Superficial digital flexor tendon (SDFT) injury leading to tendonitis is the most frequent soft tissue injury in racehorses. As tendonitis has been noted to heal slowly and imperfectly, injured tendons require long periods of rest, and the rate of recurrence of tendonitis upon return to training is high. Between 1,100 and 1,200 of the 6,400 to 7,000 racehorses currently registered with the Japan Racing Association (JRA) suffer from tendonitis, and some 70% of these return to racing without making a comeback in a single race. In view of this statistic, the JRA has conducted investigational and clinical research from various perspectives. This paper will review the results of these studies, thus providing insight into practical methods of treating and preventing tendonitis. The study results are summarized under the following headings: 1) Introduction; 2) Impacts and loads on the lower limb at the track; 3) Occurrence of tendonitis at JRA training centers; 4) The hoof and tendonitis; 5) Ultrasonic diagnostic criteria; 6) Therapeutic regimens; 7) Conclusion. We concluded that tendon injuries represent irreversible structural alterations that are unlikely to be significantly altered by therapy, so that the best outcome may be achieved by minimizing the damage done by the original injury. From this viewpoint, research efforts will be directed toward prevention and early diagnosis, rather than therapy of established lesions.

Key words: tendonitis, racehorses, tendon injury

Internationally, tendon injury has proved to be a major problem for the racing industry. The combination of an unacceptably high incidence of injury and the long duration of time for recovery and rehabilitation results in a very high financial cost. The frequency of injury is also detrimental in terms of animal welfare. The best way to deal with tendon injury and the resulting tendonitis is to make every effort to limit the extent of damage, or if possible to prevent it. However, thus far it seems that the prognosis for horses with tendonitis has not improved, nor have any effective preventive measures been instituted. To clarify the strategies that can be used to prevent equine tendonitis, an International Workshop on Equine Tendonitis was held as part of the Fifth International Conference on Equine Exercise Physiology from September 20 to 25, 1998, at Utsunomiya, Tochigi, Japan [32]. This workshop addressed a number of objectives in relation to recent and novel scientific advances in understanding tendonitis.

In Japan, as well as in western countries, tendonitis is a frustrating problem for the racing industry. An estimated 1,100 to 1,200 of the racehorses registered with the Japan Racing Association (JRA) suffer from tendonitis (mainly of the superficial digital flexor tendon; SDFT), and some 70% of these return to racing without making a comeback in a single race. Given that some 1,500 JRA horses are diagnosed as having bone fractures in any given year, the effects of tendonitis are quite significant. In view of these statistics, the JRA has assembled veterinarians, researchers, facility managers, trainers, and jockeys to establish a Committee for the Prevention of Accidents to Racehorses [30, 31]. This committee has conducted surveys to determine the associated risk factors, including factors intrinsic to the horses and factors in the horses’ environment, such as training protocols, facilities, maintenance protocols, and shoeing/foot preparations, with the aim of reducing the incidence and severity of tendonitis. Here, we report some of the results obtained from these investigations. We focus on...
the conditions related to the occurrence of tendonitis during races or training in the JRA, and on the research currently being adopted to minimize the extent of tendon damage and to prevent tendonitis.

Impacts and loads on the lower limbs at the track

Different materials, including woodchips, dirt, and turf, are used as track surfaces at training centers and on racetracks belonging to the JRA (Fig. 1) [30, 33]. It is well known that the conditions of the track surface, such as hardness and roughness, influence the incidence of injuries in Thoroughbred racehorses during training and racing [34]. We developed an instrument that could be sandwiched between the hoof and shoe of a horse to reliably measure vertical ground-reaction forces and three-dimensional acceleration at the walk, trot and canter on woodchip tracks. Details of this shoe can be found in the American Journal of Veterinary Research, volume 61, pp. 979–985 [17]. Each surface material has different features, depending on its location on the track (straight or corner), the weather, and the use of the track. Trainers need to familiarize themselves with all of the characteristics of these surface materials if they are to prevent tendon injuries in racehorses and maximize the efficiency of their training.

Is there any relationship between injuries and the characteristics of the track surface?

Turf and dirt racetracks: In the JRA, the frequency of injuries (such as broken bones and tendon ruptures) during races from 1988 to 1997 was compared for turf tracks and dirt tracks [34, 36]. The results are shown below. Track surface conditions were determined by use of a soil-shearing-strength cone penetrometer [27] and soil-moisture-content tensiometers [4]. Dirt track conditions were classified as fast, good, muddy, or sloppy, and turf track conditions were classified as firm, good, soft, or yielding.

On turf tracks, the occurrence of injuries tended to be reduced as the condition of the track deteriorated.

On dirt tracks, the occurrence of injuries increased as the condition of the track deteriorated.

On turf tracks, ‘good (fast)’ tracks were dry and hard (leading to more impact on the horse’s legs, more high speed and therefore more injury), and ‘bad (slow)’ tracks were moist and soft (causing less impact). This may be one of reasons why there were fewer injuries on slow tracks.

In contrast, dirt tracks in heavy condition showed a high water content, indicating that the condition reduces or even eliminates the shock-absorbing effect of cushioning sand, more impact on the horse’s legs and therefore more injury [46].

Woodchip and dirt training tracks: The occurrence of periostitis of the third metacarpal bone was observed in two groups of horses, one trained on a woodchip track and the other on a dirt track [29]. The occurrence of periostitis in dirt-track-trained horses (34.3%) was twice as high as in horses trained on the woodchip track (13.4%). The main reason for this result could be the differing flexibilities of the two types of track. Also, the fact that the condition of woodchip tracks is affected little by changes in weather could have contributed to this result.
How does running on rough track surfaces affect horses?

During running on rough track surfaces with many foot prints on the surface, the impact on the tip of the hoof and the outside or inside of the hoof was found to change at each step [16]. In these cases, the legs were much more severely stressed than in running on even tracks, because the joints, bones, tendons, and ligaments received irregular impacts.

Occurrence of tendonitis at JRA training centers

The JRA has between 6,400 and 7,000 racehorses, 10 racetracks, and two training centers (the Miho and Ritto Training Centers) under its management [31]. Of the racehorses, about 4,000 are repeatedly admitted and discharged from the training centers for training. The occurrence of tendonitis at JRA training centers between 1987 and 1997 is shown in Fig. 2 [35]. Between 1,100 and 1,200 racehorses belonging to the JRA suffer from tendonitis (mainly SDFT), and some 70% of them return to racing but without making a comeback in a single race on the track [35]. In 1987, a total of 24 horses at the two training centers suffered catastrophic tendon and ligament ruptures [35]. In 1987, a total of 24 horses at the two training centers suffered catastrophic tendon and ligament ruptures [35]. However, as shown later, since the construction of woodchip tracks and uphill tracks with the composition of the woodchip on the track surface providing better surface cushioning, the number of the catastrophic tendon and ligament ruptures has decreased remarkably to about 5 horses a year in recent years [35].

On the other hand, the number of tendonitis cases has increased from 937 in 1987 to 1,155 in 1991, 1,372 in 1994, and 1,271 in 1997 [35]. From these data, we suspected that although the incidence of conditions that cause catastrophic rupture of tendons and ligaments by sudden impact on tendons has decreased after the construction of woodchip tracks and uphill tracks and one of the causes of the increased incidence of tendonitis was possibly influenced by the accumulation of micro-damage to collagen fibrils in the tendons arising due to repeated stretching and contraction of the tendon during the daily training on the woodchip and uphill tracks with deeper cushion layer of these tracks. To study these matters from the biomechanical view point, we measured the modulus of elasticity (a qualitative indicator of the tendon) and the cross sectional area (an indicator of the thickness), and analyzed their relationship with exercise history. As a result of simple regression analysis, the modulus of elasticity was significantly higher when the career days, total career distance, number of layups in career, and total layup time were higher, but was significantly lower when the frequency of works during the entire career was high [44]. In addition, given that some 1,500 of the JRA horses are diagnosed as having bone fractures in any given year [35], the effects of tendonitis are quite significant. There were two periods in which the number of tendonitis cases rose noticeably (Fig. 3) [35]. These were from 1989 to 1991 (from 1,003 to 1,155 horses) and from 1992 to 1994 (1,145 to 1,372 horses).
horses). We searched for possible changes in the environment at training centers at those times, and found that changes of the training protocols in time trials, the construction of woodchip tracks, the construction and extension of uphill courses, and the popularization of diagnostic ultrasound could all be correlated with the increase in the numbers of tendonitis cases diagnosed. The mean incidences of tendonitis and catastrophic ruptures of tendons and ligaments from 1992 to 1997 per total number of horses registered with the JRA were 11.31 ± 0.65% (7,321/64,787) and 0.07 ± 0.02% (44/64,747), respectively (Table 1) [35]. The Occurrence of tendonitis as a catastrophic injury leading to direct euthanasia was 8 of 48,000 horses raced at Nakayama and Tokyo racecourses during the period 1992–1995 (0.017%). All 8 horses had a previous history of injury in the locomotor apparatus with one of the horses having a previous history of tendonitis in the same leg that later experienced a catastrophic injury and euthanasia. All horses started in races numbered 5 to 10. Seven had 1–5 wins. There was also a tendency that catastrophic injuries occurred more when the jockey was of low ranking (Seven of 8 raced on dirt and 6 of 8 in a jockey with a low ranking). The proportion of deaths attributable to tendon rupture or damage during training in the period 2000–2001 varied with the types of tracks: dirt track=0.0006% (3/472,993), woodchip track=0.0000% (0/226,833 runners), uphill track=0.0004% (1/284,211 runners) and turf track=0.0000% (0/5,204 runners) at Miho Training Center; dirt track=0.0012% (2/170,659 runners), woodchip track=0.00165 (84/249,550 runners), uphill track=0.0002% (1/401,411 runners) and turf track=0.0000% (0/4,552 runners) at Ritto Training Center. The rate of euthanasia because of fractures from racing at Japan Racing Association (JRA) racecourses 1985–1994 was 0.06%. Among all JRA horses, the right forelimb tended to be affected 10% to 20% more frequently than the left, even though in Japan racehorses train and race both clockwise and anticlockwise (Fig. 4) [35]. The increasing incidence of tendonitis with age is probably related to the arduous nature of the selection process for continued racing, as well as to age-related weakening of the tendons (Fig. 5) [35]. Of the horses affected with tendonitis in 1997, 64.5% were male, 32.6% female, and 2.9% geldings (Fig. 6) [35]. Because many fillies retire earlier than

Table 1. The mean incidences of tendonitis and catastrophic ruptures of tendons and ligaments from 1992 to 1997

<table>
<thead>
<tr>
<th></th>
<th>Tendonitis</th>
<th>Catastrophic Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11.31 ± 0.65% (7,321/64,787)*</td>
<td>0.07 ± 0.02% (44/64,747)*</td>
</tr>
</tbody>
</table>

*Parentheses indicate the number of affected horses per horses registered to JRA.

Fig. 3. Relationship between the construction of woodchip tracks and uphill courses and the rise in the number of horses affected by tendonitis.

![Graph](image)
colts and geldings, we studied the incidence of tendonitis in 3-years-olds, which were not of retirement age. In this group, 66.6% of affected horses were colts and 34.0% were fillies. In 1997, of the actual number of starters, the ratio of colts to fillies was 59.7% to 40.2%, leading to speculation that the incidence of tendonitis in colts was slightly higher. Why would this be so? The answer may lie in the fact that colts have more speed, that more time is required for conditioning and conformation, or that the differences of the incidence of tendonitis between males and females may represent differences in tendon fiber’s metabolism or responsiveness of mechanoreceptors in the tendon to exercise between the sexes as seen in orthopedic disorders in human [13] and Thoroughbred racehorses [54, 55]. A comparison of body weights revealed interesting results when tendonitis-affected horses were compared with unaffected horses [35]. Fig. 7 compares the weight distribution during racing in tendonitis-affected horses and unaffected horses. The mean body weight of affected horses was 477.8 kg for colts and 460.0 kg for fillies; affected colts were 17.8 kg heavier and fillies 12 kg heavier than unaffected horses of their respective sexes. These were statistically significant differences, that is, the probability level exceeded 95% (p<0.05). However, it is still not understood whether this indicates that only horses with a particular conformation were susceptible to tendonitis or whether heavier horses were susceptible

Fig. 4. Comparison of affected legs with tendonitis at the Ritto Training Center.

Fig. 5. Incidence of tendonitis by age from 1992 to 1997.

Fig. 6. Gender ratio in affected horses with tendonitis.
to tendonitis. Whereas nothing can be done to rectify inborn conformation faults, it is best to play it safe by paying close attention to proper conditioning of the unaffected heavier horses.

To clarify further the relationship between tendonitis and the types of training courses, a retrospective comparison was made of affected horses (52 horses at the Miho Training Center, 76 at the Ritto Training Center) and healthy ones (175 at Miho and 180 at Ritto) during daily training and trials (conducted 3 or 4 days before the major races). The run times of these horses were also compared. In trials at the Miho Training Center, affected horses were found to have run less frequently on woodchip tracks than unaffected horses. At the Ritto Training Center, it was notable that the affected horses had trained more on dirt tracks than had the healthy horses. Also, in trials at the Ritto Training Center, the affected horses had run less frequently on woodchip courses than had the healthy ones, and so were more accustomed to running on dirt [35].

In terms of run time, because only a small number of effective samples was obtained at Miho Training Center, only the data obtained at Ritto Training Center were analyzed statistically. The run times on the woodchip track of horses that later become afflicted with tendonitis were significantly faster than those of healthy horses, and they also ran faster over the uphill course (Table 2) [35]. From the survey of the mean run times for the final three furlongs at trial in Grade 1 races entry racehorses over a period of 11 years, that is, from 1987 to 1997, it was found that the use of woodchip tracks and uphill tracks for training had increased, and that mean times for the final 3 furlongs of time trials had improved by 0.3 s on dirt, 2.1 s on turf, and 0.5 s on woodchips (Table 3) [35]. The run times on the woodchip track of horses that later became afflicted with tendonitis were significantly faster than those of healthy horses, and they also ran faster over the uphill course. These findings suggest that subjecting horses to higher speeds during training might be associated with greater risk for the development of tendonitis.

### The hoof and tendonitis

As the saying goes “No hoof, No horse”. The importance of the hoof in training horses has been

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**Table 2.** The mean run times of training in horses with tendinitis and healthy horses*

<table>
<thead>
<tr>
<th>Course</th>
<th>No. of Horses</th>
<th>Woodchip</th>
<th>Uphill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horses that later become afflicted with tendonitis</td>
<td>68</td>
<td>16.7 ± 2.4 sec</td>
<td>15.8 ± 3.2 sec</td>
</tr>
<tr>
<td>Healthy Horses</td>
<td>169</td>
<td>17.8 ± 1.5 sec</td>
<td>17.0 ± 1.8 sec</td>
</tr>
<tr>
<td>t-test</td>
<td>P&lt;0.037</td>
<td>P&lt;0.059</td>
<td></td>
</tr>
</tbody>
</table>

*Ritto training center.

**Table 3.** The mean run times for the final 3 furlongs at trials (Grade 1 entry racehorse)*

<table>
<thead>
<tr>
<th>Year course</th>
<th>Dirt course</th>
<th>Turf course</th>
<th>Woodchip course</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>38.98 sec (n=154)</td>
<td>36.14 sec (n=18)</td>
<td>39.68 sec (n=9)</td>
</tr>
<tr>
<td>1997</td>
<td>38.72 sec (n=14)</td>
<td>34.20 sec (n=12)</td>
<td>38.23 sec (n=192)</td>
</tr>
</tbody>
</table>

*Ritto training center.
discussed for a long time. The hoof is not only an important organ in sustaining the life of the horse as a soliped, but also an important organ for high-speed running.

The hoof has a peculiar shape. It was adapted from the soliped’s physiology and biomechanics during the process of evolution. It has long been known that a long toe and low heel is one of the primary factors that makes a horse susceptible to tendonitis. However, it is not known how hoofs of different shapes affect the racehorse’s biomechanics and athletic performance.

As part of a shoeing study, research has been conducted on the relationships among shapes of hoofs, malfunctions of the phalangeal joints, and standing conformation. For details, see “American Farriers Journal” May/June 1998, pp. 74–76 [45].

How are hoof shape and standing conformation related to tendonitis?

It was compared the healthy foot and the foot with tendonitis (inflamed SDFT) in radiographs taken from three directions (dorsally, laterally, and frontally). The distances from a set reference point to the hoof wall and to the coffin bone were measured (Fig. 8).

- From a lateral view, the distance from the reference point to the front of the hoof was long, as was the distance from the reference point to the rear of the hoof with tendonitis.
- From a frontal view; the angle formed by the inside and outside of the hoof wall was small, and the wall was bent upward.
- From a dorsal view, the inside and outside of the basilar margin were overhung in a base-wide toe-in position, and the inside and outside of the heel were unequal.

According to these data, racehorses that suffer from tendonitis tend to have irregular hoof shapes, such as low heels (Lh), long toes (Lt), or under-run heels (Uh). Also, the base-wide toe-in position occurs frequently in these horses. We assume that this condition is similar to the spiral deformity of lower leg, in which the fetlock is internally rotated.

What are the risks related to irregular hoof shape?

In Japan, Uh is regarded as a genetic problem and has not been considered in relation to biomechanical problems. However, in Europe, the risks of Uh have attracted attention, and it is very common to adjust the problem during shoeing.

In some racing circles, people believe that the presence of a long tip on the hoof allows for longer strides and increases speed. However, our preliminary experiment, in which we artificially created Lt, indicated that Lt did not give a longer stride and in fact overburdened the leg [45].

The base-wide toe-in position with unevenness of the outside or inside of the heel and Uh creates a delay when the entire ground surface of the hoof is placed on the ground. The break-over of the hoof with Lt takes time. In Uh, for example, when a heel is lowered by forward shifting, mechanical instability is generated when a load is applied, adding significant stress to the flexor tendons. The longer toe requires the flexor tendons to take a greater load to enable the hoof to break over.

Can tendonitis be prevented by shoeing treatment?

In shoeing racehorses it is very important to understand irregular-shaped hoofs and their relationship to conformation. To observe this relationship, objective means, such as radiographs taken in three planes, should be used.

Uh is seen in young horses. When Uh occurs with incorrect standing conformation and/or offset knee, close attention should be paid and any Lt with Lh and Uh should be re-shaped by trimming and shoeing. If the condition is serious, a four-point trim should be done. When the horse is forced to rest when suffering from tendonitis, it is important to correct any irregular shape of the hoof, to make a complete angulus parietalis, and to trim the tip of the hoof and the longitudinal length of ground surface of the hoof to move the break-over point backward.

Moreover, the use of egg-bar shoes stabilizes hoof landing, reduces the burden on the SDFT, and means that the tip of the hoof is trimmed to fit the shape of the shoe. By this process, irregular hoof shapes are
corrected, and the break-over of the hoof becomes smoother.

**Ultrasonographic diagnostic criteria**

*Can diagnostic criteria be unified by using ultrasound diagnosis?*

Recently, ultrasound diagnosis has been widely used to diagnose tendonitis. From a morphological viewpoint, the presence of an anechoic area in ultrasonography has proved to be an indicator of collagen deposition in collagenase-induced tendonitis [25, 38, 43]. With this method it is now possible to ascertain the internal anatomy of the tendon; this was difficult in the past with only tactile or visual means. This means not only that there has been improved progress in diagnostic capability, but also that standard criteria can be applied to diagnostic staging, staging of healing, assessment of healing techniques, and new research. At JRA equine clinics, ultrasound diagnosis is already being used for diagnosis of tendonitis, and this diagnosis is based on diagnostic criteria widely accepted in the United States [8]. These criteria evaluate totally the status of tendons by visual information. The superficial flexor tendon is divided into 7 sections (4 cm each) from the carpus to the fetlock joint. If the diagnostic criteria used by all veterinary surgeons who are using ultrasound diagnosis can be unified, we can expect to simplify the diagnostic information and the accumulation of information. However, there are still not enough reports that have documented the use of diagnostic criteria for formulating an accurate prognosis, optimum treatment, and the diagnosis of tendonitis at an early stage. This is one of the challenges that the Committee will undertake.

*What are the significant clinical and ultrasound imaging parameters for diagnosing tendonitis?*

To determine the clinical and sonographic parameters that are useful for prognostic evaluation, principal component analysis was used on data from 146 tendonitis cases to assess the diagnostic utility of 11 clinical and ultrasonographic parameters: swelling; heat; pain; lameness at walk; lameness at trot; MIZ-SA (cross-sectional area (csa) of the tendon at the maximum injury zone); MIZ-HYP% (total lesion csa (hypoechoic fiber tracts) in the maximum injury zone); T-SA (sum of the cross-sectional areas of the SDFT in all zones, normal or abnormal - in the forelimb, this includes 7 measurement zones); T-HYP (sum of all lesion casas (hypoechoic fiber tracts at all levels)); %T-HYP (total percentage of hypoechoic fiber tracts); and echogenicity (graded from 1 to 4 as defined by Genovase et al.) [8]. The results indicated that the statistically significant diagnostic parameters or parameters indicating the extent and severity of tendonitis were MIZ-HYP%, MIZ-SA, T-HYP, T-SA, and %T-HYP (Fig. 9). The analysis also indicated that clinical observation did not adequately indicate the extent and degree of tendonitis [28].

*How are ultrasonically detected lesions of tendonitis and the prognosis of the condition related?*

Based on imaging data from ultrasound diagnosis, the lesions of tendonitis can be grouped into the following three types: 1) Type A core lesion in the cross-section of the SDFT bundle; 2) Type B peripheral or border lesion situated dorsally, palmarly, medially, or laterally in the rims and margins of the transverse section of the SDFT bundle; 3) Type C diffuse lesion that is hypoehcogenic, giving a mottled appearance to the internal architecture of the SDFT bundle. A chi-squared statistical analysis of these three types of lesions and their subsequent outcomes indicated that the likelihood of horses making a comeback with Type A or B lesions was low, while that of horses with Type C lesions was high (Table 4) [5].

*What does ultrasound imaging reveal of the prognosis for tendonitis cases?*

There are not enough reports evaluating diagnostic criteria in relation to prognosis and the presumption of an adequate treatment period. This is one of the challenges that the JRA has undertaken to meet. We examined 105 horses that entered the JTA Hot Springs Sanatorium in the 6 y from 1993 to 1998 with ultrasonically diagnosed core lesions. A follow-up survey was made to study whether or not the horses returned to racing. At the time of entry into the sanatorium, the extent of the core lesion injury was calculated as MIZ-HYP%, that is, total lesion cross-sectional area (hypoechoic fiber tracks) in the maximum injury zone. The rehabilitation methods employed were those developed by C. Gillis [10]. The horses were classified into a group that returned to racing and a group that was unable to do so. There was a significant relationship between the extent of the core lesion of tendonitis, as indicated by MIZ-HYP%,
1. Swelling
2. Heat
3. Pain
4. Lameness at walk and trot

5. MIZ-SA
The cross-sectional surface area (mm) of the tendon at the maximum injury zone in mm.

6. MIZ-HYP
The total lesion area (hypoechogenic fiber tracts) in the maximum injury zone in mm.

7. MIZ-FAS
The fiber alignment score at the maximum injury zone. Fiber alignment is graded independently of tendon echogenicity. If the fiber alignment in the "target" zone has 70-100% parallel fiber arrangement, it is scored as 0. Fiber alignment of 51-75% is scored 1. Fiber alignment of 26-50% is scored 2. Fiber alignment of 0-25% is scored 3.

8. T-SA
The sum of the cross-sectional areas of the SDFT in all zones (normal or abnormal). In the forelimb, we include 7 measurement zones (a, b, c, d, e, f, g).

9. T-HYP
This is 7 evaluations of the SDFT throughout 25-27 cm of tendon distal to the base of the accessory carpal bone (DACB).

10. T-FAS
The sum of the fiber alignment scores of all levels.

11. %T-HYP
The total percent of hypoechogenic fiber tracts.

Fig. 9. Clinical and sonographic parameters for prognostic evaluation.

Table 4. Relationship between lesion type and return to racing

<table>
<thead>
<tr>
<th>Lesion Type</th>
<th>Return to Race (%)</th>
<th>Reoccurrence of Tendinitis (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core type (N=80)</td>
<td>37.5%</td>
<td>43.3%</td>
</tr>
<tr>
<td>Border type (N=30)</td>
<td>17.09%</td>
<td>* 33.33%</td>
</tr>
<tr>
<td>Diffuse type (N=29)</td>
<td>79.03%</td>
<td>* 16.13%</td>
</tr>
</tbody>
</table>

*Statistically significant; The significance of difference of the mean was assessed using Chi-Square Test.

![Fig. 10](image)

and the possibility of return to racing: that is, the likelihood of horses making a comeback with a core lesion of 17.3 ± 10.6%, as indicated by MIZ-HYP%, was high, while that of horses with a core lesion of 25.6 ± 15.2% was low (Fig. 10). Linear regression analysis indicated a positive correlation between the MIZ-HYP% and the duration of the lay-up: length of resting period (months) = 0.161 × (MIZ-HYP%) + 3.479, p<0.05, r=0.581 (Fig. 11). The duration of the lay-up in months had a slope of 0.16 times the MIZ-HYP%. According to this equation, it is possible to estimate the required duration of the lay-up for tendonitis. However, as the correlation coefficient was only 0.8, it is necessary to supplement this relationship with other parameters.

**Can ultrasonography be useful for detecting subtle changes that precede severe tendon injuries?**

To reduce the treatment period and allow an early

![Fig. 9](image)
return to racing, we need a method to diagnose tendonitis in its early stages. We tracked 26 racehorses that had swollen front leg tendons but had no abnormalities indicating tendonitis on diagnostic ultrasound. The cross-sectional areas of the tendons in the affected (A) legs and the non-affected (N) opposite legs were measured, and their ratios (A/N) calculated. These horses continued training, and were eventually defined as two groups: those that developed ultrasonographically discernible tendonitis, and those that did not. A significant difference in A/N was observed between the groups of horses. Horses that developed tendonitis lesions tended to have an A/N > 1.2 in their prior ultrasound images, whereas in those that did not develop tendonitis the A/N tended to be smaller (Fig. 12) [21]. Therefore, we suggested that horses whose front leg tendons were swollen to more than 20% larger than normal cross-sectional areas of the tendons had a high likelihood of developing ultrasonographic evidence of tendonitis.

It is well known that magnetic resonance imaging (MRI) has an advantages of excellent inherent soft tissue contrast. But MRI has limited its applications in equine practice due to high system cost, and the requirement of general anesthesia. In the preliminary examinations, to evaluate the high potential of MRI as a diagnostic imaging tool for detecting subtle tendon injuries, antemortem evaluation of equine flexor tendons using MR was performed [22]. As a result, it was possible by this method to take antemortem MR images of equine tendon that distinguished features as well as postmortem images described in previous studies [47]. Further experimentation is needed in the detection of subtle tendon injuries.

**Do lesions that predispose to tendonitis exist?**

The opinions of researchers have been divided as to whether predisposing lesions exist for tendonitis [12, 37, 48]. As mentioned below, we obtained research results that support the opinion that sub-clinical predisposing lesions for the onset of tendonitis exist [23]. Two Thoroughbred racehorses with slight swelling, inflammation, and enlarged cross-sectional areas of their SDFT were dissected. Although no signs of tendonitis had been found on ultrasonography, discolored regions that stained dark brown were observed in the central regions of the SDFT bundles in both cases (Fig. 13) [23]. Histologically, bleeding and edema were observed in the peritendineum (endotendineum or epitendineum; loose connective tissue containing blood vessels and nerves). In addition, there was degeneration of the tendon fibers around the discolored regions. Occasionally, there was hyperplasia of the minute vessels in the peritendineum. Compared with normal tendons, affected tendons had
enlarged cross-sectional areas and significant signals on proton-spin echo imaging using nuclear magnetic resonance (NMR) microscopy. The signals appeared distinctively in the region of the peritendineum. Recent studies have shown that immunopositive cells for four cytokine antibodies (interleukin-1α, interleukin-1β, tumor necrosis factor-α and interferon-γ) were localized in peritendineum, vascular endothelium and tenocytes near the peritendineum in the inflamed tendons [15]. In vitro, we examined the effects of transforming growth factor-β1, β2 and β3(TGF-β) on the expression of mRNA for αI (XII) and αI (XII) collagens in equine tenocyte cultures by using the ribonuclease protection assay (RPA). From this experiment, it was suggested that TGF-β promoted collagen fibrogenesis in the tenocyte cultures [2]. It is well known cytokines act in various manners: either to activate or depress immune cells, cause degeneration of tissues, promote and induce cellular differentiation, and induce secretion of cytokines by other cells. These findings suggest that the discolored lesions centered on the transverse sections in the SDFT bundles were related to edema that may have originally developed from microvascular alterations in the peritendoneum, resulting in mechanical weakening of the discolored regions of the SDFT bundles. These circulatory disturbances could have been primary or inciting lesions contributing to the onset of tendonitis, or alternatively secondary changes associated with the progression of the tendonitis. As mentioned earlier, it was found that if the cross-sectional area of a tendon was swollen, there was a significant likelihood of tendonitis developing. In such cases, there would be a possibility that the flexor tendons had structural abnormalities that could act as predisposing factors.

The location of greatest occurrence of tendon injury is the mid-metacarpal region of SDFT. The mechanism is not clear. To provide the need to explore the functional implications, we preliminary observed the distribution of a three dimensional network of the cell processes of tendon cells, connexin and a component of gap junctions of the tendon cells in the tendon bundle in the direction of the longitudinal axis. Between the mid-metacarpal and metacarpophalangeal regions, there was a tendency of the difference of these index which suggests the regional difference of compressional or tensile forces applied to the tendon cell [20, 24].

**Therapeutic regimens**

The goals of therapy for tendonitis are to decrease inflammation, minimize the formation of scar tissue, and promote restoration of normal tendon structure and function. Despite the frequency of tendonitis and the range of treatments currently used, there have been no satisfactory controlled trials to determine the efficacy of available treatments. Therefore, in spite of our increased understanding of basic tendon biology, the availability of new medical treatments, and the ability to monitor healing with ultrasonography, there is no evidence that the prognosis for tendonitis has improved. As an emergency treatment, cold (with either ice or iced water hydrotherapy) should be applied. Afterward, there is a wide choice of surgical treatments such as stabbing, splitting of the injured tendon and section of the accessory ligament of the SDFT, and medical treatments such as the use of systemic or intralesional polysulphated glycosaminoglycan (PSGMG) [26, 41], beta-aminoopropionitrile (BAPN-F) [9, 39], or hyaluronic acid [1, 6, 7, 42].

**Is BAPN-F as non-surgical therapy a wonder drug?**

Currently, the use of BAPN-F is gaining popularity [8, 39]. BAPN-F has been evaluated as a scar-remodeling drug. It inhibits the enzyme lysyl oxidase in scars, thus blocking lysine deamination, an important first step in the formation of strong scar collagen cross-linking [3, 11]. The cross-linking between scar collagen molecules formed after tendon injury results in a decrease in mechanical strength of the healed tendon, possibly resulting in the high incidence of recurrence of tendonitis [11]. Therefore, the use of BAPN-F can improve the arrangement of collagen fibrils by briefly interrupting newly formed scar collagen and delaying the cross-linking. In other words, BAPN-F is considered effective in reducing the production of undeveloped immature net-patterned collagen fibrils, which occur at an early stage of tendon recovery. It also promotes the construction of collagen fibrils in a vertical direction if it is administered in conjunction with appropriate rehabilitation [10]. However, because of this mode of action, one cannot expect to reduce the duration of the healing period with BAPN-F. Administration 1 to 3 months after injury, when enzyme function is active, is most beneficial. After this time it is hard to obtain the desired result. According to our preliminary survey
results, the use of BAPN-F medication, as compared with placebo, was more effective in the alignment of tendon fibers [unpublished data]. However, there was no reduction in the length of the required treatment period [unpublished data]. The efficacy of BAPN-F has also been evaluated morphologically and biomechanically in treating injuries to the SDFT in horses [52]. BAPN-F was used to treat collagenase-induced tendonitis [6, 40, 48, 49]. BAPN-F treated tendons had many thin-diameter collagen fibrils that might have been induced by the inhibition of collagen cross-linking and a decrease in the collagen assembly, reflecting a more regular orientation than that seen in untreated collagenase-induced tendonitis [52]. The efficacy of BAPN-F has also been evaluated morphologically and biomechanically in treating injuries to the SDFT in horses [52]. BAPN-F was used to treat collagenase-induced tendonitis [6, 40, 48, 49]. BAPN-F treated tendons had many thin-diameter collagen fibrils that might have been induced by the inhibition of collagen cross-linking and a decrease in the collagen assembly, reflecting a more regular orientation than that seen in untreated collagenase-induced tendonitis [52]. The efficacy of BAPN-F has also been evaluated morphologically and biomechanically in treating injuries to the SDFT in horses [52]. BAPN-F was used to treat collagenase-induced tendonitis [6, 40, 48, 49]. BAPN-F treated tendons had many thin-diameter collagen fibrils that might have been induced by the inhibition of collagen cross-linking and a decrease in the collagen assembly, reflecting a more regular orientation than that seen in untreated collagenase-induced tendonitis [52].

Is section of the accessory ligament of the SDFT an effective surgical therapy?

Section of the accessory ligament of the SDFT is a surgical treatment for tendonitis. Proximally, most of the superficial flexor tendon becomes superficial flexor muscle. However, a portion of the tendon becomes a ligamentous structure and attaches to the palmar aspect of the radius. The surgeon must consider three parts, the tendinous portion, the ligamentous portion, and the muscular portion, as one weight-bearing structure. Essentially, the purpose of the surgery is to increase tendon flexibility by removing the inflexible ligament and, thus, to decrease the ratio of load to muscle when weight is placed on the joint. As a result, it is surmised and expected that part of the tendon’s burden is reduced to protect the recovery of the tendon [14]. However, researchers have two different opinions on the results of this operation. Although this information is anecdotal, the effectiveness of the operation has recently been called into question because racehorses that have undergone it appear to show increased susceptibility to suspensory desmitis.

How effective is cold hydrotherapy?

Exercise-induced hyperthermia in the centers of tendon bundles in athletic horses is a well-known phenomenon that may contribute to tendon injuries [50]. To confirm this relationship, we examined the existing method reported by Wilson and Goodship [50] for measuring the temperature of the centers of tendon bundles in Thoroughbred horses, and confirmed that the bundles reached over 42°C after a run. We also found that when tenocytes isolated from the SDFT of a Thoroughbred horse were cultured, their survival rate decreases after 1 hr of exposure to a temperature of 43°C [53]. Furthermore, we conducted a morphological examination concerning histological changes in the tendon caused by the treatment of
cooled and warmed after exercise. From this experiment, it was suggested that the damage to tenocytes and the increase in small diameter collagen fibrils observed in the warming limb possibly predispose to subclinical lesions of SDFT injury [19].

Thus, in an effort to prevent tendonitis, we used thermographic examination to compare the efficacy of various cold modalities as daily therapies for cooling off horses’ lower limbs. We used crushed ice, tap water, isopropyl alcohol casts, or cooling gel to cool off the legs after horses ran. Between crushed ice and tap water, there were no remarkable differences in the time it took to cool down, or in the cooling temperature. The other methods were not sufficiently effective to cool the lower limbs immediately after exercise [18].

Conclusion

Finally, we will explain the future direction of our research. The tendon is a highly differentiated tissue from an embryological perspective, and it has a low metabolic rate. The reason for this low metabolic rate is that the collagen fibrils in the tendon are made by protein that comes out of cells. Compared with protein in the cells, this extracellular protein has a low metabolic rate. Once tendonitis occurs, this characteristic makes it difficult to regenerate normal tissue, and thus it takes a long time to heal. In other words, perfect regeneration after injury is unlikely to occur, and irreversible structural alteration is unlikely to be significantly altered by any therapy. Therefore, research on tendonitis has gradually shifted from cure to prevention, such as the optimization of training regimens (distance, speed, frequency, etc.) to create a strong tendon, as well as the determination of the proper time to start training. A joint research project is currently being carried out by the JRA and a group at the Royal Veterinary College in London. This research tests the hypothesis that conditioning of tendons from a very early age will improve biological performance and reduce the incidence of injury. We hope that a new training regimen based on scientific knowledge will be developed.

Areas for current and future study

1) Formulation of a training program based on present scientific knowledge for evaluation of the conditioning of tendons in commercially trained and research horses.

It was hypothesized that if the number of tendon fibers increases in response to functional demand over a short period of time during development from the intra-uterine period to after birth, as occurs in muscle fibers, then an adequate amount of exercise stimulation to the tendons of neonatal or young foals may reinforce their tendons, thereby reducing the likelihood that they will not be affected by tendonitis when fully grown as racehorses. Joint research is currently being carried out in conjunction with Professor A. E. Goodship, Dr. R. K. W. Smith and Dr. H. L. Birch of the Royal Veterinary College, University of London, to test this hypothesis.

2) Continuation of a search for a tendon-specific marker of tendon degeneration or early tendonitis.

3) Development of a gene therapy (vaccination) method that reacts only with the target cells of tendons (collaborative research with Professor M. Yamaguchi of Ohio State University).

4) Structural analysis of the horse superficial digital flexor myotendinous junction and exploration of mechanoreceptors, with the aim of clarifying the roles of sensory and motor neurons such as the neurotendinal spindles and Vater-Pacini corpuscles as reflex connections from muscle to tendon at the site of the musculotendinous junction.

5) To clarify the effect of exercise on ultrastructure of slow and fast skeletal muscle tendon fiber in SDFT.

6) Research into the possibility of using hyperbaric oxygen therapy.

To examine whether intermittent exposure to hyperbaric oxygen (HBO) is effective in enhancing collagen synthesis and reducing the time needed for healing tendonitis, Thoroughbred horses will receive daily HBO sessions, at 2.5 atmospheres absolute and of 2 hr duration, in an equine HBO therapy chamber.

7) Development of a rehabilitation program for reducing the treatment period for tendonitis and setting up horses for early return to racing.

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