapter 5), all injections were confirmed to be intrasynovial in the DFTS,
except for one performed using the Base technique. However, it is not possible to compare accuracy and ease of performing of the four injection techniques between the cadaveric (chapter 4) and the \textit{in vivo} (chapter 5) studies since the level of experience of the operators was not the same, and the number of attempts necessary to access the DFTS was not recorded in the \textit{in vivo} study. Although not evaluated objectively, it is in our opinion likely that experienced operators can perform DFTS injections with greater accuracy and less attempts, independent on the technique used. The use of cadaveric limbs could also have affected the results obtained in chapter 4. Retrieval of synovial fluid, for example, is a common parameter used to ascertain correct needle placement in a synovial space and this was rarely possible in the specimens used in our experiment. Moreover, the characteristics of the tissues may have differed from those of living horses, probably making palpation and identification of certain structures less obvious. On the other hand, factors such as the horse’s temperament, the presence of pathological conditions limiting the choice between synoviocentesis techniques, or the limited number of attempts that can be performed in a clinical case, are not present in a cadaveric study. Nevertheless, the use of cadaver limbs allowed us to perform the study in a much larger sample.

Some authors have suggested that needle damage to the flexor tendons may occur more likely when using the Axial technique compared to other injection techniques, probably due to the little free space available in the fetlock canal (Hassel \textit{et al.}, 2000; Rocconi and Sampson, 2013). The tip of a hypodermic needle is very sharp and besides a penetrating tract it could also cause cutting lesions in the tissues. In our study, needle penetration points were often observed on the flexor tendons during limb dissection, but exact assessment of iatrogenic needle damage to the soft tissues and flexor tendons was not performed. To our knowledge, there are no studies available that have evaluated this yet. Although substantial needle damage to the tendons was not identified in our study, it
would be interesting to evaluate the possible differences in iatrogenic tissue damage between the four injection techniques, since clinicians can use this information as an additional parameter when choosing a synoviocentesis technique.

The cadaveric study presented in chapter 4 also evaluated the degree of subcutaneous leakage of methylene blue through the needle injection hole for the four different injection techniques. Methylene blue leakage spots larger than 5 mm in diameter (leakage scores 2 and 3) were observed in 62.5% of the limbs. It could be hypothesised that higher methylene blue leakage scores would be observed in limbs where increased number of attempts were necessary to access the DFTS due to induced needle damage of the synovial lining. However, further analysis of our data could not demonstrate a correlation between the number of attempts and the methylene blue leakage score. Moreover, the Axial technique showed the lowest leakage score (and highest number of attempts) compared to the other 3 techniques. Therefore, we hypothesised that local differences in the structure of the DFTS wall rather than the number of attempts are responsible for the differences in leakage observed between techniques. As mentioned in chapter 1, the palmar/plantar wall of the DFTS is formed by several annular ligaments which cover the synovial lining partially. Due to the fibrous nature of these ligaments, it could be expected that leakage of injected fluid was prevented at these points. The Axial technique is the only one performed through one of these fibrous ligaments (the PAL) and therefore it is not surprising to observe lower leakage scores with this technique. In the in vivo study (chapter 5), 40.3% of the limbs showed some degree of skin desensitisation after DFTS analgesia (vs. the 62.5% of limbs with methylene blue spots larger than 5 mm of diameter in the cadaver study), with the Axial technique showing the lowest incidence of skin desensitisation (4 out of 29 limbs, 14%).
Furthermore, the distances from the needle injection point and from the possible methylene blue subcutaneous leakage spot to the lateral palmar/plantar (digital) nerve were larger for the Axial and Distal techniques and shorter for the Proximal technique (chapter 4). This observation together with a lower leakage score of the Axial technique would suggest that when backflow of local anaesthetic solution would happen in a clinical situation, the influence on the palmar/plantar (digital) nerve would be smaller when using the Axial and Distal techniques. These observations were supported by the results of the in vivo study (chapter 5) where heel bulb desensitisation was observed more frequently when injection was performed with the Proximal technique (13 out of 29 limbs) and less frequently with the Axial and Distal techniques (4 and 5 limbs out of 29, respectively). However, both studies were performed on different sample populations (cadaver limbs vs. living horses) and it is possible that differences in tissue characteristics and/or metabolism could have influenced the results. For example, fibrin or villi sealing off the needle injection hole in the living horses could have helped to decrease the percentage of limbs where desensitisation of the heel bulbs was recorded compared to the number of limbs where leakage of methylene blue was observed (40.3% vs. 62.5%). Furthermore, it is possible that in the in vivo study (chapter 5), the gauze and tape placed over the injection site (which were not used in the cadaveric study) helped preventing backflow of local anaesthetic solution. Indeed, at the time of tape removal (T15), only 4% of the limbs showed distal desensitisation, and this percentage increased mainly from 30 minutes post-injection onwards. Therefore, we suggested that in a clinical situation the injection site should always be protected with a gauze fixed with tape after DFTS analgesia. However, further investigation should be performed comparing the use and the non-use of protective tape after DFTS injection in the same study in order to determine the potential of the gauze and tape in preventing subcutaneous leakage after intrasynovial injection.
The observed differences in leakage scores and heel bulb desensitisation between the four injection techniques together with the uniaxiallity (lateral vs. medial) of skin desensitisation recorded after DFTS analgesia in the *in vivo* study (chapter 5) would support the theory of subcutaneous leakage of local anaesthetic solution resulting in desensitisation of the palmar/plantar (digital) nerve. Indeed, in 82.8% of the limbs that expressed distal desensitisation, this occurred on the lateral heel bulb solely (ipsilateral to the injection site), whereas biaxial desensitisation was recorded in only 17.2% of the desensitised limbs. Assuming that no major anatomical differences exist between the lateral and medial aspects of the distal equine limb, diffusion of local anaesthetic solution through the synovial membrane would likely result in equal lateral and medial palmar/plantar (digital) nerve desensitisation and no differences in the percentages of skin desensitisation between the four injection techniques would be recorded. Therefore, we hypothesised that backflow of local anaesthetic solution to the subcutaneous tissues affecting the palmar/plantar (digital) nerve was the main reason for skin desensitisation recorded at the level of the heel bulbs. To confirm this hypothesis, the same study should be repeated while injecting the DFTS from the medial side, in order to evaluate whether distal desensitisation occurs then mainly on the medial side. Nevertheless, since biaxial skin desensitisation still occurred in some of our horses, the hypothesis of diffusion cannot be discarded completely.

An additional study was performed to ascertain to what degree diffusion of mepivacaine from the DFTS to other synovial structures of the equine digit occurs after DFTS analgesia (chapter 6). In this second *in vivo* study, mepivacaine was detected with an enzyme-linked immunosorbent assay (ELISA) in all the blood and synovial fluid samples obtained after DFTS analgesia. However, the mepivacaine concentrations observed in the different synovial structures of the equine digit after DFTS analgesia were
not clinically relevant (Wintzer et al., 1981; Keegan et al., 1996). Our results would therefore support the findings obtained by Harper et al. (2007) who reported no effect of DFTS analgesia on lameness originating from pain in the sole, distal interphalangeal joint or navicular bursa. However, their study was purely clinical as there were no samples taken to analyse for the presence of mepivacaine in the tissues or synovial fluid. In our study, the low mepivacaine concentrations observed in the systemic circulation (venous blood) and especially the lower concentrations observed in the contralateral compared to the ipsilateral fetlock joints, suggest that local diffusion is most likely responsible for mepivacaine redistribution in the equine digit. Quantification of mepivacaine concentrations in the tissues surrounding the DFTS could help evaluate this hypothesis. Immunocytochemistry techniques would allow for this analysis and provide more information on the diffusion of mepivacaine in the equine digit after DFTS injection (Bowker et al., 1993; 1995; 1997). However, these techniques need to be performed on tissue samples, which would have required euthanasia of the animals and, to our knowledge, specific antibodies for mepivacaine are not yet available.

Methylene blue and/or radiodense contrast medium have been routinely used in research to evaluate, for example, the distribution of local anaesthetic solution after perineural analgesia (Nagy et al., 2009; 2010; 2012; Seabaugh et al., 2011; Contino et al., 2015) or the communication between synovial structures (Hago and Vaughan, 1986; Gibson et al., 1990; Bowker et al., 1993; Seabaugh et al., 2011). Similarly, methylene blue and radiodense contrast medium were used in our studies (chapters 4 and 5) to mimic and trace the distribution pathway of mepivacaine as we assumed that these 3 substances would have equal or similar distribution behaviour. However, in several limbs the radiologic visualisation of subcutaneous leakage did not correspond with the skin desensitisation detected at the same time point (T30) at the heel bulbs using the
dynamometer. Twelve limbs showed partial skin desensitisation with no leakage radiologically visible on the T30 contrast tenograms, and 19 limbs had radiologically detectable leakage on the T30 tenograms without showing skin desensitisation. Probably, obtaining one single contrast tenogram during the 2-hours evaluation period was insufficient for the detection of subcutaneous leakage or for the evaluation of the mepivacaine distribution pathway. Moreover, radiologic evaluation provides a 2-dimensional image of a 3-dimensional event, which could have compromised the assessment of the extent and exact location of the leakage zone. On the other hand, the differences in molecular weight between the 3 substances used in our studies could also have played a role. As already suggested by some authors (Gough et al., 2002a; Nagy et al., 2012), local analgesic agents would diffuse more readily than larger molecular weight dyes and contrast media, which could explain why in our study 12 limbs showed distal limb desensitisation without subcutaneous leakage visible on the T30 tenograms (chapter 5). Another possible way to evaluate mepivacaine distribution with imaging could be the radioisotope technique, which consists in labelling the local anaesthetic solution with a radioisotope detectable by a gamma camera (Driver, 2003; Yamazaki et al., 2009). However, we are unaware of studies reporting specific protocols to trace a mepivacaine hydrochloride solution. Therefore, further investigation would be necessary before this imaging technique could be considered a better alternative for the tracing of mepivacaine after DFTS analgesia.

Time recommendations for the evaluation of regional and intrasynovial diagnostic analgesia vary depending on the zone or the anatomical structure anaesthetised and on the reference source, ranging between 5 to 30 minutes post-injection (Schmotzer and Timm, 1990; Bassage and Ross, 2010; Baxter and Stashak, 2011). Although the onset of action of the most commonly used anaesthetic solutions is from 3 to 5 minutes, more time
(10 minutes or more) might be necessary to achieve complete analgesia (Schmotzer and Timm, 1990). Therefore, it is often advised to first check the effects of regional blocks from 5 to 10 minutes after injection onwards (Bassage and Ross, 2010; Baxter and Stashak, 2011). In our studies (chapters 5 and 6), the first evaluations of heel bulb desensitisation and mepivacaine diffusion after DFTS analgesia were performed 15 minutes post-injection as this is the time when intrasynovial blocks are routinely assessed at our clinic. Further evaluation of distal limb desensitisation was performed 30, 90 and 120 minutes after DFTS analgesia (chapter 5), and of mepivacaine diffusion 60 minutes after injection (chapter 6). These later time points where selected to obtain information on how DFTS analgesia may influence the interpretation of subsequent local analgesia’s performed during the same lameness investigation. We are aware that some clinicians may prefer to check the effect of diagnostic analgesia earlier than 15 minutes post-injection and our studies did not provide information on these earlier time points. Nevertheless, our results showed that, when tape is used to protect the injection site after DFTS analgesia, there is negligible risk for inadvertent distal desensitisation (4% of limbs with distal limb desensitisation at T15) or diffusion to adjacent synovial structures (no synovial samples with mepivacaine concentrations higher than those considered clinically relevant). Nevertheless, whenever DFTS analgesia is performed, we recommend to check the sensitivity of the heel bulbs before evaluating the effect of the DFTS analgesia itself, and before evaluating subsequent intrasynovial blocks performed during the same lameness exam.

The exact dose of local anaesthetic solution necessary for full analgesia of lesions located in the DFTS has not yet been determined. In our study, mepivacaine concentrations 17 times higher than those reported clinically relevant were recorded in the DFTS 60 minutes post-injection (Wintzer et al., 1981; Keegan et al., 1996). From this
observation it could be hypothesised that rather high doses of mepivacaine are currently being used during orthopaedic examinations to perform DFTS analgesia. However, a number of studies have reported some pathologies of the DFTS responding only partially to DFTS analgesia performed with a standard dose of mepivacaine (Fiske-Jackson et al., 2013). Moreover, some authors have warned for the risk of obtaining false-negative results when small volumes of local anaesthetic solution are used for intrasynovial analgesia (Bassage and Ross, 2010).

In both in vivo studies (chapters 5 and 6), the same dose of local anaesthetic solution (1ml/50 kg bwt) was used to inject the DFTS (Harper et al., 2007; Schramme and Smith, 2010). Since the dose is body weight dependent, all horses received the same relative volume of local anaesthetic solution in the DFTS. In the cadaveric study (chapter 4), the same volume of methylene blue (10 ml) was injected in all the limbs as the body weight of the horses prior to slaughtering was not known. Some authors have demonstrated that the use of higher volumes of local anaesthetic solution increases the risk of desensitisation of other structures after intrasynovial analgesia (Schumacher et al., 2001). Most probably, larger volumes of fluid injected in a synovial cavity result in higher intrasynovial pressures, which would enhance subcutaneous leakage or diffusion of local anaesthetic solution out of the synovial cavity, thereby increasing the risk of inadvertent desensitisation of adjacent structures (Wintzer et al., 1981). In our opinion, the differences in intrasynovial pressure after injection could also explain the differences in diffusion rates observed in the study of Gough et al. (2002a) compared to ours (chapter 6). Indeed, the 5 ml of mepivacaine used in Gough’s study to inject the distal interphalangeal joint or navicular bursa (small synovial cavities) would represent a much larger relative volume compared to the 10 ml injected in the DFTS in our study (larger synovial cavity). However, the different anatomical relationships between the synovial structures evaluated
in the study of Gough et al. (2002a) and our study should also be considered when comparing diffusion between synovial cavities. Several studies have investigated the possible communication between different synovial structures in the equine foot either using dye (Bowker et al., 1993), polymer plastic (latex) (Calislar and St. Clair, 1969; Bowker et al., 1997), or radiodense contrast medium (Gibson et al., 1990). Some of these studies have suggested that communication exists between the DFTS and the distal interphalangeal joint or the navicular bursa (Gibson et al., 1990; Bowker et al., 1993; 1997). However, some authors stated that this communication would only exist in young foals (Calislar and St. Clair, 1969; De Lahunta, 1986). Our pilot study, performed on 28 cadaveric limbs of 7 foals younger than 4 weeks of age, revealed only one limb with a communication between the DFTS and the navicular bursa (chapter 1). Although we are aware that the number of animals and limbs evaluated in our study was rather low, we did find some evidence of possible communication between the DFTS and other synovial structures of the digit in a foal. Moreover, the communication observed between the DFTS and the navicular bursa in our pilot study was in a limb from a foal that was born prematurely. Hence, it could be possible that the DFTS communicates with other synovial structures in earlier phases of the prenatal development as well. Additional studies in a larger population of foals, which eventually include late stage gestation or prematurely born foals, could elucidate this further.

Besides the dose and volume of the local anaesthetic solution used to inject the DFTS and the anatomical relationship between the synovial structures, the presence of clinical conditions affecting the DFTS should also be considered as a possible factor affecting the degree of subcutaneous leakage or diffusion after DFTS analgesia. Indeed, when a good evacuation of synovial fluid from distended synovial cavities cannot be obtained, larger intrasynovial volumes (and higher intrasynovial pressures) would be
CHAPTER 7: General discussion

achieved after injecting the local anesthetic solution (Wintzer et al., 1981; Bassage and Ross, 2010). This could increase the risk of subcutaneous leakage and diffusion, and thus inadvertent desensitisation. On the other hand, it is also possible that an important dilution of the local anaesthetic solution occurs when injecting a distended DFTS, thus resulting in lower final mepivacaine concentrations and possibly less diffusion. Similarly, it has also been suggested that inflamed joints might require higher amounts of analgesic agent because the presence of esterases may accelerate drug inactivation, and the drug absorption may be enhanced by damage of the synovial wall and increased perfusion of the inflamed tissues (Wintzer et al., 1981). Furthermore, the permeability of the synovial membrane may change when inflammation is present in the digital sheath. For all these reasons, care should be taken to simply extrapolate the results of our studies performed in healthy horses to clinical cases with inflammation and/or distention of the DFTS.

1.3 Conclusions

In conclusion, the anatomical study of this thesis demonstrates that the digital manica flexoria is always present in the equine DFTS and shows different configurations that can vary between and within individuals. Recognition of this structure is important for an optimal interpretation of ultrasonographic and tenoscopic examinations.

The results of our studies about diagnostic analgesia of the DFTS have demonstrated that leakage of local anaesthetic solution from the needle injection hole to the adjacent neurovascular bundle is the most likely reason for inadvertent desensitisation of other structures in the equine digit. The importance of diffusion of local anaesthetic solution through the synovial membrane on the other hand is limited. The differences between the four synoviocentesis techniques indicate that injection at the mid-body of the proximal
sesamoid bones, through the PAL, is recommended to decrease the chances of inadvertent desensitisation of distal structures. Similarly, injection at the proximolateral outpouching of the DFTS is discouraged as this technique was associated with a high percentage of distal desensitisation.
References


The digital flexor tendon sheath (DFTS) is an important synovial structure of the equine limb which can often sustain injury. Lesions of the DFTS and its related structures frequently result in lameness, preventing the horses from performing at their intended level. It is essential for equine clinicians to accurately localise the origin of pain causing lameness, in order to provide the horses with the most optimal treatment, hence giving them a better chance for successful recovery.

The first chapter of this PhD (chapter 1) presents a review of the anatomy, physiology, and pathophysiology of the DFTS together with the possible diagnostic methods, therapeutic aspects and prognosis of the most common disorders of the DFTS in horses. In the anatomy section, a description of the gross anatomy of the DFTS and its related structures is provided, together with an overview of the innervation and blood supply of the DFTS, its function and the characteristics of the encompassed synovial fluid. Furthermore, a rationale is provided for an in-depth description of the digital manica flexoria, the structure connecting the two distal branches of the superficial digital flexor tendon (SDFT) at the distal aspect of the DFTS. The pathophysiology section focuses on the non-infectious conditions that can affect the DFTS, resulting in a primary tenosynovitis or a tenosynovitis secondary to tears affecting the digital flexor tendons or manica flexoria. The diagnosis section presents the different diagnostic methods that are currently available to localise and confirm pathology to the DFTS, including intrathecal analgesia. The controversy that exists about the specificity of this technique due to the reported desensitisation of other structures of the distal limb is highlighted. The treatment section provides an overview of the treatments that are available to manage the different DFTS conditions. Finally, the outcome of different DFTS disorders and associated risk factors are summarised in a brief paragraph on prognosis.
The scientific aims of this work are presented in chapter 2. The first objective of this PhD was to describe the existence and anatomical variation of the digital manica flexoria in the equine foot. The second objective of this PhD work was to assess the reliability of DFTS analgesia and to investigate whether and how inadvertent desensitisation of adjacent structures occurs.

In chapter 3, the presence, configuration and variability of the digital manica flexoria was studied in 144 cadaveric equine distal limbs. Systematic dissection of the limbs revealed the presence of the digital manica flexoria in all the equine feet. However, 2 different types of digital manica flexoria were identified (membranous and tendinous), each with 3 different configurations. These different configurations were strongly dependent on the location, with a membranous digital manica flexoria of the ‘synovial bridge’ type predominating in the front limbs, and a tendinous digital manica flexoria with oblique-crossing fibers in proximomedial to distolateral direction predominating in the hind limbs. Similarly, 3 different types of vincula were identified at the distal aspect of the DFTS, which were strongly related to the type of digital manica flexoria. A digital manica flexoria of the synovial bridge type was significantly associated with a lateral and medial abaxial intermediate vinculum, and a digital manica flexoria of the oblique-crossing type was significantly associated with an axial intermediate vinculum. These inter- and intra-individual variations should be considered during ultrasonographic and endoscopic examinations of the DFTS to ensure correct interpretation of the findings.

The second part of this PhD (chapters 4, 5 and 6) focused on the specificity of DFTS analgesia, in particular on the inadvertent desensitisation of structures other than the DFTS.
A first study was performed to compare the four techniques most commonly used to inject the DFTS and is included in chapter 4. A total of 120 cadaver limbs was used with 15 inexperienced operators performing each of the following injection techniques on 2 limbs: Proximal (at the proximolateral recess of the DFTS), Axial (axial to the lateral proximal sesamoid bone [PSB]), Base (at the base of the lateral PSB) and Distal (at the palmar/plantar mid-pastern). The number of attempts needed before the needle was assumed to be correctly positioned into the DFTS was recorded and 10 ml of methylene blue was injected. The limbs were systematically dissected and the injection techniques were compared regarding the accuracy of the technique, the distance between the needle entrance point and the lateral palmar/plantar (digital) nerve (D\(_N\)), the degree of subcutaneous leakage, and the distance between the border of the leakage zone and the lateral palmar/plantar (digital) nerve (D\(_{LN}\)). The Axial and Distal approaches had the highest numbers of successful injections (29/30 and 25/30, respectively). The median number of attempts was highest for the Axial approach (3 attempts). Although not significant, the median leakage score was lower for the Axial technique (score 1 on a 3 degree scale). The distances from the injection point (D\(_N\)) and from the border of the leakage zone (D\(_{LN}\)) to the lateral palmar/plantar (digital) nerve were longer for the Distal (D\(_N\) 30 mm, D\(_{LN}\) 10 mm) and Axial (D\(_N\) 23 mm, D\(_{LN}\) 18 mm) approaches. It was concluded that in the hands of inexperienced operators the Axial approach was the most successful technique for injection of the equine DFTS. Moreover, the sparse subcutaneous leakage and larger distance to the nerve observed when using this technique suggested that the risk of inadvertent palmar/plantar (digital) nerve desensitisation might be lowest when performing DFTS analgesia using the Axial approach.

To confirm the previous results and hypothesis, an in vivo study was performed evaluating the differences in skin desensitisation at the level of the heel bulbs after DFTS
analgesia using the 4 previously studied injection techniques (chapter 5). The DFTS of 9 horses were injected with local anaesthetic solution and radiodense contrast medium. In total, 72 injections were performed: one front and one hind limb/horse/session, with a total of 4 sessions/horse. Skin desensitisation at the heel bulbs was tested with a dynamometer before injection and at 15, 30, 90 and 120 minutes after injection. Overall, complete desensitisation of a heel bulb at one or more time points after injection occurred in 22 limbs (30.6%) and an additional 7 limbs showed partial desensitisation. Complete skin desensitisation occurred in 10, 3, 4 and 5 limbs using the Proximal, Axial, Base, and Distal techniques respectively. The differences between techniques were only significant 30 minutes post-injection (T30). The probability of skin desensitisation at the heel bulbs was 4 times higher when using the Proximal technique compared to the Axial and Base techniques in the forelimbs, and 3 times higher compared to the Axial and Distal techniques in the hind limbs. Skin desensitisation nearly always occurred exclusively on the lateral heel bulb. Only in 5 limbs biaxial desensitisation occurred. It was concluded that anaesthesia of the palmar/plantar (digital) nerve with concurrent distal limb desensitisation often occurs after DFTS analgesia, with a higher chance of desensitisation when using the Proximal technique. Therefore, it was recommended to always verify skin sensitivity at the heel bulbs after DFTS analgesia to avoid false interpretations about the origin of pain causing lameness.

The results of the two previous studies strongly suggested that inadvertent anaesthesia of the palmar/plantar (digital) nerve occurs via backflow of local anaesthetic solution through the needle entrance hole. However, since biaxial desensitisation had also been recorded, a study was performed to evaluate diffusion of mepivacaine from the equine DFTS to adjacent synovial structures (chapter 6). Eight experimental horses were included in the study. Under general anaesthesia, the DFTS of one front and one hind limb
were injected simultaneously with mepivacaine. Synovial fluid samples of the injected DFTS, the adjacent metacarlo-/metatarsophalangeal (MCP/MTP) joint, proximal interphalangeal (PIP) joint, distal interphalangeal (DIP) joint, navicular bursa (NB) and contralateral MCP/MTP joint were collected 15 minutes post-injection (T15) for one of the injected limbs and 60 minutes post-injection (T60) for the other limb. Venous blood samples were obtained at T0, T15 and T60 to check for systemic distribution of mepivacaine. After a 2-week washout period, the procedure was repeated using the same limbs but the time of sampling was reversed between front and hind limbs. The concentration of mepivacaine in the different samples was measured with a commercial ELISA kit. Mepivacaine concentrations in the DFTS samples, both at T15 (5077 mg/l) and T60 (3503 mg/l), exceeded by far those estimated sufficient to produce synovial analgesia (100 mg/l or 300 mg/l). Mepivacaine was found in all synovial structures adjacent to the injected DFTS and in the contralateral MCP/MTP joints, but concentrations were low, with a maximum value of only 3.2 mg/l. Except for the NB samples, the mepivacaine concentrations in the adjacent synovial structures were significantly higher at T60 compared to T15. Significantly higher mepivacaine concentrations were found in the ipsilateral MCP/MTP joints compared to their counterparts at T60. Blood samples showed significantly higher mepivacaine concentrations at T15 and T60 compared to T0. It was concluded that mepivacaine injected into the DFTS of horses diffuses towards adjacent synovial structures but without achieving clinically relevant concentrations.

The final chapter (chapter 7) contains the general discussion and the main conclusions. From the anatomical study we can conclude that the digital manica flexoria is always present in the equine DFTS with different configurations strongly dependent on the location and which can vary within and between individuals. From the studies evaluating the specificity of DFTS analgesia we can conclude that leakage of local anaesthetic
solution to the subcutaneous tissues through the needle injection hole affecting the palmar/plantar (digital) nerves is most likely the reason for desensitisation of other structures in the equine digit rather than diffusion of local anaesthetic solution through the synovial membranes. Injection at the mid-body of the proximal sesamoid bones, through the palmar/plantar annular ligament, is recommended to decrease the risk of inadvertent desensitisation of distal structures. In contrast, injection at the proximolateral outpouching of the DFTS would be discouraged, as this technique was associated with a high percentage of inadvertent distal desensitisation.
SAMENVATTING
De sesamschede is een belangrijke synoviale structuur van het distale lidmaat bij het paard waar vaak pathologie kan worden aangetroffen. Letsels ter hoogte van de sesamschede en de bijhorende structuren resulteren vaak in kreupelheid, waardoor paarden niet kunnen presteren op het gewenste niveau. Voor een dierenarts is het van essentieel belang om de oorsprong van de pijn die kreupelheid veroorzaakt accuraat te lokaliseren, zodat een optimale behandeling kan worden ingesteld die de beste kansen biedt voor succesvol herstel.

In hoofdstuk 1 van dit doctoraat worden de anatomie, fysiologie en pathofysiologie van de sesamschede besproken. Daarnaast komen de verschillende diagnostische technieken aan bod en worden de therapie en prognose van de meest frequent voorkomende aandoeningen van de sesamschede bij het paard besproken. In het deel anatomie wordt een beschrijving gegeven van de macroscopische anatomie van de sesamschede en bijhorende structuren, inclusief de innervatie en bloedvoorziening. Ook de functie van verschillende structuren in de sesamschede en de eigenschappen van het synoviaalvocht worden besproken. Bovendien wordt de rationale gegeven tot een gedetailleerde beschrijving van de “digitale manica flexoria”, een verbinding tussen de twee distale uiteinden van de oppervlakkige buigpees in het distale aspect van de sesamschede. Het deel over de pathofysiologie bespreekt de niet-infectieuze aandoeningen van de sesamschede die resulteren in een primaire tenosynovitis of een tenosynovitis secundair aan scheuren van de buigpezen of de manica flexoria. In het deel omtrent diagnose worden de verschillende methodes besproken die momenteel beschikbaar zijn om pathologie ter hoogte van de sesamschede te lokaliseren en te bevestigen, inclusief intrasynoviale anesthesie. De controverse rond de specificiteit van deze techniek, ontstaan door de gerapporteerde desensitisatie van andere structuren in het distale lidmaat, wordt belicht. Tenslotte wordt
een overzicht gegeven van de mogelijke behandelingen voor de verschillende aandoeningen van de sesamschede, van de bekomen resultaten en de daarbij horende prognose.

De wetenschappelijke doelstellingen van dit doctoraat worden beschreven in hoofdstuk 2. De eerste doelstelling van deze thesis was het beschrijven van de aanwezigheid en de anatomische variatie van de digitale manica flexoria. De tweede doelstelling was het evalueren van de betrouwbaarheid van de intrasynoviale anesthesie van de sesamschede, alsook het aantonen van eventuele ongewenste desensitisatie van nabijgelegen structuren en het bepalen van de wijze waarop deze ontstaat.

In hoofdstuk 3 worden de aanwezigheid, configuratie en variabiliteit van de digitale manica flexoria bestudeerd bij 144 geïsoleerde leden maten van paarden. Systematische dissectie toonde aan dat de digitale manica flexoria bij alle leden maten aanwezig was. Morfologisch konden 2 verschillende types digitale manica flexoria geïdentificeerd worden: het membraneuze en het tendineuze type, elk met 3 verschillende configuraties. De verschillende configuraties waren sterk afhankelijk van de lokalisatie, waarbij het membraneuze type met de configuratie ‘synoviale brug’ overheerste in de voorbenen, terwijl het tendineuze type met schuin gekruiste vezels (van proximomediaal naar distolateraal) overheerste in de achterbenen. Op gelijkluidige wijze konden 3 verschillende types vincula vastgesteld worden in het distaal deel van de sesamschede, die nauw gecorreleerd waren met het type digitale manica flexoria. Een digitale manica flexoria met een ‘synoviale brug’ configuratie was significant geassocieerd met een lateraal en mediaal abaxiaal intermediair vinculum, terwijl een digitale manica flexoria met een ‘schuin gekruiste vezels’ configuratie significant geassocieerd was met een axiaal intermediair vinculum. Deze inter- en intra-individuele variatie moet in overweging genomen worden.
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tijdens het echografisch en endoscopisch onderzoek van de sesamschede om tot een correcte interpretatie van de bevindingen te komen.

Het tweede deel van deze thesis (hoofdstukken 4, 5 en 6) belicht de specificiteit van anesthesie van de sesamschede, in het bijzonder de ongewenste desensitisatie van structuren buiten de sesamschede.

In een eerste studie werden de 4 meest courant gebruikte technieken om de sesamschede te injecteren vergeleken (hoofdstuk 4). Deze 4 injectietechnieken werden door 15 onervaren operatoren toegepast op 120 geïsoleerde distale ledematen. Iedere operator voerde telkens op een voor- en een achterbeen de volgende puncties uit: de ‘proximale’ benadering ter hoogte van de proximolaterale uitpuiling van de sesamschede, de ‘axiale’ benadering axiaal van het lateraal proximaal sesambeen, de ‘basis’ benadering aan de basis van het lateraal proximaal sesambeen, en tenslotte de ‘distale’ benadering in het midden van de kootholte. Er werd genoteerd hoeveel pogingen nodig waren vooraleer aangenomen werd dat de naald correct in de sesamschede zat, en vervolgens werd 10 ml methyleenblauw geïnjecteerd. De ledematen werden systematisch gedissecteerd en de injectietechnieken werden vergeleken op basis van accuraatheid van injectie, afstand tussen het intredepunt van de naald en de laterale palmaire/plantaire (digitaal) zenuw (D₇₅), de mate van subcutane lekkage, en de afstand van de rand van de lekkage zone tot de laterale palmaire/plantaire (digitaal) zenuw (D₇₅₋₅). De ‘axiale’ en ‘distale’ benaderingen vertoonden het hoogste aantal succesvolle injecties (respectievelijk 29/30 en 25/30). Het aantal pogingen (mediaan) voor een juiste positionering van de naald was het hoogst voor de ‘axiale’ benadering (3 pogingen). Hoewel geen statistisch significant verschil kon worden aangetoond, was de mediane score voor lekkage duidelijk lager voor de ‘axiale’ benadering (score 1 op een schaal tot 3). De afstand tussen de laterale palmaire/plantaire...
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(digitaal) zenuw en het intredepunt van de naald ($D_N$) en de rand van de lekkage zone ($D_{LN}$) waren groter voor de ‘distale’ ($D_N$ 30 mm, $D_{LN}$ 10 mm) en ‘axiale’ benadering ($D_N$ 23 mm, $D_{LN}$ 18 mm). Uit deze studie kon worden geconcludeerd dat de ‘axiale’ benadering de meest succesvolle techniek is voor injectie van de sesamschede door onervaren personen. De beperkte subcutane lekkage en de grotere afstand tot de zenuw bij deze techniek suggereren bovendien dat het risico op ongewenste desensitisatie van de palmaire/plantaire (digitaal) zenuw bij anesthesie van de sesamschede het kleinist is bij gebruik van de ‘axiale’ benadering.

Vervolgens werd een *in vivo* studie uitgevoerd om na te gaan of de 4 eerder beschreven injectietechnieken van de sesamschede een even groot risico inhouden tot het optreden van ongewenste desensitisatie ter hoogte van de hielballen (*hoofdstuk 5*). De sesamschedes van 9 paarden werden geïnjecteerd met een combinatie van lokaal anestheticum en radiodens contrastmedium. In totaal werden 72 injecties uitgevoerd: per paard werden 4 injectie-sessies uitgevoerd en per sessie werd telkens één voorbeen en één achterbeen geïnjecteerd. Huidongevoeligheid ter hoogte van de hielballen werd geëvalueerd met een dynamometer, en dit zowel voorafgaand aan de injectie als op 15, 30, 90 en 120 minuten na de injectie. Globaal werd bij 22 ledematen (30.6%) volledige ongevoeligheid ter hoogte van een hielbal waargenomen op één of meerdere tijdstippen na injectie. Zeven ledematen vertoonden partiële ongevoeligheid ter hoogte van een hielbal. Volledige huidongevoeligheid werd waargenomen bij 10 ledematen na gebruik van de ‘proximale’ benadering en bij respectievelijk 3, 4 en 5 ledematen na gebruik van de ‘axiale’, ‘basis’, en ‘distale’ benaderingen. De verschillen tussen de technieken waren enkel significant 30 minuten na de injectie. De kans op huidongevoeligheid van de hielballen was 4 keer groter met de ‘proximale’ benadering vergeleken met de ‘axiale’ en ‘basis’ benaderingen bij het voorbeen, en 3 keer groter vergeleken met de ‘axiale’ en
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‘distale’ benaderingen bij het achterbeen. Huidongevoligheid trad bijna steeds alleen ter hoogte van de laterale hielbal op. Slechts bij 5 ledematen werd biaxiale huidongevoligheid waargenomen. Uit deze studie kon besloten worden dat anesthesie van de sesamschede kan leiden tot een anesthesie van de palmaire/plantaire (digitaal) zenuw met bijhorende desensitisatie van het distale deel van het lidmaat, en dat het risico hierop groter is bij gebruik van de ‘proximale’ injectietechniek. Daarom wordt geadviseerd om na anesthesia van de sesamschede steeds de huidgevoeligheid van de hielballen te controleren, om een foutieve interpretatie omtrent de oorsprong van de pijn die kreupelheid veroorzaakt te vermijden.

De resultaten van de twee voorgaande studies suggereren dat ongewenste desensitisatie van de palmaire/plantaire (digitaal) zenuw waarschijnlijk gebeurt via terugvloei van lokaal anestheticum door de intredeplaats van de naald. Aangezien biaxiale desensitisatie echter ook af en toe werd waargenomen, moet ook rekening gehouden worden met mogelijke diffusie van lokaal anestheticum doorheen de wand van de sesamschede. De studie in hoofdstuk 6 werd uitgevoerd om de diffusie van mepivacaine vanuit de sesamschede naar nabijgelegen synoviale structuren te bestuderen. Acht paarden werden onder algemene anesthesia gebracht om de sesamschede van één voorbeen en één achterbeen gelijktijdig te injecteren met mepivacaine. Vervolgens werden stalen synoviaal vocht verzameld van de geëinjectede sesamschede, het kroongewricht, het hoefgewricht, de bursa podotrochlearis, het ipsilaterale en het contralaterale kogelgewricht, en dit na 15 minuten (T15) voor het ene lidmaat en na 60 minuten (T60) voor het andere lidmaat (voorbeen vs. achterbeen). Er werd een veneus bloedstaal genomen op T0, T15 en T60 om de systemische distributie van mepivacaine na te gaan. Twee weken later werd de volledige procedure herhaald waarbij dezelfde ledematen geëinjected werd, maar waarbij het tijdstip van de staalnamen (T15 vs. T60) werd omgewisseld tussen voor- en
achterbeen. De concentratie aan mepivacaine in de verschillende stalen werd bepaald met een commercieel verkrijgbare ELISA kit. De mepivacaine concentraties in de stalen van de sesamschede op T15 (5077 mg/l) en T60 (3503 mg/l) waren een veelvoud van de concentraties die geacht worden voldoende te zijn voor synoviale analgesie (100 mg/l of 300 mg/l). Mepivacaine kon ook aangetoond worden in het synoviaalvocht van elk onderzocht gewricht of bursa nabij de geïnjecteerde sesamschede evenals in het contralaterale kogelgewricht, maar de concentraties waren zeer laag (maximaal 3.2 mg/l). Met uitzondering van de bursa podotrochlearis, waren de mepivacaine concentraties in de nabijgelegen synoviale structuren significant hoger op T60 vergeleken met T15. In het ipsilaterale kogelgewricht werd op T60 een significant hogere mepivacaine concentratie aangetroffen dan in het contralaterale kogelgewricht. In het bloed waren significant hogere mepivacaine concentraties aantoonbaar op T15 en T60 in vergelijking met T0. Er kon besloten worden dat mepivacaine na injectie in de sesamschede van het paard wel diffundeert naar de nabijgelegen synoviale ruimten doch zonder klinisch relevante concentraties te bereiken.

Het laatste hoofdstuk (hoofdstuk 7) bevat de algemene discussie en de voornaamste conclusies. Op basis van de anatomische studie kunnen we stellen dat de digitale manica flexoria steeds aanwezig is in de sesamschede van het paard, maar verschillende configuraties vertoont die sterk afhankelijk zijn van de lokalisatie (voor- vs. achterbeen) en waarbij bovendien veel inter- en intra-individuele variaties optreden. Op basis van de studies omtrent de specificiteit van anesthesie van de sesamschede wordt geconcludeerd dat ongewenste anesthesie van de palmaire/plantaire (digitaal) zenuwen regelmatig optreedt en dat dit eerder het gevolg is van lekkage van anestheticum doorheen de intredeplaats van de naald dan van diffusie doorheen de wand van de sesamschede. Het gebruik van de ‘axiale’ injectietechniek, halverwege de proximale sesambeenderen
doorheen de palmaire/plantaire ringband, wordt aangeraden om de kans op ongewenste desensitisatie van distaal gelegen structuren te verminderen. Injectie ter hoogte van de proximolaterale uitpuiling van de sesamschede wordt daarentegen afgeraden, aangezien deze techniek geassocieerd is met een hoog risico op ongewenste distale desensitisatie.
CURRICULUM VITAE
Mireia Jordana Garcia was born the 4th of September 1982 in Vic, Spain. She studied Veterinary Medicine at the University of Barcelona and graduated in 2005.

Since very little, she already pointed out her big interest in horses and their veterinary medicine. Therefore, after her university studies she followed the last year specialisation program in equine medicine at the Faculty of Veterinary Medicine in Lyon (France). Afterwards, she continued her formation in equine veterinary medicine and surgery with a four-months internship at the equine referral hospital Clinique Vétérinaire du Grand Renaud (France) and a one-year internship at the equine referral hospital Dierenkliniek de Bosdreef (Belgium). It was during this time that her interest in equine surgery grew up. She went back to Spain (Barcelona) to work one year as a first line equine veterinarian with the equine private ambulatory practice Unitat Clinica Equina. In September 2008 she started a three-year residency program in large animal surgery at the Faculty of Veterinary Medicine of Ghent University (Belgium). In February 2012, she successfully sat the exams of the European College of Veterinary Surgeons (ECVS) becoming an ECVS Diplomate. During her residency, she started working on the topic of her PhD research “Optimised diagnosis in digital flexor tendon sheath pathology in the horse”. After passing the speciality exam, she continued working as a large animal surgeon at the Department of Surgery and Anaesthesiology of Large Animals of the Faculty of Veterinary Medicine of Ghent University, where she pursued her PhD work for another three years in combination with clinical and educational tasks.

Mireia Jordana Garcia is author and co-author of several papers published in international peer reviewed journals. Her work has also been presented at different international congresses.
Publications in national and international journals


*Winner ACVS Outstanding Surgical Resident Award 2011: Second Best Clinical Publication.*

*Article listed in the section “Highlights of recent clinically relevant papers” in *Equine Veterinary Education* 2011, **23**, 541-542.


*Article selected for discussion at the Scientific Review at the BEVA Congress 2014, Birmingham, UK.*


Publications in proceedings of national and international meetings

International oral presentations


*Winner ECVS Resident Award: Best Large Animal Presentation.


National oral presentations


Other abstracts and posters


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