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Review Article

Superficial digital flexor tendonitis in the horse

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Summary

The superficial digital flexor tendon (SDFT) is an elastic structure that during maximal exercise appears to operate close to its functional limits. The biomechanical and biochemical responses to exercise, injury, and healing are still poorly understood but ongoing research is providing valuable new information which is addressed in this review. It appears that the SDFT matures early, after which time it has limited ability to adapt to stress and undergoes progressive degeneration. Focal hypocellularity, collagen fibril degeneration, selective fibril loading and alterations in the noncollagenous matrix occurprimarily within the central core region of the midmetacarpal segment. Current treatment strategies have had equivocal results in returning animals to optimal athletic activity. To date it would seem that progressive rehabilitation programmes coupled with regular ultrasonographic evaluations are a cost-effective and comparable strategy when compared to surgical treatment methods. Recent interest in pharmacological modulation of intrinsic healing of collagenous structures has led to the investigation of various growth factors as potential therapeutic aids in the healing of tendon injuries. However, one of the major goals in tendon research, and one which holds the most optimism for success in the immediate future, is the prevention of tendon injuries.

Introduction

Superficial digital flexor tendonitis is a substantial cause of wastage within the horse industry with a reported incidence of 8–43% in racing Thoroughbreds (Genovese 1993; Goodship 1993; Wilson *et al.* 1996; C. Pickersgill and C.M. Marr, personal communications). Superficial digital flexor tendon (SDFT) injuries heal slowly, with 20–60% of affected horses returning successfully to racing but with up to 80% of horses sustaining reinjury (Silver *et al.* 1983; Bramlage 1986; Genovese *et al.* 1996; Sawdon *et al.* 1996; Genovese *et al.* 1997). There is little objective evidence that any treatment has consistent and long-lasting beneficial effects. However, recent investigations into SDFT ultrastructure, mechanical properties, response to injury and pharmacological modulation of tendon healing have provided new information on the pathogenesis of tendonitis with implications for developing more effective prevention and treatment methods. The purpose of this article is to review current knowledge of equine tendon physiology, injury, healing, and current treatment strategies.

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Tendon morphology

Tendon is composed predominantly of water (approximately 70%). Of the remaining 30% dry matter, the major constituents are collagen and a noncollagenous matrix. In the past, the collagen fibril was considered to be the primary unit contributing to the strength of the tendon, however, the covalent intra- and interfibril collagen cross-links and electrostatic cross-links provided by the noncollagenous proteins have, more recently, been considered to contribute significantly to the tendon's biomechanical properties.

Type I collagen is the most prevalent collagen in normal flexor tendon (Williams *et al.* 1980). Collagen *types II*, *III*, *IV*, and *V* are also present in normal flexor tendons although in smaller quantities and in specific locations. *Type II* collagen is found within enthesious insertions and regions where the tendon changes direction around a bony prominence, reflecting the fibrocartilage-like nature of the matrix in this region designed to withstand compressional as well as tensional forces. *Types III, IV* and *V* are confined to basement membranes and endotendon (Silver *et al.* 1983; Goodship 1993; Goodship *et al.* 1994; Perez-Castro and Vogel 1999).

Collagen molecules are arranged hierarchically into microfibrils, subfibrils, and fibrils, which are grouped into fascicles separated by the more loosely organised endotenon septa (Kastelic *et al.* 1978; Frank *et al.* 1987; Stryer 1988) (Fig 1). When the surface of a tendon is viewed at an angle the presence of a wave-form or crimp within the fascicles can be detected (Williams *et al.* 1980; Parry 1988; Goodship and Birch 1996). This crimp pattern plays a role in imparting elasticity to the tendon during the early stages of loading (up to 2–3% of

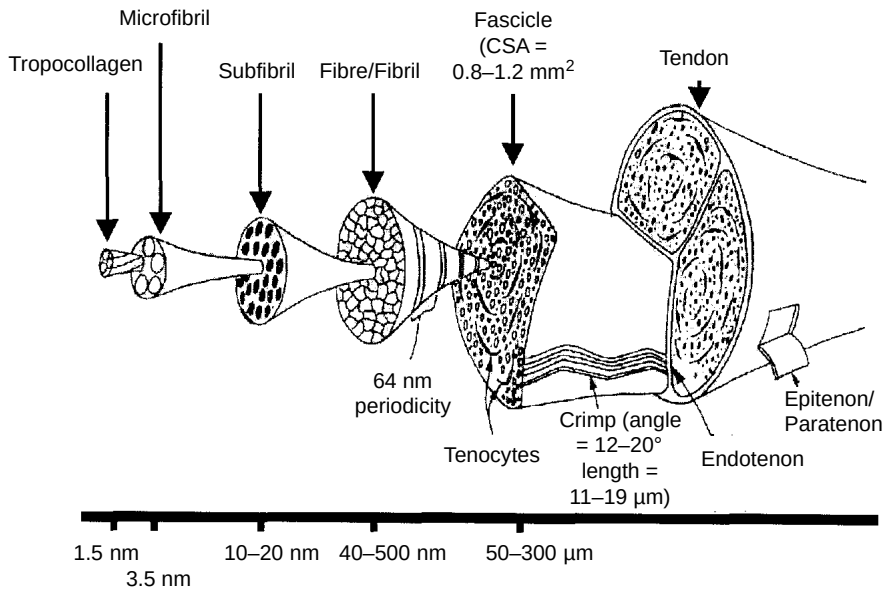

Fig 1: Schematic representation of the collagen arrangement in superficial digital flexor tendon (adapted from Kastelic et al. *1978).*

strain). Crimp angles and lengths were found to be 19–20° and 17–19 µm respectively in the midmetacarpal region of the young SDFT(Wilmink *et al.* 1992), reducing to 12–17° and 11–15µ m with ageing. The elimination of the crimp with age is thought to contribute partly to the increased stiffness of tendon with age.

The noncollagenous substance is composed of tenocytes and glycoproteins. Three distinct cell types (*I, II* and *III*), have been identified on light microscopy within the fascicles of normal equine tendon, based on the morphology of their nuclei. The distribution of cell types varies with age, between tendons and within tendons (Webbon 1978; Goodship *et al.* 1994; Smith and Webbon 1996). The functions of these different cell types are unclear but it is postulated that *Type II* and *III* cells have higher metabolic activity because their nuclei are larger and contain nucleoli. These cells may be concerned primarily with extracellular matrix synthesis (Smith and Webbon 1996) but considerably more information is needed on the nature of these different cell types and their function. There is a further population of cells resident within the endotenon septa of the tendon whose function are largely unknown.

Of the glycoproteins, cartilage oligomeric matrix protein (COMP) is one of the most abundant (Smith *et al.* 1997a). The presence of a phenotype associated with a mutation of the human COMP gene (pseudoachondroplasia), characterised by tendon and ligament laxity (Hecht *et al.* 1995; Briggs *et al.* 1995), lends credence to the hypothesis that COMP plays a structural role in tendon. Its accumulation in tendons under high loads (such as the weightbearing equine digital flexor tendons) in comparison to lower load-bearing tendons (e.g. the equine digital extensor tendons) is intriguing but not understood, especially as this pattern appears to be also present in human tendons.

Proteoglycans consist of glycosaminoglycan side-chain(s) attached to a protein core. Various glycosaminoglycans have been demonstrated within the equine SDFT including chondroitin sulphate, dermatan sulphate, keratan sulphate, heparin, heparin sulphate and hyaluronic acid (Smith and Webbon 1996), but this knowledge is only of limited benefit as this does not indicate the nature of the proteins to which they are attached. The metacarpophalangeal regions of normal SDFT contain more of the larger, cartilage-like, proteoglycans, and experience higher rates of proteoglycan synthesis compared to the midmetacarpal region. These differences probably reflect functional and metabolic variance that exists between regions of tension and compression (Smith and Webbon 1996; Perez-Castro and Vogel 1999; L. Micklethwaite *et al.*, unpublished data). The small proteoglycans decorin, fibromodulin and biglycan have been shown to occur throughout the SDFT (Smith and Webbon 1996) and are thought to influence tenocyte functions, collagen fibrillogenesis, and the spatial organisation of fibres, thereby influencing tendon strength (Hedbom and Heinegard 1993; Svensson *et al.* 1995; Gu and Wada 1996). The advent of gene knock-outs has demonstrated that a complete lack of decorin results in large irregular collagen fibrils with poor mechanical strength in skin (Danielson *et al.* 1997); however, little is known about the small proteoglycans' precise role in modulating biomechanical properties in tendons (Cribb and Scott 1995). In addition, the small proteoglycans have become increasingly recognised as potentially having a metabolic role such as the sequestration of growth factors in the matrix (Yamaguchi *et al.* 1990).

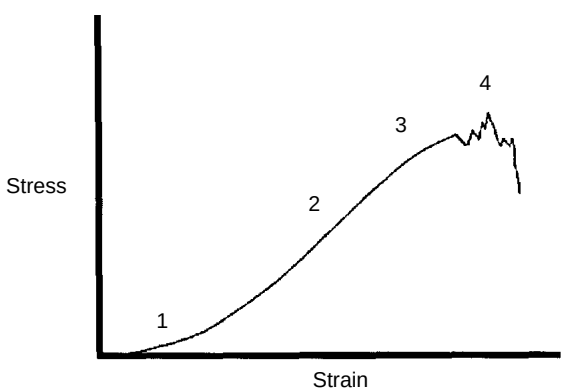

Fig 2: Simplified stress-strain curve for the superficial digital flexor tendon (from Goodship et al. *1994). Key: 1 = 'toe' region; 2 = linear deformation; 3 = yield; 4 = rupture.*

Mechanical properties of the SDFT

The *in vitro* mechanical properties of the SDFT have been characterised and shown to approximate a sigmoidal curve (Fig 2) when force is plotted against elongation (Evans and Barbenel 1975; Wilson and Goodship 1990; Crevier *et al.* 1996). There is an initial lax phase, termed the 'toe'region, where the crimp is eliminated (Cribb and Scott 1995), followed by a linear phase due to progressive stretching of the straightened collagen fibers, until tendon failure occurs at extreme forces. The methodology of *in vitro* biomechanical testing has been shown to be repeatable, and, to provide objective data on the biomechanical properties of tendons in response to various treatments (B. A. Dowling *et al.*, unpublished data).

In vivo SDFTstrain (i.e. percentage elongation) at the gallop has been reported in the range 11–16%, which is in close agreement with measured *in vitro* strains at rupture of 12–21% (Riemersma and Schamhardt 1985; Stephens *et al.* 1989; Wilson and Goodship 1990). These findings suggest that at maximal exercise the SDFToperates close to its physiological limits with a relatively narrow safety margin. Consequently, minor disruption of the tendon matrix composition and arrangement dramatically increase the incidence of tendonitis. Conversely, improving the 'quality', or strength, of the tendon matrix reduces incidence.

Effects of exercise and maturation

There appears to be an age-related trend towards tendon matrix degeneration. Most tendons in mature horses exhibit patchy acellularity, although there is no overall decrease in cell number with age in the equine superficial digital flexor tendon (Birch *et al.* 1999). Further degenerative signs become more evident in all horses age ≥ 3 years (Pool 1996) and these include matrix fibrillation, chondroid metaplasia, chondrone formation, neovascularisation and fibroplasia (Vasseur *et al.* 1985; Pool 1996). All these changes have the effect of inducing relative tendon weakness and, although an association between elastic modulus and age has been demonstrated, the correlation between decreasing mechanical strength and age has not been proven (Gillis *et al.* 1997). A recent survey of racehorses, however, demonstrated a positive, significant correlation between tendonitis and age (C. Pickersgill and C.M. Marr, personal communications).

Recent investigations have indicated that the equine SDFT attains maturity at approximately age 2 years. Collagen fibril diameter, mature collagen cross-links, and crimp morphology have stabilised by this age (Patterson-Kane *et al.* 1997a,b). Tendons from horses age over 2 years have significantly stiffer mechanical properties (Gillis *et al.* 1995b). This increased stiffness is thought to be associated with the reduction of crimp, the presence of increasing numbers of nonreducible cross-links and decreasing fascicle size in older tendons (Parry *et al.* 1978; Reiser 1994; Gillis *et al.* 1997). The cause of the decreased fascicle size is unknown but may represent splitting or degeneration of tendon fascicles with increasing age.

Reductions in collagen fibril crimp angle and length have been demonstrated in response to ageing and exercise (Wilmink *et al.* 1992; Patterson-Kane *et al.* 1997a,c, 1998). Young horses subjected to an 18 month training programme experienced selective reductions in crimp angle and length within the central region of the SDFT (Patterson-Kane *et al.* 1998). Central fibrils may reach the end of the toe region of the biomechanical response curve earlier than fibrils at the periphery, resulting in selective loading with the potential for earlier failure (Patterson-Kane *et al.* 1997a, 1998). These changes may explain the relatively high incidence of 'core' lesions with the SDFT.

Exercise also causes a reduction in the mass average diameter of collagen fibrils within the central region of the SDFT compared to the peripheral region fibrils (Patterson-Kane *et al.* 1997d). As glycation levels are unaltered, which indicates that the smaller fibrils are not new collagen, these results suggest that microdamage, with splitting of the collagen fibres, is occurring.

Exercise- and age-associated changes in the noncollagenous matrix have also been observed. COMP is accumulated during development associated with loading but levels fall in the metacarpal region of the superficial digital flexor tendon after skeletal maturity and the fall in the central region of the SDFT is accelerated by exercise (Smith *et al.* 1997a,b, 1998a). However, no direct relationship between COMP levels in equine digital flexor tendons and tendonitis has yet been established (Smith and Webbon 1996; Smith *et al.* 1997b). It is more probable that COMP levels reflect the quality of the whole tendon matrix rather than providing a direct causal relationship. However, these findings suggest that, while tendon can adapt during development, it has little capacity to do so after skeletal maturity, suffering, as a consequence, from cumulative fatigue damage (Smith *et al.* 1999). In support of this hypothesis, gene expression for the proteoglycans and collagens in the metacarpal region of bovine digital flexor tendons has been shown to be absent after skeletal maturity, while it is maintained in the compressed, metacarpophalangeal regions (Perez-Castro and Vogel 1999), an area relatively spared of injury in the equine superficial digital flexor tendon.

Aetiopathogenesis of clinical tendonitis

The above findings suggest that the majority of clinical tendonitis lesions have, as a precursor, some undetectable subclinical change that precedes clinical tendonitis and that this change is age-related and accelerated by exercise (Stromberg and Tufvesson 1969; Webbon 1977; Smith *et al.* 1999).

As yet, there is no consensus regarding the inciting insult that results in the described changes. Specific pathogenetic mechanisms of tendonitis have been investigated. These can be classified into 2 broad categories: (a) physical and (b) vascular.

(a) Physical mechanisms

Fatigue, poor conformation, lack of fitness, incoordinate muscle activity (Evans and Barbenel 1975; McIlwraith 1987) will all act to produce excessive biomechanical forces on the tendon (Silver *et al.* 1983; Crevier-Denoix and Pourcelot 1997) which may accelerate the degenerative change by physically disrupting the matrix, or are sufficient to induce full clinical tendonitis by exceeding the mechanical properties of the tendon. Other mechanisms include exercise-induced hyperthermia (Wilson and Goodship 1994), whereby temperatures of up to 45°C have been induced in the tendons at the gallop. However, these temperature rises do not induce cell death in tenocytes, a property which is present even in naïve tenocytes *in utero* (Birch *et al.* 1997b), although this temperature rise may still induce matrix damage.

(b) Vascular mechanisms

Ischaemia and reperfusion injury, and fibroblast anoxia (Goodship and Birch 1996; Gillis *et al.* 1997; Birch *et al.* 1997a,b) have also been suggested to play a role. However, the equine superficial digital flexor tendon has good vascular network (Kraus-Hansen *et al.* 1992) and blood flow in this tendon has been recorded at a level similar to that of resting skeletal muscle and is increased by exercise (Jones 1993). Furthermore, this is no evidence of hypoxia *in vivo* (A.M. Wilson, personal communication).

At present there is little experimental evidence to support or refute these potential mechanisms, but it seems logical that each may interact or summate to cause tendon injury.

From the evidence to date, it would appear alterations in central cellularity, fascicle size, fibril diameter, crimp angle, and declining concentrations of COMP reflect progressive tendon degeneration. Progressive fibrillar degeneration and selective fibril loading may subsequently result in tendon failure. How can this be prevented or reversed? Although there is little evidence of gene activity in the mature metacarpal superficial digital flexor tendon, tenocytes, if removed from these tendons and grown *in vitro*, demonstrate every ability to synthesise these matrix components in response to exogenous growth factors (R.K.W. Smith, unpublished observations). Pharmacological manipulation of tendon homeostasis and healing by such growth factors may hold the key to prevention of tendonitis and to faster repair.

Equine SDFT healing

Silver *et al.* (1983) reported naturally occurring tendonitis as fibrillar stretching, slippage and tearing followed by fibrilolysis associated with the release of enzymes from damaged fibroblasts and inflammatory cells. The healing of ligament and tendon follows a sequence of events consisting of haemorrhage, inflammation, fibroblastic proliferation, collagen production and remodelling (Jack 1950; Gelberman *et al.* 1987).

Type III collagen is one of the first collagens to be synthesised at the site of tendon injury (Silver *et al.* 1983; Watkins *et al.* 1985a). *Type III* collagen forms interfibrillar cross-links conferring early stability and mechanical strength to the site of injury (Williams *et al.* 1980; Cheung *et al.* 1983). Increased quantities of *Types IV* and *V* collagen also become evident (Williams *et al.* 1980; Silver *et al.* 1983). Following the acute stages, *Type I* collagen fibres become apparent and loose fibrils of *Type I* and *III* predominate until 6 months postinjury. After this period, linearly arranged *Type I* collagen fibrils prevail, indicating progressive remodelling and normalisation of the healing tissue (Watkins *et al.* 1985a). Abnormal quantities of *Type III* collagen, smaller collagen fibrils and lack of fibre bundles and linear arrangement may still be detected up to 14 months postinjury (Silver *et al.* 1983) and probably persist even longer. It is the abnormal composition and arrangement of matrix in fibrous scar tissue, which has poor biomechanical properties in comparison to normal tendon, and the slow rate of healing that are believed to be responsible for the high incidence of reinjury (Pool 1996).

Diagnosis of tendonitis

Ultrasonography is presently the most common technique used to diagnose tendonitis and monitor healing. Over the past decade it has become an affordable noninvasive method that enables repeated assessment of lesions over time (Rantanen 1982). Subsequent investigators have described the physics of ultrasound as well as techniques, instrumentation and ultrasonographic anatomy of the equine limb (Hauser *et al.* 1985; Genovese *et al.* 1985, 1986; Hauser 1986; Rantanen 1993a,b). Ultrasonography and histology findings in tendonitis and throughout tendon healing have been found to be closely correlated (Reef *et al.* 1989; Crass *et al.* 1992; Marr *et al.* 1993b), indicating that it is a useful noninvasive technique for monitoring tendon repair.

The commonly measured variables include tendon and lesion cross-sectional area, lesion type and location, and fibre alignment (Genovese *et al.* 1985, 1986, 1990, 1996; Nicoll *et al.* 1992; Smith *et al.* 1994; Gillis *et al.* 1995a,b). An increase in tendon cross-sectional area is reportedly the most sensitive indicator of fibre damage (Genovese *et al.* 1996) and for detecting reinjury during the convalescent period when the reintroduction of exercise may be excessive. Therefore, its measurement during rehabilitation should not be overlooked. Additional measurements include changes in echogenicity and the calculation of a severity rating score (Genovese *et al.* 1990; Nicoll and Wood 1991; Nicoll *et al.* 1992, 1993; Wood *et al.* 1993). The severity rating score, although found to be correlated with outcome, is complicated and difficult to use clinically. A good fibre alignment after healing is believed to be most correlated with a successful outcome. These measurements provide quantitative data upon which decisions concerning appropriate treatment and prognosis can be made. However, time and equipment constraints often preclude the use of these measurements in general equine practice. Further information of the diagnosis and progression of tendonitis in the horse may be provided in the future by the use of serological markers. Several candidates are currently undergoing investigation, including COMP (Smith and Heinegard 1999).

Treatment of tendonitis

Tendonitis results in permanent alteration of the tendon's molecular composition and biomechanical properties. As such, damaged tendon can no longer function normally and reinjury is common. Many medical and surgical procedures have been advocated in the treatment of equine tendonitis; however, there is little objective evidence that any have consistent and enduring beneficial effects.

A methodical approach to the treatment of tendonitis has been described by dividing the periods of tendon injury, healing and rehabilitation into acute (inflammatory), subacute (repair), and chronic (remodelling) phases (Bramlage 1991a). These categories allow application of specific therapies based on an understanding of tendon pathology and repair. The various therapeutic procedures can be classified into physical, pharmacological, surgical groups (Bramlage 1991a,b, 1992; Henninger 1992; Bertone 1996).

Physical therapy

Physical therapies in the form of ice application, hosing, bandaging and box rest have been the cornerstones of treatment in the acute stages of tendonitis where a reduction of inflammation is indicated to limit the action of damaging proteolytic enzymes on the remaining intact tendon matrix (Bramlage 1992). In the past, heel elevation has been recommended, however recent work has demonstrated no

beneficial effect on SDFT strain and may, in some circumstances, actually increase it (Lochner *et al.* 1980; Stephens *et al.* 1989; Riemersma 1996a). Physiotherapy in the form of controlled exercise may be commenced during the repair phase once inflammation has subsided depending on lesion characteristics. There are numerous reports of the benefits of controlled active and passive exercise regimens on the healing and rehabilitation of musculoskeletal tissues (Takai *et al.* 1991; Buckwalter 1996; Genovese *et al.* 1996).

Controlled exercise programmes have been developed for rehabilitation of SDFT injuries in the horse (Gillis 1996, 1997). Incremental increases in exercise from hand walking through to cantering have been described for periods extending up to 12 months postinjury. Ultrasonography of tendon healing is performed at approximately 3-monthly intervals and the exercise regimen applied according to findings (Gillis 1996). The duration of rehabilitation is critical, with studies demonstrating poorer prognosis for return to racing without reinjury in horses rested for <6 months (Genovese *et al.* 1996, 1987).

In one study, 71% of horses subjected to a controlled exercise programme raced at least once compared to 25% of horses subjected to pasture rest alone suggesting some benefit in controlled exercise regimens (Gillis 1997), while similar figures were recorded in a study of hunter and point-to-point horses (75% subsequently raced at least once after an average of 13.5 months rest and controlled exercise; Marr *et al.* 1993a). The findings of a retrospective study on the effect of conservative management alone determined that 59.4% of horses raced on 5 or more occasions (Sawdon *et al.* 1996). However, no information was provided on the average duration before work or racing was recommenced, nor on the initial severity of the tendon lesions. The results from these studies compare favourably with those obtained from more invasive treatments. Therefore, controlled exercise with careful monitoring using diagnostic ultrasound remains the mainstay of successful rehabilitation of tendon injuries in the horse.

Pharmacological therapy

Anti-inflammatory drugs: Early (less than 24 h postinjury) use of short-acting corticosteroids would appear to be beneficial to reduce the acute inflammatory reaction that is damaging to the remaining intact fibrils, although there is no proof of an improved outcome with their use. Delayed use of corticosteroids is not believed to be helpful as they will inhibit the fibroblastic response which is necessary for tendon healing. Intralesional use of depot corticosteroids has been shown to have detrimental effects including collagen necrosis and hyalinisation (Pool *et al.* 1980), although this effect may be due to the carrier rather than the corticosteroid itself. Dimethylsulphoxide has also been used for its proposed anti-inflammatory effects. However, in murine tendons it has been shown to weaken the healing tendon (Albrechtsen and Harvey 1982). The use of nonsteroidal anti-inflammatory drugs (NSAIDs) is controversial for their effect on inflammation. It has been difficult to demonstrate experimentally in the horse a significant anti-inflammatory action by many of the most commonly used NSAIDs and their major function must therefore be considered that of providing analgesia (May and Lees 1996).

Sodium hyaluronate (HA): The use of intralesional or peritendinous HA in the treatment of acute tendon injury has yielded conflicting results. Initial studies reported that HA improved tendon healing based on subjective, ultrasonographic interpretation (Spurlock *et al.* 1989; Gaughan *et al.* 1991; Gift *et al.* 1992). Significant reductions in the extent of postsurgical adhesion formation were observed in intrasynovial tendons (Thomas *et al.* 1986; Gaughan *et al.* 1991). Other investigators have reported limited effects on the *in vitro*, biomechanical properties of collagenous tissues and healing tendons (Oxlund and Andreassen 1980; Salti *et al.* 1993). In horses, a study on the effect of HA on collagenase-induced tendonitis failed to show any significant benefit (Foland *et al.* 1992) and clinically, intralesional HA had no significant beneficial effect on the recurrence of equine superficial flexor tendonitis when compared to untreated cases (Dyson 1997).

Polysulphated glycosaminoglycans (PSGAG): PSGAGs are believed to inhibit macrophage activation, collagenase and metalloproteinase activity, properties potentially useful in the acute stages of tendonitis. Therefore, PSGAGs have been injected intralesionally at this stage (Smith 1992). In addition, there has been some suggestion that they improve collagen fibril organisation and stimulate tenocytes to produce collagen, HA and glycosaminoglycans (W.R. Redding *et al.*, unpublished data). *In vitro* investigations have demonstrated enhanced proline incorporation in tendon explants treated with PSGAG suggestive of increased collagen production (Riley *et al.* 1997). Evaluation of the beneficial effects of PSGAG in clinical tendonitis is based on subjective clinical and ultrasonographic measurements, without conclusive proof of significant improvement of prognosis over other treatments. Recurrence rates of tendonitis after PSGAG therapy have been reported to be between 42.5 and 44.4% (Dow *et al.* 1996; Dyson 1997; W.R. Redding *et al.*, unpublished data).

Beta-aminoproprionitrile fumarate (BAPN-F): BAPN-F is the toxic agent found in the seeds of the plant *Lathyrus odoratus* (sweet pea). BAPN-F binds to the enzyme lysyl oxidase thereby inhibiting the deamination of lysine, the first step in the formation of inter- and intramolecular collagen fibre covalent cross-links (Stryer 1988). By virtue of its action, BAPN-F is proposed to prevent excessive cross-linking in the early stages of tendon repair and promote the linearisation of collagen fibres under the influence of controlled exercise (Genovese 1992). Initial results showed that 80% of equine SDFT treated with intralesional BAPN-F had at least a 75% improvement in ultrasonographic measurements (Genovese 1992). However, long-term data on the return to racing results of horses treated with BAPN-F has been less convincing, with between 45 and 50% of treated horses returning to maximal athletic activity (Reef *et al.* 1996, 1997). BAPN-F should probably be considered only for cases of severe tendonitis. It requires a strict and carefully controlled exercise regimen with regular ultrasound examinations and, therefore, is only appropriate for the committed owner.

Surgical treatment

Accessory ligament desmotomy: The rationale for transection of the accessory ligament of the superficial digital flexor tendon (ALSDFT) is to increase the involvement of the SDFT muscle by lengthening the ALSDFT-SDFT complex and thereby reduce the peak loads on the SDFT at full weight bearing in the chronic phase when the animal returns to work (Bramlage 1996). Return to racing results, following ALSDFT desmotomy, are somewhat

varied. Between 52 and 82% of treated horses have returned to race at or above their previous level or on at least 5 occasions without reinjury (Bramlage *et al.* 1988; Fulton *et al.* 1994; Hogan and Bramlage 1995; Bramlage and Hogan 1996; Ordidge 1996; Gibson *et al.* 1997). A prospective study demonstrated that exercise following desmotomy of the ALSDFT resulted in deterioration of the ultrasonographic appearance of acute tendonitis (Davis *et al.* 1994). An *in vitro* investigation into the biomechanical effects of desmotomy of the ALSDFT determined that SDFT strain and metacarpophalangeal joint hyperextension increased following transection of the ALSDFT which would appear to be counterproductive (Shoemaker *et al.* 1991). A later study found that horses treated surgically were 1.3 times more likely to race on 5 or more occasions, but that there was a trend towards an increased risk of new or recurrent injury. These horses were also 5.5 times more likely to experience suspensory ligament injury (Gibson *et al.* 1997). The findings of these studies question the validity of the rationale for ALSDFTdesmotomy.

Percutaneous tendon splitting: Percutaneous tendon splitting has been used to treat chronic cases of tendonitis as early as 1931, although the method has since been modified and refined many times (Åsheim 1964; Sevelius 1964; Nilsson 1968; Stromberg *et al.* 1974; Webbon 1979; Stashak 1987; Allen 1992; Bramlage 1996). Tendon splitting was thought to improve vascularisation (Åsheim 1964); however, later investigators found that tendon splitting resulted in increased trauma, and granulation tissue production, no alteration in collagen production and continued lameness (Stromberg *et al.* 1974; Silver *et al*. 1983).

More recently, tendon splitting has been revisited as an effective technique for the management of acute, rather than chronic, tendonitis where it was thought to allow evacuation of the intratendonous haematoma and oedema, reduce lesion size, and improve collagen fibril orientation (Henninger *et al.* 1990; Henninger 1992; Pool 1996). As such, its use is limited to the treatment of anechoic core lesions (Bramlage 1996). One study found that 68% of treated horses were able to return to racing at or above their preinjury performance level (Allen 1992). To date, controversy exists between investigators as to the long-term effectiveness of tendon splitting because the quality of repair and return to race form are variable and often not superior to other treatment methods (Henninger 1994). A less invasive and damaging form of tendon splitting may be achieved with the use of multiple needle sticks.

Synthetic tendon implants: Augmentation of tendons and ligaments through the use of carbon fibre implants was initially demonstrated in nonequine species (Jenkins 1976, 1977). The results of these early studies encouraged the application of carbon fibre implants in the treatment of flexor tendonitis and lacerations in the horse (Vaughan and Edwards 1978; Goodship *et al.* 1978, 1980; Littlewood 1979; Brown and Pool 1983). However, it was found that carbon fibre induced persistent abnormalities in newly formed collagen, and return to racing results were comparable to other treatment methods (Goodship *et al.* 1985; Reed *et al.* 1994). The selection of this implant did not take into account the large strains occurring within equine digital flexor tendons. Carbon fibre is inextensible and shear forces are therefore generated at the surface of the implant which were probably responsible for continued tenalgia in many cases treated with carbon fibre. Implants are probably not indicated in cases of strain-induced tendonitis as the paratenon usually remains intact and not only provides it own scaffolding for repair but also is responsible for generating a significant part of the fibroblastic response.

Counterirritation: Counterirritation, through the application of topical 'blister ointments', line firing or pin firing, used to be one of most common methods employed in the treatment of chronic musculoskeletal injuries in horses (Fraser 1940; McCullagh and Silver 1981). It was thought that a beneficial effect would be incurred within the tendon as a result of increased vascularity and inflammatory cell exudate caused by the intense inflammatory reaction induced by such procedures. Eventually it was shown that firing had no direct benefit on tendon healing, *Type I* collagen content, or athletic performance and, in fact, often delayed healing and increased the incidence of peritendinous adhesions (Silver *et al*. 1983). It is now considered an inappropriate treatment but there are still many supporters for its use, especially within the UK. Like many treatments for tendonitis in the horse, conclusive proof of its effectiveness (or ineffectiveness) is elusive.

Miscellaneous therapies

Other treatments for superficial flexor tendonitis include therapeutic low intensity ultrasound (Morcos and Aswad 1978), low frequency infrared laser therapy (McKibbin and Paraschak 1983; Marr *et al.* 1993a), and electromagnetic field therapy (Norrie 1975; Auer *et al.* 1983; Watkins *et al.* 1985b). The results of such treatment methods are varied and, in the case of electromagnetic field therapy, have been shown to delay collagen maturation in healing tendons (Watkins *et al.* 1985b). More recently, low intensity magnetic fields were found to have no effect on regional blood flow in the equine metacarpus (Ramey *et al.* 1998). In most cases, it would appear that the results obtained using these strategies do not exceed those obtained by conservative methods.

Future research areas

There is an essential need to understand the normal homeostatic mechanisms in tendon. The development and refinement of recombinant DNA technology, coupled with advanced understanding of cellular regulation has improved our knowledge in these areas and has resulted in investigation of various growth factors, which are believed to be integral to development and homeostasis of connective tissues, as therapeutic agents in musculoskeletal healing. To date, the effects of growth hormone, insulin-like growth factor-1, and transforming growth factor beta-1 on the metabolism of equine tendon have been examined.

Direct and indirect effects on cell replication, and collagen and proteoglycan synthesis have been attributed to growth hormone in many organs and tissues (Maor *et al.* 1989; Jørgensen 1989; Christensen and Oxlund 1994; Mauras *et al.* 1996). The development of equine recombinant growth hormone (Equine somatostatin eST)[1] has provided an opportunity for investigation of its effects on a number of physiological responses in the horse (Malinowski *et al.* 1997). Studies examining the effect of eST on tendon healing are underway (Mickelthwaite *et al.* 1998; B.A. Dowling, unpublished data). Preliminary results have shown a stimulatory effect on tendon cross-sectional area and proteoglycan production. Additional research into the effects of eST on tendon metabolism are indicated and future biomechanical and biochemical analyses will hopefully provide additional information.

Initial studies found that insulin-like growth factor-1 (IGF-1) had no detectable effect on collagen synthesis in healing or normal ligament explants (Murphy *et al.* 1994). However, later studies showed IGF-1 resulted in an increase in net collagen and proteoglycan synthesis, in canine cruciate ligament explants *in vitro*, and positive effects on collagen synthesis, cellular activity and *Type I* collagen production in equine SDFT explants (DesRosiers *et al.* 1996; Murphy and Nixon 1997). Intratendonous IGF-1 resulted in enhanced ultrasonographic properties and *Type I* collagen expression in experimental tendonitis (Dahlgren *et al.* 1998). Transforming Growth Factor Beta-1 (TGFβ-1) has been shown to stimulate production of *Type I* collagen in healing rabbit medial collateral ligament explants (Murphy *et al.* 1994). TGFβ-1 supplementation of equine tenocyte explants *in vitro* resulted in stimulation of COMP production and cell replication (Smith *et al.* 1998b, 1999). The use of one growth factor may not be sufficient to improve the quality of tendon healing. However, cocktails of appropriate growth factors may have better potential, but further research is necessary to identify the important growth factors in tendon development and homeostasis. We need to consider not the promotion of tendon repair, which the tendon does extremely well, but tendon regeneration instead, but for this the secrets of tendon development need to be unlocked.

Conclusions

It is only relatively recently that research efforts have yielded information on the normal physiological maturation process, effects of exercise and training, and the pathophysiology of SDFT injury in the equine athlete. Much still needs to be determined but these studies have indicated that, after maturity, tendons have limited adaptive mechanisms. The age and exercise-related alterations in tendon cellularity, fibril morphology, and noncollagenous matrix, suggest progressive degeneration. These changes, coupled with a narrow biomechanical safety margin are likely to be conducive to clinical tendonitis.

Evaluation of tendon injury has been based primarily on ultrasonographic examination, which, although reliable, provides limited objective data on the biochemical and biomechanical properties of the tendon. Objective measurements using *in vitro* and/or *in vivo* biomechanical techniques should not be overlooked in the evaluation of potential future treatment methods.

SDFT healing is similar to other tissues and variable, necessitating further studies into the biochemical and biomechanical processes involved. Consequently it is not surprising that the efficacy of proposed treatment regimens is equivocal and the results of clinical trials vary. Largely any recommendations for the treatment of tendonitis at this time, whether surgical or conservative, are based on limited objective information. At present no single universal treatment method has emerged and, in most instances, clinical experience influences recommendations. It would appear that early aggressive anti-inflammatory treatment and combined treatment strategies, such as tendon stabbing for core lesions, and controlled exercise regimens, coupled with regular ultrasonographic examinations are the best most clinicians can offer. As more objective information becomes available on which to rationalise treatment regimens, there is no doubt that treatment strategies will improve. Research investigating pharmacological methods of modulating tendon homeostasis and healing is likely to continue, given some of the early encouraging results and may hold the key to effective treatment and prevention.

Manufacturer's address

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