Influence of track surface on the equine superficial digital flexor tendon loading in two horses at high speed trot


UMR INRA-ENVA 957 de Biomécanique et Pathologie Locomotrice du Cheval, Ecole Vétérinaire d’Alfort, 7 avenue du Général de Gaulle, 94704 Maisons-Alfort cedex, France.

Keywords: horse; tendon load; track; high speed; ultrasound

Summary

Reasons for performing study: Although track surfaces are a risk factor of tendon injuries, their effects on tendon loading at high speed are unknown. Using a noninvasive ultrasonic technique, it is now possible to evaluate the forces in the superficial digital flexor tendon (SDFT) in exercise conditions.

Objectives: To compare the effects of an all-weather waxed track (W) vs. a crushed sand track (S), on the SDFT loading in the trotter horse at high speed.

Methods: Two trotter horses were equipped with the ultrasound device (1 MHz ultrasound probe, fixed on the palmar metacarpal area of the right forelimb). For each trial, data acquisition was made at 400 Hz and 10 consecutive strides were analysed. In each session, the 2 track surfaces were tested in a straight line. The speed was imposed at 10 ms strides were analysed. In each session, the 2 track surfaces were tested in a straight line. The speed was imposed at 10 ms and recorded. The right forelimb was also equipped with a dynamometric horseshoe and skin markers. The horse was filmed with a high-speed camera (600 Hz); all recordings were synchronised. Statistical differences were tested using the GLM procedure (SAS; P<0.05).

Results: Maximal tendon force was significantly lower on W compared with S. In addition to maximal force peaks around mid-stance, earlier peaks were observed, more pronounced on S than on W, at about 13% (Horse 2) and 30% (both horses) of the stance phase. Comparison with kinematic data revealed that these early peaks were accompanied by plateaux in the fetlock angle-time chart. For high tendon forces, the tendon maximal loading rate was significantly lower on W than on S.

Conclusions and potential clinical relevance: The all-weather waxed track appears to induce a lesser and more gradual SDFT loading than crushed sand. The SDFT loading pattern at high speed trot suggests proximal interphalangeal joint movements during limb loading.

Introduction

Tendon lesions are the most frequent nonfatal injuries reported in racehorses (Williams et al. 2001). Despite numerous and various therapeutic approaches, the medical and economic incidence of these lesions is still very high. In this context, prevention appears all the more crucial. Among the possible risk factors of racing or training injuries, ground surface quality has long been incriminated and its influence on the incidence of musculoskeletal injuries, especially tendon injuries, has been demonstrated (Bailey et al. 1998; Williams et al. 2001).

Beside epidemiological studies, investigation of the biomechanical effects of ground surfaces on the equine tendons has been very limited so far, mainly for technological reasons. Indeed, the only direct methods of tendon strain or force measurement available until recently were invasive (Lochner et al. 1980; Stephens et al. 1989; Riemersma et al. 1996; Takahashi et al. 2006). Beyond ethical considerations, these techniques are difficult to use, especially under training or racing conditions (Ravary et al. 2004).

An ultrasonic technique of tendon force measurement, based on the measurement of speed of sound (SOS) in the tendon, has been developed (Pourcelot et al. 2005). The reproducibility of the SOS measurements in a given subject has been demonstrated and this method has been applied to the evaluation of the effects of corrective shoeings on the superficial digital flexor tendon (SDFT) loading at the walk and slow trot (Crevier-Denoix et al. 2004).

The objective of the present study was to demonstrate the feasibility of using the ultrasound technique at high speed in the harness trotter horse, and to apply it to compare the effects of different ground surfaces on the SDFT loading in the training conditions. Given the increasing interest in synthetic track surfaces in the horse industry, comparison is made between an all-weather waxed track and a traditional crushed sand track.

Materials and methods

Two trotter horses (Horse 1: 16-year-old gelding, 560 kg; Horse 2: 3-year-old filly, 540 kg) were equipped with the ultrasound device (Pourcelot et al. 2005): a 1 MHz ultrasound probe (40 g), composed of 4 transducers (one acting as an emitter, the other 3 as receivers), was fixed on the skin of the palmar metacarpal area of the right forelimb by means of an adapted boot (Fig 1A); this probe was connected to an electronic module placed on the sulky.

For each trial, data acquisition was made at 400 Hz and 10 consecutive strides were analysed. Two sessions (on 2 different days) were performed with Horse 1 and one session with Horse 2; in each of them, 2 different track surfaces of the same training centre for trotters, all-weather waxed (W) and crushed sand (S),

*Author to whom correspondence should be addressed.

[Paper received for publication 00.00.00; Accepted 00.00.00]
were tested in a straight line and repeated alternatively 3 times in a random sequence. The speed of the trot was imposed at 10 ms, controlled by the driver, and recorded. The right foot was also equipped with a 3D dynamometric horseshoe (Robin et al. 2009), and 7 reflective markers were placed on the right forelimb (Fig 1B). The horse was filmed with a high-speed camera (600 Hz); all recordings were synchronised. The SOS was measured (Pourcelot et al. 2005), then converted to tendon force using experimental data of each session.

A tendon force-SOS relationship was determined for each session using mid-stance phase SOS data and simultaneously recorded vertical ground reaction force (GRF), and considering the proportionality demonstrated ex vivo for the mid-stance phase by Jerbi et al. (2000) between SDFT (traction) force and GRF (average ratio between both forces: 0.76). The tendon force-SOS relationship (unique for each experimental session) was then used to convert SOS data of all tests of the corresponding session, i.e. obtained on both track surfaces, in tendon force.

Data were analysed using the General Linear Model procedure (SAS Institute). The model included horse as a repeated effect, and speed as a covariate to account for the effect of speed on dependent variables. Least square mean differences were used for pair wise comparisons between surfaces (W vs. S). Significance was set at P<0.05.

Results

No significant difference in the horses’ speed was found between the 2 track surfaces (mean ± s.d. W, 10.01 ± 0.35 vs. S, 9.90 ± 0.29 m/s). Although the general pattern of the SDFT loading during the stance phase was similar in both horses (Fig 2), differences could be observed that had some correspondence in kinematics and ground reaction force charts (Fig 3). Maximal tendon force (for both horses) was significantly lower on W (6542 ± 1008 N) compared with S (7065 ± 831 N). This maximal loading was also slightly, but significantly, delayed on W compared with S (51.7 ± 7.0% of the stance phase vs. 49.5 ± 7.1%). In addition to the maximal force peaks around mid-stance, one or 2 earlier and lower force peaks were observed, occurring respectively at about 13% (Horse 2) and 30% (both horses) of the stance phase; these were more pronounced on S than on W (Fig 2). Comparison with kinematic data of each stride (Fig 3) revealed that these early peaks were accompanied by short plateaux in the fetlock angle-time chart, and for the second peak, that it occurred just after maximal interphalangeal joints flexion (decrease of the palmar angle of these joints), i.e. concomitant with the beginning of interphalangeal extension (increase of the palmar angle).

Above a tendon force corresponding to 90% of the horse’s body weight (i.e. 4944 N for Horse 1, 4768 N for Horse 2), the tendon maximal loading rate was significantly lower on W (274 ± 179 kN/s) than on S (371 ± 192 kN/s) and it occurred significantly later (36 ± 15% vs. 28 ± 11% of the stance phase duration).

![Fig 1: Experimental device. A) The ultrasonic probe, covered with acoustic gel, is inserted in an adapted (windowed) tendon boot and placed in contact with the skin of the palmar metacarpal area. B) The probe in the boot is then maintained by an elastic band and connected to an electronic module placed on the sulky. On the same forelimb, reflective markers are facing the main limb joints (shoulder, elbow, carpus, fetlock, coffin) and the foot. On each joint, the angle considered (dorsal vs. palmar) is indicated; for all joints, flexion is defined as a decrease of the angle, extension as an increase.](image)

![Fig 2: Comparison of the SDFT forces (mean curves ± s.d.) during the stance phase on the all-weather waxed (light grey) and crushed sand (dark grey) tracks. Time is expressed in % of the stance phase duration. A: Horse 1 (2 sessions); B: Horse 2 (1 session).](image)
Fig 3: Synchronised recordings of the horizontal (GRFx) and vertical (GRFz) components of the ground reaction force, SDFT force, fetlock joint (dorsal) angle and interphalangeal joints (palmar) angle of 3 different tests. On each chart, the stance phases of the successive strides of the corresponding test are superimposed. This figure illustrates the comparison between Horses 1 and 2 on a given surface (S = crushed sand track), and the comparison between surfaces (S vs. W = all-weather waxed tack) for Horse 2. Time is expressed as % of the stance phase duration.
Discussion

The present study has demonstrated that noninvasive measurement of tendon loading is now possible at high speed (training conditions) using the ultrasound technique. On average, the variability of tendon force measurement, over the 10 strides of each test was 4.18% (coefficient of variation over the stance phase). This is very close to the corresponding variability of the vertical ground reaction force, observed in the present study (3.78%).

Conversion of SOS in tendon force was based on the assumption that SDFT force is proportional to the vertical GRF around mid-stance phase, which has been established in ex vivo studies performed on isolated forelimbs (Jerbi et al. 2000), and is consistent with previous in vitro and in vivo studies (Rooney et al. 1978; McGuigan et al. 2003). The ratio between tendon force and GRF is necessarily influenced by the limb conformation of each horse, and using a unique ratio induces a systematic error in the final tendon force values. However, this error has no impact on the pattern of tendon force charts. Furthermore, since the same tendon force-SOS relationship was used for both track surfaces in each session, this method does not interfere with the differences in tendon loading observed between the 2 surfaces. Lastly, the levels of SDFT maximal forces obtained here are compatible with the few data published for horses at the trot, canter and gallop (Meershoek et al. 2002; Swanstrom et al. 2005; Butcher et al. 2007).

Beside the comparison between track surfaces, the ultrasound technique was used to obtain, for the first time, the equine SDFT loading pattern at a high speed trot. One, or 2 (Horse 2), tendon force peaks were observed around mid-stance phase, when vertical GRF, elbow flexion and fetlock extension (i.e. decrease in the dorsal angle of both joints) are maximal. This maximal SDFT loading at mid-stance was expected from previous studies using invasive devices (Stephens et al. 1989; Riemersma et al. 1996; Takahashi et al. 2006). However, the present study revealed that, in addition to these maximal peaks, the SDF force showed in both horses an earlier peak at about 30% of the stance phase, just after maximal interphalangeal joints flexion (Fig 2). This peak, which appeared more pronounced on sand than on the all-weather waxed track, corresponded with a maximal extension peak of the carpal joint, and was followed by a clear plateau in the fetlock joint extension pattern (Fig 3).

In Horse 2, the ultrasound recordings revealed another tendon force peak at about 13% of the stance phase, more distinct on S than on W (in Horse 1, this event is just marked by a discrete inflexion, Fig 2). This peak was subsequent to a phase of maximal extension rate of the fetlock joint (as visually assessed through the slope of the curve) and again, was immediately followed by a plateau in the extension phase of this joint, and a decrease in the flexion rate of the interphalangeal joints. These combined events suggest, in both cases (13% and 30% peaks), a proximal interphalangeal (PIP) joint extension movement, although no direct investigation of this joint was provided in the present study (the angle measured combines both proximal and distal interphalangeal joints).

The PIP extension could be provoked by the high tension of the SDFT, consequence of the initial high extension rates of the fetlock and carpal joints (Denoix 1994). Conversely, as a consequence of the PIP extension movement, the fetlock joint is slightly raised, as illustrated by the brief relief in the fetlock extension phase (plateaux). Kinematic data obtained using skin markers (and a fortiori a marker placed on a boot) should be considered with some caution. However, the existence of a PIP joint extension at 30% of the stance phase is consistent with previous descriptions made using invasive kinematic devices: Chateau et al. (2004) and Clayton et al. (2007) observed the beginning of the extension phase of the PIP joint at 25–34% of the stance phase at slow trot. An earlier PIP joint extension movement (after hoof stabilisation) has never been described before; it could be an individual variation in digital joint angle movements, revealed by the ultrasound technique.

In the present study, only 2 horses were tested and these first observations need to be confirmed on additional horses. Nevertheless, Figure 3 confirms that tendon force peaks measured with the ultrasound technique also had some correspondence in the evolution of the vertical (Fz) and horizontal longitudinal (Fx) components of the ground reaction force during the stance phase. This can be observed especially for the tendon force peak at 13% in Horse 2 (both with Fx and Fz), and for that at 30% in both horses (mainly with Fz). Therefore, the present study demonstrates the high sensitivity of the ultrasound technique to subtle variations of SDFT loading pattern during the stance phase, not only between conditions in a given subject but also between individuals.

According to these preliminary results, the shock-absorbing properties of the all-weather waxed track, confirmed through the accelerometric and GRF recordings also performed in the experiments (Chateau et al. 2009; Robin et al. 2009), have significant effects on the SDFT loading: this surface induces a lesser and more gradual loading, with lower and delayed peaks. These results are consistent with those obtained with the 3D dynamometric horseshoe (maximal values of the horizontal and, to a lesser extent, vertical components of the GRF, significantly lower on W than on S). The differences observed both in maximal SDFT force and loading rate are also probably correlated with differences in the kinematics of the limb joints between the 2 surfaces, especially in the first half of the stance phase.

Beside smoother digital joint angle changes in W compared with S, a higher deformability of the all-weather waxed track probably induces more penetration of the foot, especially its caudal part (heels) during limb loading, on W compared with S. This would explain both the more progressive SDFT loading, and the relative delay in the subsequent events of the stance phase, observed both in the GRF (Robin et al. 2009) and the tendon loading pattern. The evaluation of track surfaces performance was not included in this study, but as far as horses’ safety is concerned, since both maximal SDFT force and loading rate were significantly lower in the all-weather waxed track tested, it can be concluded that this surface appears safer in terms of forelimb SDFT injury risk.

Acknowledgements

The authors thank the Conseil Régional de Basse-Normandie, the Haras Nationaux and the Fonds interministériel de compétitivité des entreprises for their financial support to this project, and the Pôle de compétitivité Filière Equine for their technical assistance.

The authors also thank M. Walazyć (SECF) and the farriers of the Garde Républicaine de Paris for their contribution.

Manufacturer's address

1SAS Institute Inc., Cary, North Carolina, USA
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**Author contributions**