Biomechanical and wearability testing of novel legwear for variably limiting extension of the metacarpophalangeal joint of horses

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OBJECTIVE
To evaluate the ability of novel legwear designed to limit extension of the metacarpophalangeal joint (MCPJ) to redirect loading forces from the flexor apparatus during walk, trot, and canter on a treadmill and during unrestrained and restrained activity in a stall.

ANIMALS
6 adult horses without musculoskeletal disease.

PROCEDURES
Legwear-derived force data were recorded under 4 conditions: inactive state (unlimited legwear extension) and 3 active (restrictive) states (mild, 30° extension; moderate, 20° extension; or maximum, 10° extension). Associations between peak legwear loads and torques among legwear states and treadmill gaits and stall activities were assessed. The hair coat and skin of the forelimbs were examined for any legwear-induced adverse effects after testing.

RESULTS
During the treadmill exercises, moderate restriction of legwear extension resulted in significantly higher peak load and torque than mild restriction, and faster speeds (canter vs walk or trot and trot vs walk) yielded significantly higher peak load and torque. During in-stall activity, maximum restriction of legwear extension yielded significantly higher peak load and torque than moderate restriction. Unrestrained in-stall activity resulted in significantly higher peak load and torque than restrained activity. The legwear caused minimal adverse effects on the hair coat and skin of the forelimbs.

CONCLUSIONS AND CLINICAL RELEVANCE
Findings suggested that the legwear variably reduced peak loads on the flexor apparatus. Extension of the MCPJ may be incrementally adjusted through the legwear such that return to activity may be controlled, and controlled return to activity is crucial for rehabilitating flexor apparatus injuries. (*Am J Vet Res* 2021;82:39–47)

The horse is adapted for energetically economical locomotion, with large muscles associated with the proximal portions of the FLs to facilitate rapid FL swinging and propulsion.[1] The lighter distal (vs proximal) portion of the FL includes the flexor apparatus, a system of tendons and ligaments located principally on the limb's palmar aspect that allows highly efficient elastic energy storage and return.[1] However, the flexor apparatus must tolerate high mechanical strain[2] during weight-bearing to stabilize the MCPJ,[3] dampen impact forces,[4] and store elastic strain energy.[2,5] Indeed, mechanical strains of the flexor apparatus in horses exceed the physiologic limits of those of other species,[6-8] reflecting the specialized ability of the digital flexor tendons in horses to, for example, function close to their ultimate tensile strain,[9,10] such that they are prone to overstrain injury.[11]

Overstrain injuries of the flexor apparatus usually occur because of repetitive loading. This causes cumulative microdamage to the tendon matrix and can lead to clinical flexor tendinopathy of the tendons of the apparatus, which are often already weakened by degenerative changes.[12-15] Lesions of the flexor apparatus range from individual fiber disruption to complete rupture of a tendon or ligament; the magnitude and number of loading cycles contribute to the risk of microscopic damage and, ultimately, macroscopic tendon or ligament rupture.[16-18] Following injury, tendons and ligaments in horses are poorly regenerative, and any reparative process is slow and favors scar tissue formation.[19] The latter predisposes

ABBREVIATIONS

Active$_{max(10°)}$	Maximum legwear extension limitation (10° extension)
Active$_{mild(30°)}$	Mild legwear extension limitation (30° extension)
Active$_{mod(20°)}$	Moderate legwear extension limitation (20° extension)
FL	Forelimb
MCPJ	Metacarpophalangeal joint
η_p^2	Partial êta-squared

to reinjury, reduced mechanical performance, pain, and lameness. An optimal clinical outcome for resolution of an injury of the flexor apparatus necessitates a balance between immobilization in the immediate postinjury period and reintroduction of controlled exercise thereafter.[20]

Tendon and ligament healing are influenced by mechanical factors, and early mobilization aids repair by decreasing adhesion formation, increasing tendon strength, restoring gliding surfaces, and, at the microscopic level, increasing protein synthesis and stimulating fibroblasts.[21-24] Furthermore, physical activity can accelerate the disappearance of aberrant nerves from the tendon, reduce load-associated pain, and regulate expression of neuronal substances.[25-28] Tendon remodeling is also facilitated by weight loading, which promotes collagen synthesis and fiber cross-linking.[27,29] Exercise, however, can be damaging if applied inappropriately,[20] such as with high-impact and excessive loading.[30] Healing may be facilitated by applying an orthotic that can selectively restrict MCPJ extension during rehabilitation, recognizing that MCPJ extension while load bearing is indirectly proportional to flexor tendon and ligament strain.[31] With this approach, load on the damaged and adjacent soft tissues could be preferentially limited and then progressively increased on the basis of the patient's stage of rehabilitation.

We propose that horses with flexor apparatus injuries may benefit from the application of legwear that variably and mechanically limits MCPJ extension. Results of limited published studies[32-35] that included examination of the effects of existing legwear on MCPJ kinematics are inconclusive or contradictory. Therefore, development and validation of legwear that mechanically supports the MCPJ during equestrian sporting activities and rehabilitation are warranted.

The primary aim of the study presented here was to determine the extent to which a prototype of novel rehabilitative legwear can redirect loading forces away from the flexor apparatus, principally to the dorsal aspects of the third metacarpal (cannon) bone and proximal interphalangeal (pastern) region, during walk, trot, and canter and during unrestrained (freedom of movement) and restrained (in-hand) stall activity. The secondary aim was to assess legwear integrity and wearability for safety and comfort during these activities and examine the interaction between the body and the wearable object.

Materials and Methods

Animals

Six horses (mean [SD] age, 11.00 [5.22] years; body weight, 575.67 [61.78] kg; height, 1.64 [0.07] m) were used. Each horse was visually assessed by a veterinarian (CAK-H) for musculoskeletal soundness with the American Association of Equine Practitioners' lameness scale[36] and nuclear scintigraphy, ultra-

sonography, and radiography of the FLs to confirm the absence of preexisting musculoskeletal disease. Approval for this study was granted by the Tufts University Institutional Animal Care and Use Committee (No. G2014-13).

Prior to testing, horses were regularly trained on a high-speed treadmill[a] for a mean (SD) of 8.92 (3.51) months and were habituated to the legwear for 7.83 (3.20) months during overground (in-hand) and treadmill exercises. The horses had similar exercise regimens to reasonably standardize physical fitness.

Because each horse had a unique conformation and cadence at a walk, trot, and canter, the treadmill was set at equivalent, predetermined dimensionless speeds (V) according to the following equation:

$$V = \frac{v}{\sqrt{l_0 g}}$$

where v = speed, l_0 = height at the withers, and g = constant of gravity.[37] This allowed scaling for differences in acceleration and gravitational forces resulting from variation in horse height.[37]

Legwear

The legwear[b] was applied to the distal portion of each FL **(Figure 1)**. Each legwear piece had an upper and a lower hemicircumferential cuff that was constructed of glass-impregnated polymer and affixed to an aircraft-grade aluminum scaffold. The cuffs were connected by aluminum side bars to a hinge with a laterally positioned titanium adjustable stop, which could be manually adjusted to limit hinge range of motion and potentially MCPJ extension.

Under each cuff, an outer layer of firm polyurethane and inner layer of polymeric padding were molded to fit the legwear snugly and cushion the FL **(Figure 2)**. Each cuff abutted soft tissues associated with the dorsal, medial, and lateral aspects of the cannon region (upper cuff) and the full circumference of the pastern region (lower cuff). Importantly, the upper cuff avoided contact with the flexor apparatus. Hook-and-loop fasteners reinforced with buckled straps ensured secure and intimate contact between the padding and FL such that the activated legwear could restrict MCPJ extension while minimizing motion of the legwear relative to the limb.

The legwear in the active state was designed to limit MCPJ extension, whereas the legwear in the inactive state was designed to permit unlimited MCPJ extension. Activated legwear may be applied with mild ($active_{mild[30°]}$), moderate ($active_{mod[20°]}$), or maximal ($active_{max[10°]}$) attenuation of legwear extension. When the legwear was activated through the adjustable stop, the lower cuff engaged the immovable stop on the upper cuff to create equal and opposite force vectors occurring partway through extension of the MCPJ during FL loading **(Figure 3)**.

Engagement of the stop system (collectively includes adjustable and immovable stops) was intended to effectively create a truss between the upper (cannon region) and lower (pastern region) cuffs (Figure 3). The truss provided resistive torque against MCPJ extension without abruptly halting extension by mildly compressing the padding and permitting controlled motion of the legwear relative to the FL. Reaction loads from this resistive torque were then transmitted by the cuffs to the FL. At each end of the truss, one force element was parallel and another was perpendicular to the longitudinal axes of both the cannon and pastern regions.

Legwear testing treatments

The 4 legwear treatments assessed were the inactive state that permitted unlimited legwear extension and 3 active states ($active_{mild[30°]}$, $active_{mod[20°]}$, and $active_{max[10°]}$) that restricted legwear extension. Treatment order was randomized by use of an online application.[c]

Instrumentation

Force data were collected with a telemetric system.[d] A force sensor[e] was affixed to the loading surface of the immovable arm of the adjustable stop of the legwear to record the force exerted on the legwear. These data were wirelessly transmitted to the base unit[f] and then exported to an electronic spreadsheet[g] for calculating peak load normalized to body weight. Trigonometric transformation of peak load data yielded torque.

Study design

Force data for treadmill gaits—Prior to data collection, each horse, without legwear, completed a 20-minute warm-up on a treadmill, which consisted of a walk, trot, and canter. Force data were then recorded via telemetry while horses were exercised on a treadmill wearing the legwear on each FL in the
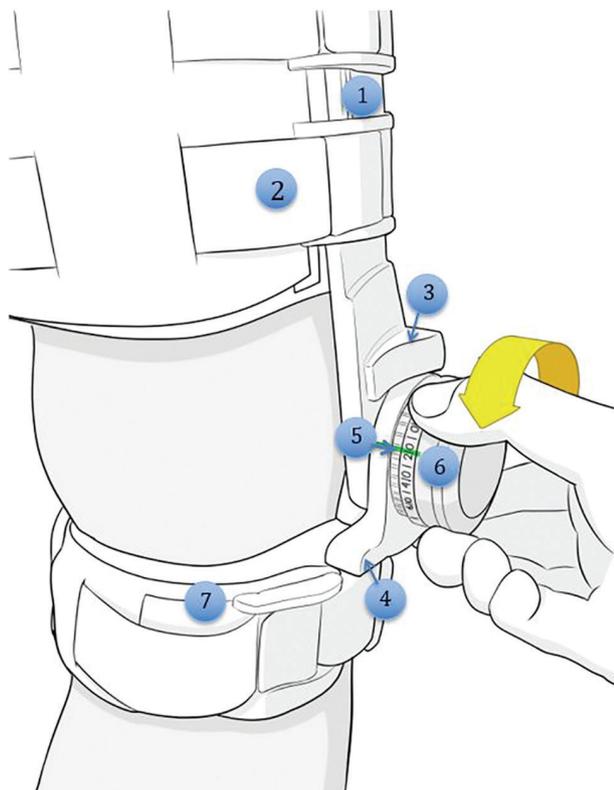
Figure 1—Drawing depicting the prototype novel legwear applied to the right FL of a horse. The MCPJ is elevated and flexed, as seen from a palmarolateral perspective. In an active state, the immovable stop variably restricts legwear motion and, hence, MCPJ extension. The operator manually adjusts the setting of the immovable stop by simultaneously lifting outward and rotating the toothed adjustable outer ring to a new setting relative to the inner ring. Magnetic attraction between the outer and inner rings helps reseat the device once the appropriate level of restraint has been selected. 1 = Upper lateral aluminum sidebar. 2 = 1 of 2 buckled straps that traverse the outer circumference of the legwear to reinforce the hook and loop–derived snug fit of the upper cuff. 3 = Immovable stop of the upper cuff. 4 = Adjustable stop of the lower cuff. 5 = Inner ring of the stop system. 6 = Moveable outer ring of the stop system with inscribed settings (in degrees). 7 = Lower cuff with single buckled strap. (Drawing used with permission by Manta Product Development Inc.)
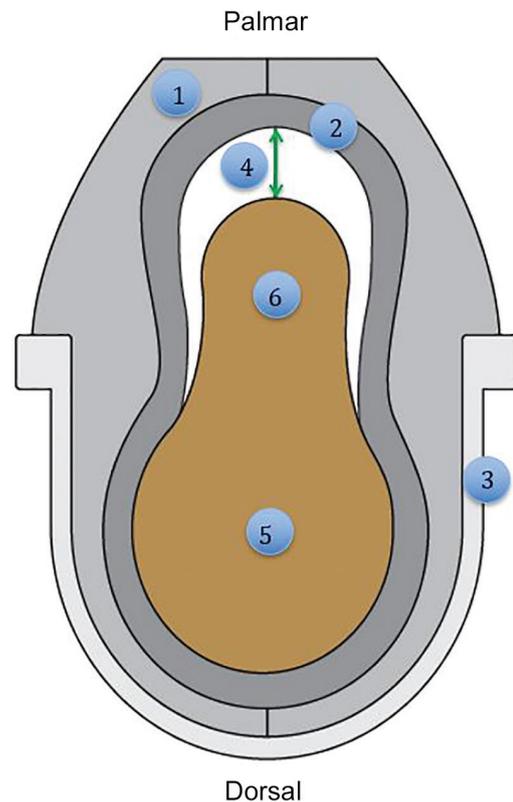
Figure 2—Drawing depicting a cross section through the middle portion of the third metacarpal (cannon) region of a horse with the novel legwear in Figure 1. Note the dual-layer padding that is molded to the FL and intimately contacts the dorsal, medial, and lateral aspects of the cannon region without contacting the flexor apparatus. 1 = Outer polymeric padding. 2 = Inner polymeric padding. 3 = Upper cuff hardware. 4 = Space separating padding from the flexor apparatus. 5 = Cannon bone and adjacent soft tissues. 6 = Flexor apparatus and adjacent soft tissues. (Drawing used with permission by Manta Product Development Inc.)

A

B
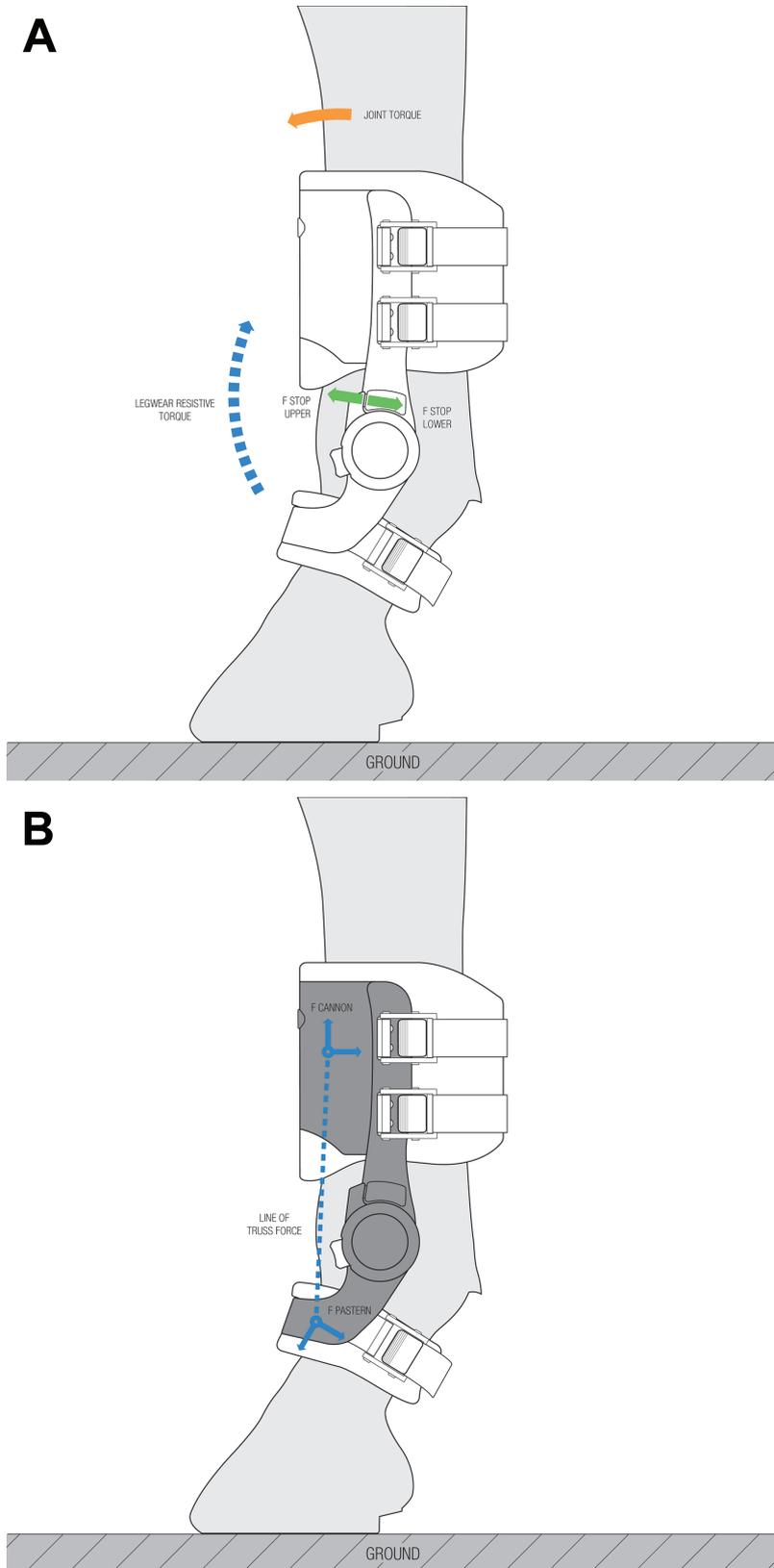
Figure 3—Drawings depicting the novel legwear in Figure 1 applied to an FL of a horse (lateral view). A—When the legwear is activated, the adjustable stop on the lower cuff engages the immovable stop on the upper cuff (adjustable and immovable stops collectively called the stop system) partway through extension of the MCPJ during limb loading. When this occurs, the torque of the MCPJ (orange arrow) is proportionally transferred to the adjustable stop, creating equal and opposite force vectors (F STOP UPPER and F STOP LOWER; green arrows). B—Engagement of the stop system effectively creates a rigid body of the upper and lower cuffs, allowing the legwear to act as a truss (dotted line) between the cannon and pastern regions. This truss provides resistive torque, restricting MCPJ extension. At both ends of the truss, one force element is parallel and another force element is perpendicular to the longitudinal axes of both the cannon (F CANNON) and pastern (F PASTERN) regions. (Drawing used with permission by Manta Product Development Inc).

beyond that deemed physiologically appropriate for trot and canter (some horses stumbled) and was, therefore, excluded from further evaluation. Owing to assumed symmetry of walk and trot, only data from the right FL were analyzed for those gaits. For canter, however, data from left and right FLs (leading and trailing FLs and vice versa) were collected. Horses were permitted to canter on their preferred lead. Peak load was recorded, and torque was subsequently calculated for 6 complete strides for each sequential gait (in order: walk, trot, and canter) and randomized treatment (inactive, active$_{mild[30°]}$, and active$_{mod[20°]}$).

Force data for in-stall activity—Legwear was similarly applied as for the treadmill gaits but, in the stall, was only worn for 2 active states (active$_{mod[20°]}$ or active$_{max[10°]}$). In an initial evaluation of mildly restrictive legwear (active$_{mild[30°]}$), it rarely redirected any load (consistently measured 0 N/kg), likely because the peak MCPJ angle was insufficient to engage the stop system. Accordingly, only moderately (active$_{mod[20°]}$) and maximally (active$_{max[10°]}$) restrictive states were subsequently selected for study. The MCPJ restriction achieved with these 2 states would be suitable for use during early stages of healing, for which substantial unloading of the affected

inactive and active states. On the basis of preliminary visual observation by a veterinarian (CAK-H) of several horses wearing legwear in the active states, active$_{max(10°)}$ was considered to restrict MCPJ extension

flexor apparatus by restricting MCPJ extension is desirable.[38-40] Force data were recorded via telemetry from both FLs for 30-second periods while each horse was unrestrained (free movement in the stall) and restrained

(horse held in 1 location on a lead by a handler). Each horse underwent 4 treatments (active$_{mod[20°]}$ and active$_{max[10°]}$ during unrestrained and restrained movement) in random[c] order on the same day without rest or removal of the legwear between treatments. Peak legwear load and legwear torque were determined for each 30-second period.

Wearability—Legwear wearability was visually assessed during the treadmill gaits and, on a different day from when in-stall force data were acquired, during unrestrained in-stall activity every 15 minutes for a total of 2 hours, with the legwear in the inactive and active (active$_{mild[30°]}$ or active$_{mod[20°]}$) states. Prior to and after each treadmill exercise and in-stall unrestrained activity, the distal portion of the FLs were visually inspected for evidence of disruption of the hair coat and skin inflammation or abrasion and palpated for heat and swelling of the soft tissues and signs of pain.

Statistical analysis

Descriptive statistics (mean [SD]) were calculated, assuming normal distribution, for peak load and torque data. Data were determined to be normally distributed with Shapiro-Wilk and Kolmogorov-Smirnov tests. The associations of legwear state and treadmill gait or in-stall activity data with the outcomes of peak legwear load and legwear torque were assessed with mixed-effects models. In-stall peak load and torque for the right and left FLs were initially compared, and no significant differences were noted. Therefore, side (left vs right) was not included in the subsequent models.

The initial models included the main effects of legwear state and treadmill gait–in-stall activity and the interaction term of legwear state with treadmill gait–in-stall activity. When the interaction term was not significant, it was removed from the model. In addition, η_p^2 was reported, which represented the partial proportion of variance accounted for by the effect being tested (ie, effect size expressed as a proportion from 0 to 1). Because peak load and torque were based on the same measurement, their underlying

relationship was the same although their absolute values differed. Thus, regression models with the same predictors would produce the same results. All data were analyzed with statistical software.[h] Values of P < 0.05 were considered significant; post hoc analyses (multiple comparisons) were not performed because this study was preliminary.

Results

Force data for treadmill gaits

Data for peak load and torque for gaits (walk, trot, and canter) with legwear in the 2 active states (active$_{mild[30°]}$ or active$_{mod[20°]}$) are summarized **(Table 1)**. In the inactive state, no load (0 N/kg) was registered by telemetry. The faster gaits (canter vs walk or trot and trot vs walk) had a significantly (P < 0.001) higher peak load and torque than the slower gaits **(Table 2)**. For the canter, differences in peak load and torque between the leading and trailing FLs were not significant (P = 0.57).

The initial model showed that the interaction term of legwear state and gait was not significant (P = 0.98) for peak load and torque. After removing the interaction term from the model, gait ($F_{3,15}$ = 82.98; P < 0.001; η_p^2 = 0.61) and legwear state ($F_{1,5}$ = 23.32; P = 0.005; η_p^2 = 0.13) were significantly related to peak load and torque. With the inclusion of all gaits, the active$_{mod(20°)}$ state resulted in significantly (P = 0.005) higher peak load (active$_{mod[20°]}$ minus active$_{mild[30°]}$, 0.28; 95% CI, 0.13 to 0.43) and torque (0.011; 95% CI, 0.005 to 0.017) than the active$_{mild(30°)}$ state.

Force data for in-stall activity

Data for peak load and torque for unrestrained and restrained activity with active legwear states are summarized (Table 1). The initial model showed that the interaction term of legwear state and activity was not significant (P = 0.91) for peak load and torque. After removing the interaction term from the model, activity ($F_{1,5}$ = 24.22; P = 0.004; η_p^2 = 0.29) and legwear state ($F_{1,5}$ = 12.97; P = 0.016; η_p^2 = 0.18) were significantly related to peak load and torque

Table 1—Mean ± SD peak load and torque determined for active legwear states (active$_{mild[30°]}$, active$_{mod[20°]}$, and active$_{max[10°]}$) during walk, trot, and canter in the leading (LF) and trailing (TF) FLs on a treadmill and unrestrained and restrained activity in a stall for 6 horses without musculoskeletal disease.

Variable		Treadmill			In-stall	
	Gait	Active$_{mod(20°)}$	Active$_{mild(30°)}$	Activity*	Active$_{max(10°)}$	Active$_{mod(20°)}$
Peak load (N/kg)	Walk	0.350 ± 0.287	0.134 ± 0.159	Unrestrained	0.793 ± 0.532	0.475 ± 0.304
	Trot	1.028 ± 0.503	0.721 ± 0.352	Restrained	0.365 ± 0.357	0.080 ± 0.055
	Canter LF	1.53 ± 0.466	1.247 ± 0.406			
	Canter TF	1.504 ± 0.530	1.181 ± 0.390			
Torque† (N•m/kg)	Walk	0.013 ± 0.011	0.005 ± 0.006	Unrestrained	0.031 ± 0.020	0.018 ± 0.012
	Trot	0.034 ± 0.020	0.028 ± 0.014	Restrained	0.014 ± 0.014	0.003 ± 0.002
	Canter LF	0.060 ± 0.018	0.048 ± 0.018			
	Canter TF	0.058 ± 0.021	0.046 ± 0.015			

*Unrestrained movement in which horses moved about freely within a stall. Restrained movement in which horses were held in 1 location on a lead by a handler. †Trigonometric transformation of peak load data yielded peak torque, such that torque = sensor load/([cos θ] X moment arm), where θ = angle of sensor load to perpendicular load (28.23°) and moment arm = length from line of force application to axis of rotation (34.25 mm).

Table 2—Mean difference and pairwise comparisons of peak load and torque, normalized for body weight, for gaits obtained for the horses of Table 1 while on a high-speed treadmill.

Variable	Gait 1	Gait 2	Difference	95% CI	P value
Peak load (N/g)	Canter LF	Canter TF	0.05	−0.13 to 0.23	0.57
	Canter LF	Trot	0.52	0.34 to 0.69	< 0.001
	Canter LF	Walk	1.15	0.97 to 1.33	< 0.001
	Canter TF	Trot	0.47	0.29 to 0.64	< 0.001
	Canter TF	Walk	1.10	0.92 to 1.28	< 0.001
	Trot	Walk	0.63	0.46 to 0.81	< 0.001
Torque† (N•m/kg)	Canter LF	Canter TF	0.002	−0.005 to 0.009	0.57
	Canter LF	Trot	0.020	0.013 to 0.027	< 0.001
	Canter LF	Walk	0.044	0.038 to 0.052	< 0.001
	Canter TF	Trot	0.018	0.011 to 0.025	< 0.001
	Canter TF	Walk	0.043	0.036 to 0.050	< 0.001
	Trot	Walk	0.025	0.018 to 0.031	< 0.001

See Table 1 for remainder of key.

Table 3—Mean difference and pairwise comparisons of peak load and torque, normalized for body weight, for in-stall activity (unrestrained and restrained) and legwear states obtained for the horses of Table 1.

	Activity (unrestrained − restrained)			Legwear ($active_{max[10°]}$ − $active_{mod[20°]}$)		
Variable	Difference	95% CI	P value	Difference	95% CI	P value
Peak load (N/g)	0.41	0.20–0.63	0.004	0.016	0.008–0.024	0.004
Torque† (N•m/kg)	0.30	0.09–0.52	0.016	0.012	0.004–0.020	0.016

See Table 1 for remainder of key.

(Table 3). With the inclusion of both activities, the $active_{max(10°)}$ state had significantly ($P = 0.016$) higher peak load and torque than the $active_{mod(20°)}$ state. The differences in load and torque between the $active_{max(10°)}$ and $active_{mod(20°)}$ states did not vary between the restrained and unrestrained activity levels (data not shown), but unrestrained activity yielded significantly ($P = 0.004$) higher peak load and torque than those for restrained activity.

Wearability

After completing the treadmill exercises, 3 horses had no visible evidence of disruption of the hair coat and skin inflammation or abrasion. Hair disturbances were apparent on the proximodorsal aspect of the cannon region of each FL of one horse, and another horse had minor unilateral superficial abrasion of the medial aspect of the cannon region. A third horse had bilateral superficial abrasions and mild soft tissue swelling over the area of the proximal aspects of the medial and lateral suspensory ligament branches. Because the legwear was not removed between treatments, correlations between the legwear state and hair coat and skin effects could not be determined. The structural integrity of the legwear was maintained throughout testing for all horses.

During in-stall wearability testing, no alterations in behavior were observed in any of the horses. In 2 horses, bilateral roughening of the hair coat was observed on the proximodorsal aspects of the cannon and midpastern regions for both legwear states ($active_{mild[30°]}$ or $active_{mod[20°]}$).

Discussion

This study provided a kinetic analysis of novel, variably restrictive legwear intended for use with horses rehabilitating from injuries of the flexor apparatus. The ability of this legwear to mechanically redirect loading forces away from the flexor apparatus and onto the dorsal aspects of the cannon and pastern regions was examined in 6 horses without musculoskeletal disease during treadmill and in-stall activities. Significant increases in peak load and torque were demonstrated with increasing restriction of legwear range of motion (extension), speed during ambulation, and stall activity. The legwear remained structurally sound and caused only mild adverse physical effects of the FL when worn continuously for 2 hours.

The benefits of an early return to a graduated exercise regimen are well recognized for rehabilitating horses with flexor apparatus injury.[38,41,42] However, rehabilitation needs to be carefully controlled to avoid overloading the flexor apparatus and causing further injury. Thus, this novel legwear, which was designed to limit MCPJ extension and thereby redirect loading forces away from the flexor apparatus, was believed to have clinical applications for controlled rehabilitation of a variety of horses with flexor apparatus injury across a range of activities. Findings from this study implied that this legwear was effective in reducing flexor apparatus load not only during ambulation, but also during in-stall wear when a horse is not necessarily in motion. Therefore, it may be effective for

patients, particularly in the acute postinjury phase when these horses are largely stall bound.

Torque describes the propensity for a force to cause rotation of a body.[43] In the present study, 2 types of torque were considered when the legwear was activated: torque exerted on the lower portion of an FL around the fixed pivot of the MCPJ and torque exerted on the fixed pivot of the legwear hinge. Normally, the MCPJ experiences positive torque as a result of body weight loading of the FL, which, if unopposed, causes the MCPJ to collapse (hyperextend).[5,44] Instead, this positive torque is countered largely by the flexor apparatus (negative torque), with its elasticity and associated structures (eg, muscle).[44,45] Consequently, net torque (positive minus negative torque) approximates zero in a standing horse; therefore, the MCPJ is stable. In the present study, legwear torque contributed to negative torque produced by the flexor apparatus and reduced the support function of the flexor apparatus.[44] Legwear torque can be described as a percentage of previously published values of torque derived from an MCPJ model with legwear in a moderately restricted state (ie, active$_{mod[20°]}$)[46]; on the basis of those published values and the results of the present study, negative torque produced by the legwear could have contributed enough torque such that the torque provided by the flexor apparatus could have been reduced by up to 3.6% at walk, 3.4% at trot, and 4.3% at canter.

To our knowledge, the percentage of torque reduction required to benefit the mechanical environment of a healing flexor apparatus with tendinopathic or desmopathic injury is unknown. However, a reduction of 3% to 4% during normal ambulation likely has merit, recognizing that in horses with flexor apparatus injury, the structures of the flexor apparatus are largely intact and fully functional, aside from those affected by the injury. Therefore, we theorize that legwear-derived torque reduction might benefit an injured horse in several ways as follows: by helping the intact structures of the ipsilateral flexor apparatus bear any additional load generated from pain-induced or other alterations in gait; reducing the load on the affected structure, thereby reducing risk of its additional injury and optimizing the biomechanical environment for healing; and countering any excess load applied to the flexor apparatus of the contralateral (unaffected) FL because of load redistribution.

For horses of the present study, 2 hours of continuous wear of the legwear caused hair coat roughening during in-stall activity (n = 2) and treadmill exercises (1). Additionally, minor superficial skin abrasions were noted under the upper cuff of 2 horses after treadmill exercises, emphasizing the importance of correct fit and selection of padding materials. This prototype legwear had a dual-layer padding system that was analogous to that of running shoes for people, which, if shoes are appropriately constructed with cushioned soles, can mitigate the impact from a shock wave transmitted to the skeleton and, for each foot, redistribute loads and lessen pressure on

its plantar surface.[47] Similarly, in the present study, compression of the legwear padding in response to loading and some movement of the legwear relative to the FL attenuated the impact force when the activated legwear restricted extension.

Many running shoes for people combine stiff foam or padding geometry with soft foam to balance motion control of the ankle and shock attenuation.[47] The legwear padding was similarly constructed of an outer layer of firm polyurethane intended to fit the legwear snugly to the FL and prevent excessive motion of the legwear relative to the FL. The inner layer provided a cushioned surface in direct contact with the limb. On the basis of the results of the present study, this prototype legwear has been redesigned[i] by use of thermoformable padding, similar to that used in professional ice skating and skiing boots, such that a more customized fit with the limb is possible.

Although not directly addressed in this study, the legwear may provide additional limb support whenever the MCPJ angle is adversely increased by factors such as unusual limb conformation,[48] activity (controlled vs uncontrolled), gait or speed,[49] surface,[50] shoeing,[51] fatigue,[52,53] or the addition of a rider.[54,55] Activated legwear may also benefit injured horses by reducing perceived pain, which is proportional to loading of the injured structure.[56] Reduced pain might prompt accelerated voluntary increases in range of motion, with the horse less apt to guard the limb[57] or alter its posture in anticipation of pain,[58] and might improve functional outcome because of early accelerated mobilization.[59]

A principal drawback of the present study was the inability to interpret the legwear load and torque data regarding specific changes in the mechanical environment of each principal flexor apparatus structure. In healthy horses, limb load is variably distributed as a function of gait. At a walk, MCPJ extension is countered primarily by the deep digital flexor tendon; with increasing speed, the suspensory ligament and superficial digital flexor tendon contribute to counterresistance.[10,60] In tendinopathy and desmopathy, confounding factors such as pain and compensatory behaviors complicate an understanding of load distribution among components of the flexor apparatus after injury.[61] Ultimately, invasive methodologies may be required to characterize relative distribution of load among normal and healing flexor apparatus tissues within the same limb across gaits and in the presence and absence of legwear.

Determination of the appropriate magnitude and frequency of load for a horse with an injured flexor apparatus undergoing controlled exercise is challenging. Rehabilitative exercises are often individualized on the basis of chronicity, severity, and location of the injury; response to therapy; presence of comorbidities; and the horse's behavior.[30] Consequently, few publications[30,38,41,42] detail recommendations for the care provider. Inadequate mobilization can result in loss of athletic use of a horse, whereas overloading may worsen the injury.[20] The perceived benefit of

the legwear is an ability to incrementally adjust the amount of mechanical support for the MCPJ via the variably adjustable stop. Therein, reducing the load applied to the flexor apparatus during the early stage of rehabilitative exercise should improve patient comfort, while providing moderated stimulation for the injured flexor apparatus to heal by mechanically supporting the apparatus as it gradually strengthens.[58] On the basis of previous reports,[24-29] a progressive increase in load thereafter is expected to facilitate a return to function. The means by which tendinopathy and desmopathy are currently managed, especially physiotherapeutic regimens, are limited. Findings of the present study suggested that this novel legwear may complement currently accepted rehabilitative interventions.

Acknowledgments

Footnotes

a.   EquiGym LLC, Lexington, Ky.
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c.   True random number generator, Random.org. Randomness and Integrity Services Ltd, Dublin, Ireland. Available at: random.org. Accessed Jan 15, 2015.
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