Effects of injury to the suspensory apparatus, exercise, and horseshoe characteristics on the risk of lateral condylar fracture and suspensory apparatus failure in forelimbs of Thoroughbred racehorses

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Objective—To assess concurrently the effects of moderate ligamentous suspensory apparatus injury (MLSAI), racing-speed exercise, and horseshoe characteristics on risk of catastrophic suspensory apparatus failure (SAF) or metacarpal condylar fracture (CDY) in forelimbs of racehorses.

Sample population—Cadavers of 301 Thoroughbred racehorses (108 with SAF, 33 with CDY, and 160 control horses).

Procedure—A cross-sectional epidemiologic study was used to describe distributions and relationships between MLSAI, exercise, and horseshoe variables. Logistic regression was used to assess potential risk factors for developing SAF and CDY.

Results—Exercise variables were more highly associated with age than height of a steel bar affixed to the ground surface of the front of a horseshoe (ie, toe grab) or sex. Marginal associations were detected between MLSAI and age and height of toe grab. Higher risk for developing SAF was associated with MLSAI, use of a pad on a horseshoe, longer interval since last period of ≥ 60 days without a race or timed workout (ie, layup), 2 to 5 career races, and higher intensity of recent exercise. Higher risk for developing CDY was associated with MLSAI, male horses, age between 2 and 5 years, higher intensity of recent exercise, and longer interval since layup.

Conclusions and Clinical Relevance—Recognition of MLSAI and rehabilitation of affected horses should reduce incidence of SAF and CDY. Horses in long-term continuous training with recent high-intensity exercise are at greater risk for injury. Use of pads in horseshoes was associated with SAF, although the relationship may not be causal. (*Am J Vet Res* 2004;65:1508–1517).

Catastrophic musculoskeletal injury is an ongoing concern for the horse racing industry. Reportedly, there are fatal injuries for 1 to 3 of every 1,000 race starts,[1-4] and musculoskeletal injuries have been implicated in 83% of racehorse deaths.[5] The suspensory apparatus of the forelimb (comprising the suspensory ligament, proximal sesamoid bones, and distal ligaments of the proximal sesamoid bones) is reportedly the most common site of catastrophic injuries, accounting for 21% to 91% of injury-related deaths.[1-6] The lateral condyle of the third metacarpal bone is the second most common site of catastrophic injuries, accounting for 10% to 25% of injury-related deaths.[2,5,6,a]

Anatomic and epidemiologic evidence supports the hypothesis that **suspensory apparatus failure (SAF)** and metacarpal **condylar fracture (CDY)** are related injuries. The suspensory apparatus of the forelimbs is located adjacent to the metacarpus, and the metacarpal condyles articulate with the proximal sesamoid bones when a limb is fully loaded.[7] Fracture of the proximal sesamoid bones is the predominant cause of SAF,[2,4,6] and CDY originates on the palmar aspect of the metacarpal condyle, the region that articulates with the proximal sesamoid bones.[7] In the most severe situation, lateral CDY is seen in conjunction with SAF.[8-10]

In addition to physical proximity, SAF and CDY share risk factors. Preexisting mild injury of the suspensory apparatus has been associated with subsequent severe or catastrophic injuries of the forelimb suspensory apparatus or CDY.[1,6,11] A steel bar affixed to the ground surface of the front of the shoe (ie, toe grab) on horseshoes is a reported risk factor for catastrophic forelimb SAF and CDY,[12] although the association between toe grabs and SAF was not confirmed in another study.[13] Racing and training schedules have been associated with several musculoskeletal injuries,[14-17] including SAF,[14] although the magnitude and direction of effect have varied. Exercise has not specifically been studied as a risk factor for CDY, but exercise has been associated with groups of various cat-

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astrophic and noncatastrophic musculoskeletal injuries[18-20] that have included CDY.

Exercise, shoeing and horseshoes, and palpable injuries of the suspensory apparatus have all been studied as individual risk factors for development of SAF, CDY, and other injuries, although the factors may be interrelated.[1,6,11-14,18-21] Shoeing and horseshoes are believed to vary depending on stage of training, which is related to exercise, and palpable injuries of the suspensory apparatus are reportedly dependent on exercise.[21] In 1 study,[11] investigators reported that exercise patterns and toe grabs were apparently both risk factors for palpable injuries to the suspensory apparatus, although neither association was statistically significant. The objective of the study reported here was to concurrently evaluate extant injury to the ligamentous suspensory apparatus, racing-speed exercise, and horseshoe characteristics as risk factors for development of fatal SAF or CDY in a population of Thoroughbred racehorses in California.

Materials and Methods

Study population—Bilateral forelimb specimens distal to the antebrachiocarpal joint were obtained from 327 horses that died between November 19, 1999, and November 16, 2002; these specimens were included in another study.[a] Only limbs without catastrophic injury (injury resulting in death or euthanasia of the horse) were examined. All horses that die or are euthanatized at racetracks in California are necropsied by pathologists at the California Animal Health and Food Safety Laboratory System as part of the California Horse Racing Board Postmortem Program. Thus, the 327 horses represented 53% of the 621 horses necropsied as part of the Postmortem Program during a 3-year period. Information on identification, age, sex, date, cause of death, and racetrack at which death occurred was obtained for each horse, as described elsewhere.[a]

Three horses were excluded because they were not listed in the official Thoroughbred registry. Other horses were excluded because they had bilateral catastrophic injuries to the forelimbs (n = 5), hind limb SAF (2), or hind limb CDY (16). After excluding these 26 horses, 301 horses were eligible for risk-factor analysis.

Injury to the ligamentous portion of the suspensory apparatus—The suspensory apparatus from each forelimb that did not have catastrophic musculoskeletal injury was removed, sectioned, and assessed visually for evidence of **moderate ligamentous suspensory apparatus injury (MLSAI)**, as described elsewhere.[a] Briefly, the suspensory apparatus from the region of the carpometacarpal joint to the terminus of the insertion of the oblique distal ligaments of the proximal sesamoid bones was removed from both forelimbs, frozen overnight (in an anatomic orientation), and sectioned at 8 sites evenly distributed along the length of the suspensory ligament and distal ligaments of the proximal sesamoid bones. The proximal surface of each cut section was assessed visually for injury, and limbs with ≥ 1 section that had a purple lesion ≥ 2 mm in width were categorized as having MLSAI.

For subjects with a catastrophically injured forelimb, MLSAI for the contralateral limb (evident or not evident) was recorded on the assumption that the suspensory apparatus of only the catastrophically injured limb sustained acute damage during the course of the catastrophic (fatal) injury. For cadavers without catastrophic injuries to the forelimbs, the MLSAI (evident or not evident) of the left or right forelimb was randomly selected and recorded.

Racing-speed exercise—For each horse, career race and timed racing-speed workout reports were obtained from official racing industry records.[22] Reports included information on the date and distance of each race and timed workout in a horse's racing career. A computer program was devised[b] to parse the commercially available race and exercise information into 21 variables, many of which were included in another study[19] that described exercise patterns over time for each horse (**Appendix**).

Horseshoe characteristics—For each horse, both hooves were cleaned and several factors recorded, including shoe type (aluminum racing plate; wide web, rolled toe plate[c]; angled toe, full heel plate[d]; steel training plate; or none), height of toe grab (none, < 10 mm; very low, 10 to < 12 mm; low, 12 to < 14 mm; regular, 14 to < 16 mm; or high, ≥ 16 mm), rim (evident or not evident), pad (evident or not evident), and heel traction (evident or not evident). Height of the toe grab was measured from the solar surface of the hoof wall to the maximal height of the toe grab by use of a graduated step wedge. Categories for measured height of toe grabs corresponded to the distance that a toe grab extended beyond the ground surface of the shoe (0 mm, > 0 to ≤ 2 mm, > 2 to ≤ 4 mm, > 4 to ≤ 6 mm, and > 6 to ≤ 8 mm for none, very low, low, regular, and high categories, respectively). Height recorded corresponded to the height of the toe grab at the time of necropsy, which on shoes worn for a period may have been lower than the height of the toe grab at the time of shoe application.

For horses in which 1 horseshoe had been removed at the time of necropsy, characteristics of the other horseshoe were recorded because agreement among horseshoe characteristics for the left and right limbs of a horse is > 99%.[23] For horses with differing characteristics between the left and right horseshoes, data from the shoe on the limb used for MLSAI assessment were recorded.

Data analysis—Descriptive statistics for exercise, age, sex, and horseshoe characteristics were generated for horses with forelimb CDY, horses with forelimb SAF, and horses without either injury (control group). Distribution of cause of death and racetrack at which the death occurred has been described for this study sample.[a] We used χ^2 tests[24,e] to compare categoric variable distributions between the SAF, CDY, and control groups. Population means for normally distributed variables (as determined by use of the Kolmogorov-Smirnov test[25]) were compared[e] among the SAF, CDY, and control groups by use of a 1-way ANOVA[26]; when differences were found, multiple paired comparisons were made by use of the Tukey Honestly Significantly Different test[27] to determine differences among groups. Similarly, ranks for continuous nonnormally distributed variables ($P \le 0.05$ on Kolmogorov-Smirnov test[25]) were compared[e] by use of a Kruskal-Wallis 1-way ANOVA by ranks[28] followed by paired comparisons with Mann-Whitney tests.[29]

Values for η^2 (eta^2), Spearman ρ, Cramer's V, and the Mantel-Haenszel χ^2 were used[e,f] to assess the degree to which exercise, age, height of toe grab, MLSAI, and sex were interrelated. Values for η^2 are used with categoric and interval data and measure the percentage of variance in 1 variable explained linearly or nonlinearly by a second variable.[30] Spearman ρ measures the degree of monotonic correlation between 2 ordinal variables.[31] Cramer's V assesses whether a significant association exists between a nominal and categoric variable.[32] The Mantel-Haenszel χ^2 assesses whether there is a linear association between 2 ordinal variables.[33] For use with η^2, each continuous exercise variable was transformed by categorization into intervals comprising one twentieth of the difference between the 5th and 95th percentiles.

Univariate logistic regression[g] was used to test associations among horseshoe characteristics, exercise, MLSAI, and SAF and between each of these same factors and forelimb CDY. For the SAF outcome, horses that died or were euthanatized as a result of forelimb SAF were considered case horses, those that died or were euthanatized as a result of forelimb CDY were excluded from the analyses, and the remaining horses were considered control horses. For the CDY outcome, horses that died or were euthanatized as a result of forelimb CDY were considered case horses, those that died or were euthanatized as a result of forelimb SAF were excluded, and the remaining horses were considered control horses. The assumption of linearity in the logarithmic odds was assessed for all continuous variables by categorizing each variable into quantiles, fitting the categorized variable to the data by use of univariate logistic regression analysis, and plotting the median of each category against the logarithm of the odds ratio for that category. When a line fit to the plot had an $R^2 \geq 0.75$ (a cutpoint believed by one of the authors [AEH] to document linearity), the assumption of linearity was considered adequate and the variable was further analyzed in its continuous form. Categoric transformation was retained for variables that were not linear in the logarithmic odds. Age, sex, racetrack, MLSAI, exercise, and horseshoe variables that improved fit for the model (likelihood ratio statistic, $P \leq 0.10$; compared with a baseline model that contained only an intercept term) were eligible for inclusion in a multivariate model. A multivariate logistic regression model[g] was constructed in accordance with recommended guidelines.[34] Age, sex, and any a priori risk factors (MLSAI or height of toe grab) that were not in the best-fitting multivariate model were separately forced into the final model as potential confounders and removed when odds ratios changed by < 10% after addition of the term. Model fit was assessed by use of the sum of the deviance residuals[34] and was considered adequate at $P > 0.05$.

Results

Sample population—Of the 301 horses used for data analysis, 108 (36%) had forelimb SAF, 33 (11%) had forelimb CDY, and 160 (53%) had neither forelimb injury and were categorized as control horses. Age was significantly (Cramer's V, 0.19; $P = 0.01$) associated with sex **(Table 1)**. The proportion of colts decreased with age as the proportion of geldings increased. Distributions of age and sex did not differ significantly ($P = 0.10$) by injury category (SAF, CDY, or control group).

Exercise variables—Exercise data were available for 301 racehorses, 49 (16%) of which had MLSAI. Eighteen (6%) racehorses (11 horses that were 2 years old and 7 horses that were 3 years old) were listed in the official Thoroughbred registry but had no officially recorded races or timed workouts. These horses were included in the analyses but had values of 0 for distance-related variables and missing values for variables related to layup. An additional 19 (6%) horses (12 that were 2 years old, 4 that were 3 years old, 2 that were 4 years old, and 1 that was 5 years old) had not raced, although timed workouts had been recorded.

All exercise variables were nonnormally distributed ($P < 0.001$). Ranks among SAF, CDY, and control groups differed significantly (Kruskal-Wallis, $P = 0.02$) for all cumulative career variables (ie, race distance, workout distance, total distance, number of races, number of workouts, and number of career days), all mean career variables (ie, mean race distance, mean workout distance, and mean total distance), 1 variable for active periods (ie, active days), and 3 time variables (ie, days since layup, distance in last month, and distance in last 2 months; **Table 2**). Ranks did not differ significantly ($P = 0.16$) among groups for any layup variables (ie, number of layups, total layup days, mean layup days, or layup percentage), 3 variables for active periods (days between races while active, days between workouts while active, and mean number of days to accumulate 0.2 km [1 furlong] of exercise while active), or 2 time variables (difference in distance for each of last 2 months and difference in distance for last 2 months and months 3 and 4 before death or euthanasia). For all cumulative career variables, values were significantly ($P = 0.01$) higher in the SAF group than the control group, whereas for horses with CDY, the only cumulative career variable that was significantly higher than the corresponding value for the control group was workout distance. Both SAF and CDY groups had significantly higher values than the control group for all 3 mean career variables. Values for the variable active days were significantly ($P < 0.001$) greater for the SAF group than the control group but were not significantly different between the CDY and control groups. For the time variables days since layup, distance in last month, and distance in last 2 months, values were significantly ($P = 0.01$) higher for the SAF and CDY groups than the control group. Values did not differ significantly ($P = 0.11$) between the SAF and CDY groups for any variables identified by use of the Kruskal-Wallis procedure.

Of 301 horses, 292 (97%) were shod at the time the forelimbs were harvested and examined (274 [94%] with aluminum racing plates; 10 [3%] with steel training plates; 5 [2%] with angled toe, full heel plates; and 3 [1%] with wide web, rolled toe plates). Twenty-six (9%) shod horses had no toe grabs, 73 (25%) had very low toe grabs, 107 (36%) had low toe grabs, 75 (26%) had regular toe grabs, and 11 (4%) had high toe grabs. Forty-five (15%) shod horses had rim shoes, 82 (28%) wore pads, and 13 (4%) had heel traction devices (7 jar caulks [rectangular projection on the quarter of the shoe perpendicular to the branch and approximately 1 cm in front of the heel of the shoe] and 6 mud nails [nails with raised heads of various sizes and shapes]). Distribution of shoe type, height of toe grab, rim shoes, and heel traction devices did not differ significantly ($P = 0.18$) among injury categories (ie, SAF, CDY, and control groups),

Table 1—Distribution of age and sex for 301 Thoroughbred racehorses that died or were euthanatized at racetracks in California during a 3-year period (1999 to 2002).

Age (y)	Gelding No. (%)	Male No. (%)	Female No. (%)	All horses
2	18 (15)	12 (17)	20 (18)	50
3	41 (34)	32 (46)	35 (32)	108
4	23 (19)	19 (27)	31 (28)	73
5	16 (13)	3 (4)	19 (17)	38
> 5	22 (19)	4 (6)	6 (5)	32
Total	**120 (100)**	**70 (100)**	**111 (100)**	**301**

Table 2—Distribution of values for exercise variables in Thoroughbred racehorses without suspensory apparatus failure (SAF) or metacarpal condylar fracture (CDY; control group), forelimb SAF, or forelimb CDY.

Variable	Control group		SAF		CDY	
	n	Median (range)	n	Median (range)	n	Median (range)
Cumulative career						
Race distance (No. of furlongs)*	160	33 (0–670)[a]	108	54 (0–488)[b]	33	54 (0–176)[a]
Workout distance (No. of furlongs)*	160	86 (0–704)[a]	108	123 (6–461)[b]	33	107 (0–319)[b]
Total distance (No. of furlongs)*	160	117 (0–1,097)[a]	108	188 (6–857)[b]	33	166.5 (0–464)[a]
No. of races*	160	5.5 (0–83)[a]	108	8 (0–107)[b]	33	7 (0–22)[a]
No. of workouts*	160	20 (0–149)[a]	108	28 (2–103)[b]	33	27 (0–65)[a]
Career days*	160	416 (0–2,556)[a]	108	535 (16–2,808)[b]	33	418 (0–1,523)[a]
Mean career						
Mean race distance (No. of furlongs)*	160	6.0 (0–9.2)[a]	108	6.3 (0–8.8)[b]	33	6.6 (0–8.1)[b]
Mean workout distance (No. of furlongs)*	160	4.2 (0–5.3)[a]	108	4.3 (3.0–5.1)[b]	33	4.4 (0–5.4)[b]
Mean total distance (No. of furlongs)*	160	4.6 (0–6.6)[a]	108	4.8 (3–6.1)[b]	33	5.1 (0–6.0)[b]
Layups						
No. of layups	144	1 (0–6)	108	1 (0–7)	31	1 (0–5)
Total layup days	144	178 (0–2,366)	108	173 (0–875)	31	83 (0–675)
Mean layup days	144	141 (0–1,183)	108	126 (0–611)	31	83 (0–468)
Layup percentage	144	33 (0–99)	108	30 (0–93)	31	12 (0–84)
Variables during active periods						
Active days*	160	243 (0–2,003)[a]	108	348 (16–2,022)[b]	33	327 (0–919)[b]
Days between races while active	119	39 (15–225)	106	38 (18–170)	28	40 (15–104)
Days between workouts while active	144	11.3 (1–36)	108	12 (4–77)	31	12 (7–24)
Mean No. of days to accumulate 1 furlong of exercise while active	144	1.9 (0–7)	108	1.9 (1–3)	31	1.8 (1–3)
Time						
Days since layup*	160	95 (0–1,743)[a]	108	222 (0–1,640)[b]	33	237 (0–591)[b]
Distance in last month (No. of furlongs)*	160	14 (0–34)[a]	108	18 (0–37)[b]	33	18 (0–33)[b]
Distance in last 2 months (No. of furlongs)*	160	26 (0–54)[a]	108	34 (0–58)[b]	33	34 (0–58)[b]
Difference in distance for each of last 2 months (No. of furlongs)	119	2.0 (–20.5 to 23.5)	104	3.3 (–23.5 to 22.5)	31	3.0 (–20.0 to 25.0)
Difference in distance for last 2 months and months 3 and 4 before death or euthanasia (No. of furlongs)	93	1.5 (–21.0 to 38.0)	99	4.5 (–30.0 to 42.0)	30	5.7 (–20.5 to 33.5)

*Ranks among SAF, CDY, and control groups differed significantly (P = 0.02; Kruskal-Wallis test).
[a,b]Within a row, values with different superscript letters differ significantly ($P < 0.05$; Mann-Whitney test).
Workouts = Officially timed workouts (ie, sprints). Total distance = Distance raced plus distance of workouts. Career days = Date of death minus date of first recorded speed event (race or workout). Layup = Period of ≥ 60 days without a recorded speed event (race or workout). Active periods = Periods during which horses conducted recorded speed events (race or workout) with < 60 days between successive events. Days since layup = Days since end of most recent layup; if horse had no layups, then days since start of career. For conversion, 1 furlong = 0.2 km.

whereas distribution of use of pads did differ significantly (P = 0.01) among groups. Pads were found on shoes of a higher proportion of horses in the SAF group (38% [41/108]) than for horses in the CDY (24% [8/33]) or control (20% [33/163]) groups. Height of toe grab did not vary significantly on the basis of sex (P = 0.40) or age (P = 0.55) of horse.

Exercise values were more highly associated with age than with height of toe grab or sex (**Table 3**). Age accounted for 79% of the variation in career days, 63% of the variation in active days, and between 53% and 59% of the variation in other cumulative career variables (ie, race distance, workout distance, total distance, number of races, and number of workouts). Twenty-five percent of the variation in mean race distance (which increased with age) was associated with age, as was 22% of the variation for days between races while active (which decreased with age) and 21% of days between workouts while active (which increased with age). Age was associated with 32% to 47% of the variation in layup variables. Median values for number of layups and total layup days increased with age, whereas mean layup days and layup percentage were lower for 2- and 3-year-old horses than for horses ≥ 4 years old. Height of toe grab was associated with 6% to 16% of variation for exercise variables (**Table 4**). Sex was associated with 5% to 13% of the variation for exercise variables (data not shown).

Of 49 horses with MLSAI, 27 (55%) died or were euthanatized because of SAF, 8 (16%) died or were euthanatized because of CDY, and 14 (29%) died or were euthanatized because of other causes. The MLSAI was associated with age (P = 0.06) and height of toe grab (P = 0.08) but not with sex (P = 0.31; **Table 5**). The relationship between MLSAI and age was not linear because MLSAI affected < 13% of 2-, 3-, and 5-year-old horses but > 20% of 4-year-old horses and horses > 5 years old.

Risk factor analysis—On the basis of results of univariate analyses of risk factors for SAF, variables eligible for inclusion in a multivariate logistic regression model included MLSAI, race distance, workout distance, total distance, number of races, number of workouts, career days, mean race distance, mean workout distance, mean total distance, layup percentage,

Table 3—Median values for exercise variables* among age groups and the proportion of variance in each exercise variable accounted for by age (η^2 value) for 301 Thoroughbred racehorses.

	Age (y)					
Variable	2	3	4	5	≥ 5	η^2
Cumulative career						
Race distance (No. of furlongs)	5.5	28.5	68.5	113.5	229.3	0.56
Workout distance (No. of furlongs)	30.0	84.0	133.0	202.0	248.5	0.53
Total distance (No. of furlongs)	37.5	113.5	190.5	292.0	539.8	0.59
No. of races	1.0	4.0	10.0	16.0	29.0	0.57
No. of workouts	8.0	19.0	32.0	47.0	60.5	0.56
Career days	92.0	320.0	676.0	947.0	1583.5	0.79
Mean career						
Mean race distance (No. of furlongs)	5.0	6.1	6.4	6.7	6.7	0.25
Mean workout distance (No. of furlongs)	3.7	4.2	4.4	4.3	4.4	0.19
Mean total distance (No. of furlongs)	3.9	4.7	4.9	5.1	5.3	0.31
Layups						
No. of layups	0.0	1.0	1.0	1.0	3.0	0.42
Total layup days	0.0	82.0	286.0	294.0	472.0	0.47
Mean layup days	0.0	82.0	165.5	147.7	177.0	0.33
Layup percentage	0.0	21.4	37.5	33.0	37.7	0.32
Variables for active periods						
Active days	81.0	219.0	385.0	582.0	948.0	0.63
Days between races while active	41.2	43.0	37.2	37.0	29.7	0.22
Days between workouts while active	9.9	11.0	11.7	11.6	15.0	0.21
Mean No. of days to accumulate 1 furlong of exercise while active	2.9	1.9	1.9	1.9	1.9	0.11
Time						
Days since layup	81.0	166.0	200.0	270.0	227.5	0.22
Distance in last month (No. of furlongs)	11.5	16.0	16.5	15.5	20.0	0.11
Distance in last 2 months (No. of furlongs)	23.5	31.0	32.0	30.5	29.8	0.11
Difference in distance for last 2 months and months 3 and 4 before death or euthanasia (No. of furlongs)	10.5	1.0	5.5	2.0	4.5	0.10

*Variables with η^2 values < 0.10 have been omitted.
See Table 2 for remainder of key.

Table 4—Median values for exercise variables* among categories for height of toe grab and the proportion of variance in each exercise variable accounted for by height of toe grab (η^2 value) for 301 Thoroughbred racehorses.

	Height of toe grab†					
Variable	None	Very low	Low	Regular	High	η^2
Cumulative career						
Race distance (No. of furlongs)	14.5	34.0	38.0	58.5	66.0	0.15
Workout distance (No. of furlongs)	82.0	98.0	106.5	105.0	81.0	0.12
Total distance (No. of furlongs)	94.8	132.0	167.8	170.3	152.5	0.10
No. of races	2.5	5.0	6.0	9.0	9.0	0.14
No. of workouts	19.5	23.0	24.0	25.0	19.0	0.13
Career days	471.0	462.0	516.5	468.0	415.0	0.13
Mean career						
Mean workout distance (No. of furlongs)	4.2	4.2	4.3	4.3	4.3	0.10
Mean total distance (No. of furlongs)	4.5	4.7	4.8	4.8	4.7	0.10
Layups						
Total layup days	193.0	179.0	146.0	146.0	133.0	0.10
Mean layup days	135.0	140.0	106.8	118.8	133.0	0.11
Variables for active periods						
Active days	239.0	243.0	299.5	328.0	306	0.16
Days between races while active	46.3	41.0	40.0	35.0	31.9	0.16
Days between workouts while active	10.8	11.1	11.4	11.8	13.3	0.11
Time						
Days since layup	97.0	143.0	163.5	236.5	221.0	0.16
Distance in last month (No. of furlongs)	11.5	16.0	16.0	16.5	20.0	0.10
Distance in last 2 months (No. of furlongs)	26.5	29.5	29.0	31.0	36.0	0.14

*Variables with η^2 values < 0.10 have been omitted. †Height of toe grab corresponded to the distance that a steel bar affixed to the ground surface of the front of a horseshoe extended beyond the ground surface of the shoe and was classified into categories as follows: none, 0 mm; very low, > 0 to ≤ 2 mm; low, > 2 to ≤ 4 mm; regular, > 4 to ≤ 6 mm; or high, > 6 to ≤ 8 mm.
See Table 2 for remainder of key.

active days, mean number of days to accumulate 1 furlong of exercise while active, days since layup, distance in last month, distance in last 2 months, difference for distance in last 2 months and months 3 and 4 before death or euthanasia, height of toe grab, and use of a shoe pad. Among univariate analyses, the variable that best fit the data, as determined by model deviance, was days since layup. The best-fitting multivariate model (deviance, 288.7 on 256 degrees of freedom; $P = 0.08$) included days since layup, distance in last month, use of a shoe pad, number of races, and MLSAI (**Table 6**).

Risk of developing SAF was twice as high for a horse wearing a shoe pad or with MLSAI. Risk increased with distance exercised in the last month and days since layup. A horse that had sprinted 3.6 km (18 furlongs) in the last month was 1.2 times more likely to develop SAF than a horse that had sprinted 2.8 km (14 furlongs) during the same time period (calculated by multiplying the coefficient for distance in last month [ie, 0.04] by 4, which was the difference between 14 and 18 furlongs; the resulting product was then exponentiated). Compared with a horse with < 49 days since layup, a horse with 121 to 214 days since layup, 215 to 319 days since layup, and > 319 days since layup had 3.4, 3.9, and 5.9 times greater risk of developing SAF, respectively. Risk of developing SAF varied nonlinearly with number of races in a horse's career. Compared with a horse with 0 or 1 race in its career, a horse with 2 to 5 career races was 4 times more likely to develop SAF. The point estimate for risk of developing SAF was higher among horses in races 2 to 5 than for horses in races 6 to 107, but wide confidence intervals allowed for the possibility that risks among races 2 to 107 were similar (point estimate of risk, > 1.5).

Table 5—Associations between height of toe grab, age, and sex with moderate ligamentous suspensory apparatus injury (MLSAI) in 301 Thoroughbred racehorses.

Factor	Category	No MLSAI No. (%)	MLSAI No. (%)	Total
Height of toe grab	None	30 (86)	5 (14)	35
	Very low	64 (88)	9 (12)	73
	Low	91 (85)	16 (15)	107
	Regular	60 (80)	15 (20)	75
	High	7 (64)	4 (36)	11
	Total	**252 (81)**	**49 (19)**	**301***
Age (y)	2	45 (90)	5 (10)	50
	3	94 (87)	14 (13)	108
	4	56 (77)	17 (23)	73
	5	34 (89)	4 (11)	38
	> 5	23 (72)	9 (28)	32
	Total	**252 (81)**	**49 (19)**	**301†**
Sex	Gelding	105 (87)	15 (13)	120
	Male	58 (83)	12 (17)	70
	Female	89 (80)	22 (20)	111
	Total	**252 (81)**	**49 (19)**	**301‡**

*$P = 0.08$ (Mantel-Haenszel χ^2 test). †$P = 0.06$ (Cramer's V statistic). ‡$P = 0.31$ (Cramer's V statistic).
See Table 4 for remainder of key.

Table 6—Best-fitting multivariate model of risk factors for forelimb SAF in Thoroughbred racehorses.

Factor	Category	Coefficient	Odds ratio	Lower 95% CI	Upper 95% CI
Days since layup*	49–120	0.13	1.14	0.36	3.66
	121–214	1.23	3.43	1.13	10.37
	215–319	1.35	3.85	1.20	12.39
	320–1,743	1.78	5.92	1.71	20.45
Distance in last month	Per furlong	0.040	1.041	1.002	1.081
Shoe pad*	Used	0.71	2.04	1.09	3.81
No. of races*	2–5	1.45	4.25	1.54	11.76
	6–9	0.59	1.81	0.60	5.46
	10–17	0.21	1.23	0.38	4.01
	18–107	0.78	2.19	0.70	6.87
MLSAI*	Evident	0.85	2.34	1.05	5.19

*Reference values are 0 to 48 days since layup, no shoe pad, 0 to 1 race, and no MLSAI evident.
95% CI = 95% Confidence interval. 1 furlong = 0.2 km.

Table 7—Best-fitting multivariate model of risk factors for forelimb CDY in Thoroughbred racehorse, adjusted on the basis of height of toe grab.

Factor	Category*	Coefficient	Odds ratio	Lower 95% CI	Upper 95% CI
Distance in last 2 months	Per furlong	0.04	1.04	1.01	1.07
MLSAI*	Evident	1.55	4.73	1.43	15.59
Age (y)*	3	–0.51	0.60	0.15	2.33
	4	–0.85	0.43	0.10	1.85
	5	1.28	3.59	0.69	18.62
	> 5	–3.21	0.04	0.00	0.90
Sex*	Male	1.49	4.44	1.41	14.00
	Female	–0.22	0.80	0.27	2.40
Days since layup	Per day	0.003	1.003	1.001	1.006

*Reference values are 2-year-old geldings with no evidence of MLSAI.
See Table 6 for remainder of key.

In univariate analyses of risk factors for development of CDY, sparse data in shoe characteristics and height of toe grab categories prevented model convergence for those variables. The categories of regular and high for height of toe grab were grouped; thus, height of toe grab was modeled as a 4-category variable. On the basis of results of univariate analyses, several variables were eligible for inclusion in multivariate modeling (age, sex, MLSAI, mean race distance, mean workout distance, mean total distance, layup percentage, days since layup, distance in last month, and distance in last 2 months). On the basis of univariate analysis, the initial variable used in the multivariate model was distance in the last 2 months (**Table 7**). The best-fitting multivariable model (deviance, 135 on 182 degrees of freedom; $P = 0.99$) included distance in last 2 months, MLSAI, age, sex, and days since layup; it was adjusted for height of toe grab, which increased the estimated risks associated with MLSAI and age of 5 years by 12% and 16%, respectively. Risk of developing CDY was 4.7 times greater in horses with MLSAI; 25 times greater in 2-year-olds, as compared with horses > 5 years old; and > 4.4 times higher in males than in geldings or females. Risk was 1.5 times higher for each 2-km (10-furlong) increase in distance exercised in the last 2 months and 1.1 times higher for each additional month in training without a layup.

Discussion

In the study reported here, MLSAI was a risk factor for developing SAF and CDY and it was the strongest predictor for developing CDY. Detection of MLSAI increased the odds of catastrophic CDY 5-fold and of SAF 2-fold. These results are consistent with other reports[1,6,11] in which palpable injuries of the suspensory apparatus were associated with a 3- to 7-fold increase in the likelihood of SAF or CDY. The MLSAI may be part of a shared etiopathogenesis for SAF and CDY. Alternatively, MLSAI may be an easily identifiable indicator of musculoskeletal overuse. In either case, assessment of MLSAI by palpation or ultrasonography can yield important information regarding injury risk for Thoroughbred racehorses. Detection and management of MLSAI may reduce the likelihood of subsequent injury.

Exercise was also a risk factor for developing SAF and CDY, specifically the distance exercised in the last month or 2 months and the number of days since layup. With each additional furlong during a workout or race during the last 1 or 2 months, the odds of developing SAF or CDY increased by 4%. With each additional day since layup, the odds of developing CDY increased by 0.3%, whereas for the first 120 days after returning from layup, the odds of developing SAF remained relatively constant but increased thereafter by 3- to 6-fold. Although an increase in risk of 0.3% or 4% seems small when considering the impact of a single day or furlong, respectively, these risks become important when considering larger values for time and distance. A typical horse in the SAF or CDY groups had been in continuous training 4 months longer than a typical control horse and was sprinting an additional 0.8 km (4 furlongs) each month.

The combination of recent exercise, cumulative exercise, and moderate injury as risk factors for catastrophic injury was consistent with the theory that accumulated microdamage acquired via intensive exercise without sufficient repair time may predispose a horse to fractures. Periodic reductions in exercise intensity in horses that have been continuously in race training for > 6 months, especially when they have MLSAI, may reduce the likelihood of overt injury.

The risks of injury associated with recent high-speed exercise, although significant, were lower than those reported in other studies[14,19] that did not include MLSAI as a risk factor. High-speed exercise has been associated with palpable injuries of the suspensory apparatus[11,21]; some of the risk attributed to exercise in other studies may also have been related to the development of MLSAI. This hypothesis agrees with the results of a study[20] in which an increase in exercise during the 1 and 2 months prior to death or euthanasia was not a risk factor for injury when other factors, including preexisting injury such as MLSAI, were included in the analysis. The MLSAI would likely have been detected during a veterinarian assessment of risk, which was associated with a 10-fold increase in the risk of catastrophic injury[20] and was based in part on prerace palpation of the distal portion of the limbs. Although MLSAI may be a better indicator of risk for developing SAF, exercise remains an important risk factor for developing SAF because it is associated with development of MLSAI[21] and is thus on the causal pathway of SAF.

Horseshoe characteristics were associated with injury, but the factor most strongly associated with injury was use of pads; thus, our study differed from another study[12] in which toe grabs were the most strongly associated factor. Height of toe grab, which has been associated with development of SAF and CDY,[12] did not significantly increase risk of either injury in the study reported here when we accounted for other risk factors. Toe grabs are a risk factor for development of MLSAI,[11] and they were associated with MLSAI and exercise in our study (Tables 4 and 5). The stronger association between height of toe grab and development of SAF or CDY reported in another study[12] may have included the unmeasured effects of MLSAI and exercise. Alternatively, the effect of height of toe grab in the study reported here may have been diluted by reshoeing horses that had signs of soreness because of industry awareness of risks associated with toe grabs. Although height of toe grab was not included in either logistic regression model in our study, it may remain a risk factor for both injuries by contributing to MLSAI.

To our knowledge, the use of pads with horseshoes has not been associated with development of SAF. In another study,[12] investigators did not find an association between use of pads and development of SAF or CDY. Pads are designed to decrease limb concussion and reduce the risk of injury, and they may have done so for injuries other than SAF. Although unknown, it is possible that pads increased strain on soft tissue structures such as the suspensory apparatus. Alternatively, the association between use of pads and SAF may have not been causal (ie, a horse at risk for developing SAF may have been lame or sore; thus, pads were used). However, if the association between SAF and use of pads was the result of preexisting injury, we would have expected a similar association between development of CDY and use of pads. The reason for the association between use of pads and development of SAF is unclear. Horses in which pads are used should be monitored for development of injuries to the suspensory apparatus.

Other factors were also associated with development of SAF and CDY. Risk of developing SAF was associated with number of races, whereas risk of developing CDY was associated with age and sex. A horse in career race number 2 to 5 was 4 times more likely to develop SAF than a horse with more or fewer races. This spike may result when a horse entering race training accumulates sufficient fatigue damage that overt injuries occur. Alternatively, number of races may be associated with another unknown risk factor for SAF that was not measured in our study.

Risk of developing CDY was highest among males and horses 2 to 5 years old. The apparent sudden decrease in risk between the ages of 5 and > 5 years of age may have been attributable to a healthy-horse effect wherein horses predisposed to CDY injury retire by the age of 5 years, leaving an injury-resistant population of older horses. The increased risk of developing CDY among males was unexpected, and its cause is undetermined. Because geldings lack breeding potential, it has been assumed that geldings are more likely than sexually intact males to be overtrained and develop a serious injury and less likely to be treated rather than euthanatized after developing a fracture, but this assumption was not supported by the study reported here. Assessment of age-sex interaction was not possible because of sparse data for males and females in the older age categories.

Risk factors for development of SAF and CDY that have been studied separately were found to be interrelated.[11-15,18,19] Age and sex were associated, as were age and exercise, age and MLSAI, height of toe grab and MLSAI, and exercise and height of toe grab. Awareness of the complex relationships between these variables may aid in design of future studies and interpretation of published results.

In this cross-sectional study, covariates were recorded at the same time as outcome; therefore, it was not possible to determine temporal relationships between the studied risk factors and injury outcome. The MLSAI may have been a risk factor for development of SAF and CDY or it may have been a result of a catastrophic injury and excessive weight-bearing on the contralateral limb in the horse's subsequent steps. However, several pieces of evidence supported our hypothesis of a causal relationship between MLSAI and development of SAF or CDY. The results of the study reported here are consistent with results reported for other studies[1,6,11] of an association between preexisting palpable injuries of the suspensory apparatus and subsequent development of SAF or CDY. If MLSAI was subsequent to catastrophic injury as a result of weight redistribution on the forelimbs, then horses that died or were euthanatized because of other catastrophic forelimb injuries would have a similar prevalence of MLSAI. Furthermore, because MLSAI prevalence in our study horses did not differ between horses with catastrophic forelimb injuries other than SAF or CDY and horses without catastrophic injury,[a] it is unlikely that MLSAI was part of the catastrophic injury. Collectively, these findings support the concept that MLSAI preceded SAF and CDY.

Our multivariate model for risks associated with development of CDY closely fits the observed data ($P = 0.996$), whereas our comparable model for development of SAF did not ($P = 0.078$). In its final form, the SAF model accurately predicted outcome in 73% of horses, compared with 85% for the CDY model. Attempts to improve model fit included addition of interaction terms and potential confounders and assessments to detect outlying data points. Addition of interaction terms for many of the terms in the final SAF model did improve model fit but at the expense of interpretability; thus, odds ratios became extreme and biologically implausible. Poor SAF model fit may have been attributable to the effects of risk factors not measured in the study.

Any epidemiologic study is limited by the factors chosen for study. In the study reported here, we chose to concurrently examine several factors (exercise, MLSAI, and horseshoe characteristics) that had separately been associated with injury development[11-15,18,19] and were believed to be potentially interrelated. Our approach yielded results that differed from those that had been reported when the factors were studied separately. Conversely, other factors not measured in our study, such as racetrack,[1,35] track surface,[35] track condition,[35] horse class,[1] and race number,[1] also reportedly increase risk of developing musculoskeletal injury and could have been related to factors included in our study. Inclusion of these additional factors, or other as-yet-undiscovered factors, in an analysis of injury could more precisely estimate the effects of each risk factor and result in conclusions that differed from those reported here.

The control group in our study included catastrophically injured and noninjured horses. Inclusion of horses with other catastrophic injuries allowed for identification of risk factors associated specifically with development of SAF or CDY without identification of risk factors common to development of all musculoskeletal injuries. However, it has been reported that specific catastrophic injuries (eg, humeral fractures) have been associated with specific exercise patterns, such as a short interval since layup.[17] To assess bias on the control group from exercise-associated risk resulting from specific musculoskeletal injuries, the data were modeled again by use of horses without musculoskeletal injury as a control group. In both analyses, the same exercise variables were identified as risk factors for development of injuries (data not shown).

Forelimb SAF and metacarpal CDY were associated with MLSAI, high-speed exercise, and in the case of SAF, use of pads on horseshoes. Although palpable injuries of the suspensory apparatus, exercise, and horseshoe characteristics have been separately identified as risk factors for SAF and CDY, inclusion of all factors in a single analysis yielded important new findings. The risks of injury associated with recent exercise and height of toe grab were lower when MLSAI was accounted for. Exercise and toe grabs may affect risk of MLSAI; however, once it has developed, MLSAI is the stronger predictor of subsequent injury. Seventy-one percent (35/49) of horses with MLSAI died or were euthanatized because of SAF or CDY. Reducing exercise intensity in horses with MLSAI (or resting those horses) until the injury has healed may decrease the incidence of SAF and CDY in Thoroughbred racehorses.

[a]Hill AE. *Epidemiologic investigation of non-catastrophic suspensory apparatus injury in California Thoroughbred racehorses*. PhD Dissertation, University of California, Davis, Calif, 2003.
[b]Borland C++ builder, version 5.0, Inprise Corp, Scotts Valley, Calif.
[c]Natural balance shoe, Equine Digit Support System Inc, Penrose, Colo.
[d]World racing plate, Thoro'Bred Inc, Anaheim, Calif.
[e]SPSS, version 10.0, SPSS Inc, Chicago, Ill.
[f]PROC FREQ, SAS, version 8.02, SAS Institute Inc, Cary, NC.
[g]Egret for Windows 2.0, Cytel Software Corp, Cambridge, Mass.

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Appendix appears on the next page

Appendix

Definition of exercise variables included in risk-factor analysis.

Variables	Definition
Cumulative career variables	
Race distance	Distance raced
Workout distance*	Distance of workouts
Total distance	Distance raced plus distance of workouts
No. of races	No. of races performed
No. of workouts*	No. of workouts conducted
Career days	No. of days in career (ie, date of death minus date of first recorded speed event [race or workout])
Mean career variables	
Mean race distance	Total of all distances raced divided by No. of races
Mean workout distance	Total of all workout distances divided by No. of workouts
Mean total distance	Total distance divided by the sum of the No. of races plus No. of workouts
Layup variables†	
No. of layups	No. of layups
Total layup days	Total No. of days spent in layup
Mean layup days	Total layup days divided by No. of layups
Layup percentage	Total layup days divided by the No. of career days and the quotient multiplied by 100
Variables for active periods	
Active days	Career days minus total layup days
Days between races while active	Active days divided by No. of races
Days between workouts while active	Active days divided by No. of workouts
Mean No. of days to accumulate 1 furlong of exercise while active	Active days divided by total distance
Time variables	
Days since layup	Days since end of last layup; if horse had no layups, then days since start of career
Distance in last month	Total distance during the 30 days prior to death or euthanasia
Distance in last 2 months	Total distance during the 60 days prior to death or euthanasia
Difference in distance for each of last 2 months	Difference in total distance during 30 days prior to death or euthanasia minus total distance during days 31 to 60 prior to death or euthanasia
Difference in distance for last 2 months and months 3 and 4 before death or euthanasia	Difference in total distance during the 60 days prior to death or euthanasia minus total distance during days 61 to 120 prior to death or euthanasia

*Workouts refers to officially timed workouts (ie, sprints). †A layup is a period of ≥ 60 days without a recorded speed event (race or workout). ‡Active periods are periods during which horses conducted recorded speed events (race or workout) with < 60 days between successive events.

For all variables, distances were in furlongs (1 furlong = 0.2 km) and times were in days.