Risk factors for proximal sesamoid bone fractures associated with exercise history and horseshoe characteristics in Thoroughbred racehorses

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Objective—To assess individual and combined associations of high-speed exercise and horseshoe characteristics with risk of forelimb proximal sesamoid bone fractures and proximal sesamoid bone midbody fractures in Thoroughbred racehorses.

Animals—269 deceased Thoroughbred racehorses.

Procedures—A case-control study design was used to compare 121 horses with a fracture of at least 1 of 4 forelimb proximal sesamoid bones (75 horses had a midbody fracture) and 148 horses without a forelimb proximal sesamoid bone fracture. Univariable and multivariable logistic regression analyses were used to evaluate potential risk factors for association with proximal sesamoid bone fracture.

Results—Compared with horses that died without proximal sesamoid bone fractures, horses that died with proximal sesamoid bone fractures were more likely to be sexually intact males, spend more time in active training and racing, complete more events, train and race longer since their last layup, have higher exercise intensities during the 12 months prior to death, and have greater cumulative distances for their career. Horses with proximal sesamoid bone midbody fractures were more likely to be sexually intact males, train and race longer since their last layup, and have higher exercise intensities during the 12 months prior to death.

Conclusions and Clinical Relevance—Limiting exercise intensity and the continuous time spent in activity during a horse's career may decrease the frequency of forelimb proximal sesamoid bone fractures in Thoroughbred horses. (*Am J Vet Res* 2007;68:760–771)

Substantial physical demands are placed on the musculoskeletal system of Thoroughbred racehorses during the high speeds reached during racing and training.[1] Musculoskeletal injuries that range from soft tissue damage to complete bone fracture can be acute manifestations of chronic musculoskeletal damage accumulated during training and racing.[2,3] Although bone and supportive structures of the musculoskeletal system commonly adapt to increasing frequency and intensity of exercise and avoid overt injury,[4-6] repetitive activity incurred in a time frame insufficient for adaptation leads to injury.[7] The latter scenario plays a key role in the development of stress fractures of long bones, which are known to progress to a complete fracture if repetitive activity resumes without sufficient time for adequate healing and repair.[8]

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Abbreviations

PSB	Proximal sesamoid bone
CAHFSL	California Animal Health and Food Safety Laboratory
CHRB	California Horse Racing Board
OR	Odds ratio

Proximal sesamoid bone fractures are the principal cause of catastrophic suspensory apparatus failure in Thoroughbred racehorses.[9-12] No epidemiologic studies have directly investigated the role of Thoroughbred racehorse exercise history or horseshoe characteristics (ie, toe grabs) in the etiopathogenesis of PSB fractures. Closely related studies[11,13-18] of suspensory apparatus injuries, including fractures of the PSBs, have revealed associations between catastrophic suspensory apparatus injury and horse demographics (age or sex), horseshoe characteristics, hoof toe-heel angle, mild suspensory apparatus injury, and exercise history. Risk factors for catastrophic suspensory apparatus injury in Thoroughbred racehorses include increasing age,[13] male sex,[13] horseshoe toe grabs,[14] horseshoe pads,[15] increasing hoof toe-heel angle,[16] prior evidence of mild suspensory apparatus injury found during physical examination,[10,17,18] actively training but not racing,[13] greater time between layups, 2 to 5 career races, and high exercise intensity.[15] Conversely, no association was found between catastrophic suspensory apparatus injury and cumulative exercise history variables.[13] Several of these factors could be managed for the prevention of PSB fractures.

Results of previous studies[14,15] indicate that complete long bone fractures are often preceded by stress fractures that are likely related to repetitive activities[2,3] and that risk for development of a suspensory apparatus failure increases with exercise intensity and use of horseshoe toe grabs or pads. It is likely that fractures of the PSBs result from similar injury because of repetitive exercise and share these risk factors. The study reported here was performed as an extension of a prior descriptive study[19] of PSB fractures in deceased California Thoroughbred racehorses to determine risk factors for PSB fractures in the same group of horses. The objectives of the present study were to evaluate racing-speed exercise history and horseshoe modifications, separately and concurrently, as risk factors for development of PSB fractures in a population of racing Thoroughbred horses that died at racetracks in California.

Materials and Methods

Horses—Two hundred sixty-nine racing Thoroughbred horses, age 2 to 5 years, that died between November 11, 1999, and December 19, 2002, and were necropsied through the CAHFSL for the CHRB Postmortem Program were studied. Pathologists at the CAHFSL examine all horses that die or are euthanized on sanctioned racetrack premises in California. Six hundred sixty Thoroughbred horses were examined through the CHRB Postmortem Program during that time period. This study sample (41% of all necropsied horses for the time period of the study) was a convenience sample dictated by the ability of pathologists and staff to collect, package, and send bilateral forelimb samples (from the carpus distally) from distant laboratories to our research facility. The present study examined PSBs from 269 of 301 horses that were studied previously for risk factors for suspensory apparatus failure, lateral condylar fracture, and horseshoe characteristics.[15] Thirty-two horses were excluded from the study on the basis of age ≥ 6 years or lack of official exercise history. Necropsy data were obtained from the CAHFSL records and included age (years) and sex (female, gelding, or sexually intact male) of each racehorse. Age and sex for all horses that raced or had officially timed workouts at racetracks in California during the same time period were obtained as a customized report from a commercial database.[a]

PSB fractures—Evidence, or lack thereof, of fractures of the forelimb PSBs and location of the fracture within the body of the PSB were previously reported.[19] Briefly, locations of fractures in the medial and lateral PSBs of the left and right forelimbs were determined from palmarodorsal contact radiographs. Proximal sesamoid bone fracture location was categorized as apical (proximal third), midbody (middle third), basilar (distal third), or abaxial or axial for longitudinally oriented fractures adjacent to the abaxial and axial surfaces, respectively. Chip fragments of ≤ 2 mm in greatest dimension on the palmarodorsal radiographic projection were not included as fractures. Horses with a fracture in any PSB were designated as cases, and horses that did not have a PSB fracture were used as control horses.

Racing-speed exercise history—Career race and officially timed work reports for each horse were obtained from a commercial database of official racing industry records.[a] The reports include the distance (in furlongs) and date of each race and officially timed racing-speed workout in each horse's racing career. From the distance and date information, variables were created by extracting the commercial data by use of a custom-made computer program used in a previous study[15] and were used to describe exercise characteristics over time for each horse. Variables were related to career (from the date of the first recorded event to date of death), layup, and active (nonlayup) portions of the career, where a layup is defined as a period of ≥ 60 days without a recorded race or an officially timed workout. Variables included events (**Appendix 1**), distances (**Appendix 2**), and time periods of racing and training (**Appendix 3**). Within each variable class, variables were separated into cumulative measures (eg, No. of workouts, races, and days in racing) and rate measures (eg, workouts/y, furlongs/mo).

Horseshoe characteristics—Toe grab height, rim, and pad devices were recorded for this group of horses in a prior study.[15] Toe grab was categorized into 5 height intervals at necropsy by measuring the height of a steel bar affixed to the ground surface at the front of the shoe (ie, toe grabs). Height categories were based on the distance that the toe grab projected from the track surface of the shoe (0 mm, > 0 to ≤ 2 mm, > 2 to ≤ 4 mm, > 4 to ≤ 6 mm, and > 6 to ≤ 8 mm). Horseshoe rims and pads were recorded as present or absent.

Statistical analysis—Distributions of age and sex between case and control horses and between horses with midbody fracture and control horses were compared by use of χ^2 analysis.

Logistic regression[b] was used to assess univariable relationships for age, sex, exercise, and horseshoe variables between control and case horses and between control horses and the subset of horses with a PSB midbody fracture and to identify candidate variables for multivariable analyses. Significance was set at $P < 0.05$.

Exercise and horseshoe variables that were associated with case horses or the subset of horses with

Table 1—Distribution (No. of horses) of age and sex categories in deceased Thoroughbred racehorses without PSB fracture (control horses; n = 148), with any forelimb PSB fracture (121), or with forelimb midbody PSB fracture (75).

Variable	Control	PSB fracture	Midbody fracture
Age (y)			
2	26	18	12
3	57	47	29
4	42	35	20
5	23	21	14
All ages	148	121	75
Sex			
Female	66	41	18
Gelding	57	45	32
Sexually intact male	25	35	25

a midbody PSB fracture with a value of $P \leq 0.2$ were included as candidate variables in a starting model for multivariable analyses. Age (2, 3, 4, or ≥ 5 years, treated as a categoric variable and a continuous variable) and sex (female, sexually intact male, or gelding) were included in all models as potential confounding variables because results of prior studies[9,13,15,20,21] indicated that these were associated with risks for general musculoskeletal injuries. Model fit was estimated by use of the Hosmer-Lemeshow goodness-of-fit statistic; a higher *P* value was considered to indicate a better fit to the model. Stepwise forward and backward logistic models were examined. Significance level of the χ^2 value for entering variables into the forward and stepwise logistic regression models was set at 0.05. Associations were reported as crude ORs (univariable) or adjusted ORs (multivariable models) and 95% confidence intervals.

Results

PSB fractures—Of the 269 horses, 121 (45%) had a PSB fracture of 1 or more of the 4 PSBs in the forelimbs **(Table 1)**. Seventy-five of the 121 horses had a midbody PSB fracture. The remaining 148 horses had no forelimb PSB fracture and were designated as control horses. Causes of death for the 148 control horses included nonmusculoskeletal medical causes (eg, colic, pleuropneumoniae [32%]), humeral fracture (11%), carpal bone fracture (10%), third metacarpal lateral condylar fracture (8%), third metacarpal diaphyseal fracture (7%), pelvic fracture (7%), proximal phalangeal fracture (5%), suspensory ligament avulsion with lateral condylar fracture (4%), tibial fracture (3%), vertebral fractures (3%), suspensory ligament avulsion (3%), scapular fractures (2%), laminitis (2%), middle phalangeal fracture (1%), superficial digital flexor tendon laceration (1%), and hind limb PSB fracture (1%).

Age—Age distribution for all horses that had a race or officially timed workout in California during the same time period as the study population differed significantly ($P < 0.001$) from the age distribution for all 269 horses in the study population. Two-year-old horses were underrepresented and older horses (ages 3, 4, and 5 years) were overrepresented in the

Table 2—Age and sex distributions (No. [%]) among 269 deceased Thoroughbred racehorses with and without PSB fractures (sample population) and all horses that raced or had officially timed workouts in California (racetrack population) during a 37-month study period.

	Age (y)				
Group and sex	**2**	**3**	**4**	**5**	**All ages**
Sample population					
Female	19	35	34	19	107 (40)
Gelding	16	39	25	22	102 (38)
Sexually intact male	9	30	18	3	60 (22)
Total	**44 (16)**	**104 (39)**	**77 (29)**	**44 (16)**	**269 (100)**
Racetrack population					
Female	5,164	5,838	3,451	1,610	16,063 (46)
Gelding	3,271	3,670	2,618	1,651	11,210 (32)
Sexually intact male	2,385	2,712	1763	917	7,777 (22)
Total	**10,820 (31)**	**12,220 (35)**	**7,832 (22)**	**4,178 (12)**	**35,050 (100)**

Table 3—Associated ORs for age as a continuous variable in deceased Thoroughbred racehorses without PSB fracture (control horses; n = 148), with any forelimb PSB fracture (121), or with forelimb midbody PSB fracture (75).

	Control	PSB fracture				Midbody fracture			
Variable	**Median (range)**	**Median (range)**	**OR**	**95% CI**	***P* value**	**Median (range)**	**OR**	**95% CI**	***P* value**
Age (y)	3 (2–5)	3 (2–5)	1.08	0.84–1.37	0.534	3 (2–5)	1.20	0.91–1.59	0.201

Odds ratios calculated with control horses as the referent group via univariate analysis.
CI = Confidence interval.

Table 4—Associated ORs for sex categories with sexually intact males as the referent group in deceased Thoroughbred racehorses without PSB fracture (control horses; n = 148), with any forelimb PSB fracture (121), or with forelimb midbody PSB fracture (75).

	PSB fracture			Midbody fracture		
Sex	**OR**	**95% CI**	***P* value**	**OR**	**95% CI**	***P* value**
Female	0.44	0.23–0.85	0.038	0.27	0.13–0.58	0.002
Gelding	0.57	0.30–1.1	0.566	0.57	0.28–1.15	0.760
Sexually intact male	Referent			Referent		

See Table 3 for key.

study population, compared with the live racetrack population (**Table 2**).

Distribution of horses by age groups was not different between control and case horses or between control horses and the subset of cases with midbody fractures (**Table 3**). Age was treated as a continuous variable because univariable relationships with categoric age groups were approximately linear for comparisons of interest. As such, individual ORs by age level were not calculated.

Sex—Sex distribution of all horses that had a race or an officially timed workout in California was not significantly different from sex distribution of case horses (*P* = 0.08 [Table 2]). Sex distribution of case horses and horses with a midbody fracture differed significantly from that of control horses (**Table 4**). Compared with female horses, sexually intact male horses were 2.3 or 3.7 times as likely to incur any fracture or midbody fractures, respectively, of the PSBs. Proximal sesamoid bone fractures and PSB midbody fractures in geldings

Table 5—Distribution of variables associated with racing and training among deceased Thoroughbred racehorses without PSB fracture (control horses; n = 148), with any forelimb PSB fracture (121), or with forelimb midbody PSB fracture (75).

	Control	PSB fracture				Midbody fracture			
Variable	Median (range)	Median (range)	OR	95% CI	*P* value	Median (range)	OR	95% CI	*P* value
Events									
Works	21 (1–94)	26 (2–98)	1.02	1.00–1.03	0.028	26 (4–89)	1.015	1.000–1.030	0.058
Races	6 (0–43)	8 (0–41)	1.03	0.99–1.06	0.075	7 (0–34)	1.017	0.983–1.053	0.331
Events	26 (1–127)	36 (2–118)	1.01	1.00–1.02	0.026	36 (4–109)	1.010	0.999–1.021	0.083
Layups	1 (0–4)	1 (0–4)	0.93	0.72–1.20	0.565	1 (0–4)	1.015	0.762–1.353	0.918
Event rates									
Works/career y	22.1 (2.7–76.0)	23.3 (4.5–55.6)	1.00	0.98–1.02	0.824	20.9 (4.5–47.0)	0.994	0.972–1.018	0.641
Races/career y	4.7 (0–23.8)	6.4 (0–15.6)	1.07	1.01–1.14	0.020	5.8 (0–15.6)	1.036	0.968–1.108	0.309
Events/career y	29.3 (2.7–76.0)	31.1 (5.5–62.9)	1.01	0.99–1.03	0.568	28.8 (5.5–55.5)	0.999	0.977–1.021	0.905
Works/active y	33.7 (10.2–78.2)	31.9 (15.1–81.1)	0.98	0.96–1.01	0.131	31.8 (18.7–81.1)	0.992	0.968–1.016	0.502
Races/active y	7.8 (0–23.8)	9.0 (0–24.1)	1.07	1.01–1.12	0.025	9.0 (0–24.1)	1.040	0.980–1.105	0.196
Events/active y	41.4 (25.5–78.2)	40.6 (24.0–81.1)	0.99	0.97–1.02	0.454	40.8 (26.3–81.1)	0.997	0.969–1.027	0.849

Works = Workouts. Events = Combined workouts and races.
See Table 3 for remainder of key.

Table 6—Distribution of variables associated with distances of racing and training among deceased Thoroughbred racehorses without PSB fracture (control horses; n = 148), with any forelimb PSB fracture (121), or with forelimb midbody PSB fracture (75).

	Control	PSB fracture				Midbody fracture			
Variable	Median (range)	Median (range)	OR	95% CI	*P* value	Median (range)	OR	95% CI	*P* value
Career distances (furlongs)									
Works	92 (3–397)	111 (6–461)	1.00	1.00–1.01	0.035	111 (15–412)	1.00	1.00–1.01	0.066
Races	36 (0–326)	50 (0–292)	1.00	0.99–1.01	0.088	48 (0–227)	1.00	0.99–1.01	0.339
Events	130 (3–622)	170 (6–597)	1.00	1.00–1.01	0.035	168 (15–576)	1.00	1.00–1.00	0.110
Accrued distance before death (furlongs)									
1 mo	15 (0–37)	18 (0–32)	1.05	1.02–1.08	0.004	18 (0–32)	1.04	1.01–1.08	0.019
2 mo	28 (0–58)	34 (0–58)	1.03	1.01–1.05	0.004	33 (0–58)	1.02	1.00–1.05	0.029
4 mo	49 (0–107)	63 (5–108)	1.03	1.01–1.04	< 0.001	62 (5–108)	1.02	1.01–1.03	0.001
6 mo	62 (0–160)	85 (6–161)	1.02	1.01–1.03	< 0.001	82 (12–161)	1.02	1.01–1.03	< 0.001
8 mo	75 (0–215)	109 (6–196)	1.02	1.01–1.02	< 0.001	106 (12–196)	1.01	1.01–1.02	< 0.001
10 mo	88 (0–256)	121 (6–226)	1.01	1.01–1.02	< 0.001	115 (14–226)	1.01	1.00–1.02	< 0.001
12 mo	93 (0–256)	128 (6–268)	1.01	1.00–1.01	< 0.001	126 (15–264)	1.01	1.00–1.01	0.002
Distance/event (furlongs)									
Works distance	4.26 (1.33–5.31)	4.29 (3.00–5.36)	1.55	0.96–2.50	0.075	4.3 (3–5.1)	1.57	0.90–2.73	0.113
Races distance	6.10 (0–9.15)	6.33 (0–8.33)	1.21	1.07–1.38	0.003	6.3 (0–8.3)	1.20	1.03–1.39	0.017
Events distance	4.68 (1.33–6.51)	4.79 (3.00–6.12)	1.48	1.04–2.12	0.031	4.7 (3.2–6.1)	1.38	0.92–2.06	0.118
Distance rates (furlongs/mo)									
Works/career mo	7.6 (0.9–25.6)	8.1 (1.7–18.4)	1.02	0.96–1.08	0.526	7.7 (1.7–18.4)	1.01	0.95–1.08	0.739
Races/career mo	2.6 (0–12.6)	3.6 (0–9.3)	1.15	1.03–1.28	0.014	3.2 (0–9.3)	1.07	0.95–1.21	0.252
Events/career mo	11.4 (0.9–29.4)	11.8 (1.7–22.6)	1.05	0.99–1.10	0.086	11.8 (1.7–22.6)	1.02	0.97–1.09	0.412
Works/active mo	11.8 (4.0–25.6)	11.3 (4.9–25.0)	0.98	0.93–1.05	0.599	11.3 (6.2–25.0)	1.01	0.94–1.08	0.815
Races/active mo	4.1 (0–12.5)	4.7 (0–13.9)	1.12	1.02–1.23	0.023	4.5 (0–13.9)	1.07	0.97–1.19	0.180
Events/active mo	15.8 (4.3–29.4)	16.0 (9.0–25.0)	1.03	0.97–1.10	0.298	16.2 (9.0–25.0)	1.04	0.97–1.12	0.246

See Tables 3 and 5 for key.

Table 7—Distribution of variables associated with duration of racing and training among deceased Thoroughbred racehorses without PSB fracture (control horses; n = 148), with any forelimb PSB fracture (121), or with forelimb midbody PSB fracture (75).

	Control	PSB fracture				Midbody fracture			
Variable	Median (range)	Median (range)	OR	95% CI	*P* value	Median (range)	OR	95% CI	*P* value
Career days	442 (7–1,415)	460 (16–1,303)	1.00	1.00–1.00	0.323	444 (79–1,303)	1.00	1.00–1.00	0.251
Active (nonlayup) days	272 (7–1,123)	315 (16–1,024)	1.00	1.00–1.00	0.037	298 (18–919)	1.00	1.00–1.00	0.144
Layup time	154 (0–745)	111 (0–699)	1.00	0.99–1.00	0.399	140 (0–699)	1.00	0.99–1.00	0.783
Mean layup length	116 (0–525)	101 (0–611)	1.00	0.99–1.00	0.714	123 (0–611)	1.00	0.99–1.00	0.574
Days since last layup	46 (0–1,040)	153 (0–837)	1.00	1.00–1.00	0.010	117 (0–837)	1.00	1.00–1.00	0.019
Days between works for career	16.5 (4.8–136.3)	15.7 (6.6–81.3)	0.99	0.97–1.01	0.152	17.5 (7.8–81.3)	0.99	0.97–1.01	0.414
Days between races for career	65 (15.3–669)	56.8 (23.4–359)	1.00	0.99–1.00	0.075	60.6 (23.4–359)	1.00	0.99–1.00	0.419
Days between events for career	12.4 (4.8–136.3)	11.8 (5.8–66)	0.98	0.95–1.00	0.099	12.7 (6.6–66)	0.99	0.96–1.01	0.358
Days between works for active periods	10.8 (4.7–35.8)	11.4 (4.5–24)	1.02	0.96–1.08	0.586	11.5 (4.5–19.5)	1.00	0.93–1.06	0.873
Days between races for active periods	41.3 (15.3–225)	40 (15–170)	1.00	0.99–1.01	0.349	40.5 (15–170)	1.00	0.99–1.01	0.835
Days between events for active periods	8.8 (4.7–14.3)	9 (4.5–15.2)	1.03	0.91–1.12	0.630	8.9 (4.5–14)	1.00	0.86–1.16	0.991
Days to 1 work furlong for career	4.0 (1.2–32)	3.7 (1.6–17.6)	0.94	0.87–1.01	0.091	3.9 (1.6–17.6)	0.96	0.88–1.04	0.286
Days to 1 race furlong for career	9.3 (2.4–102.9)	8.2 (3.2–119.7)	0.98	0.97–1.01	0.170	9 (3.2–119.7)	1.00	0.98–1.02	0.727
Days to 1 event furlong for career	2.6 (1–32)	2.5 (1.3–17.6)	0.90	0.80–1.00	0.059	2.6 (1.3–17.6)	0.94	0.85–1.04	0.241
Days to 1 work furlong for active periods	2.5 (1.2–7.4)	2.7 (1.2–6)	0.97	0.77–1.23	0.820	2.6 (1.2–4.8)	0.89	0.68–1.18	0.423
Days to 1 race furlong for active periods	6.5 (2.4–27.2)	6 (2.2–28.3)	0.99	0.94–1.03	0.512	6.3 (2.2–28.3)	1.01	0.97–1.06	0.603
Days to 1 event furlong for active periods	1.9 (1–7)	1.9 (1.2–3.3)	0.72	0.46–1.13	0.153	1.9 (1.2–3.3)	0.70	0.41–1.20	0.196

See Tables 3 and 5 for key.

did not differ in distribution between females and sexually intact males.

Univariable analysis—Fractures of the PSB were significantly associated with several exercise variables (**Tables 5–7**). All horses had a recorded workout, but 29 of the 269 horses had not raced.

Events—Horses with any fracture of the PSBs had more total workouts and events than horses without PSB fracture (Table 5). Horses with any PSB fracture also had a greater number of races per year for their career and for the portion of their career that they were actively racing (ie, not in a layup period) than horses without PSB fracture.

Distances—Horses with any PSB fracture had more career workouts and event furlongs and greater accrued monthly distances before death; longer distances per race and event; and more race furlongs per month during their career and during time of active racing (ie, not in a layup period) than horses without a PSB fracture (Table 6). Horses with PSB fractures consistently had more total furlongs per month during the last 8 of the 12 months prior to death, compared with horses without PSB fractures (**Figure 1**). Horses with a PSB midbody fracture had significantly greater accrued monthly distances before death and significantly higher distance per race than horses without PSB fractures.

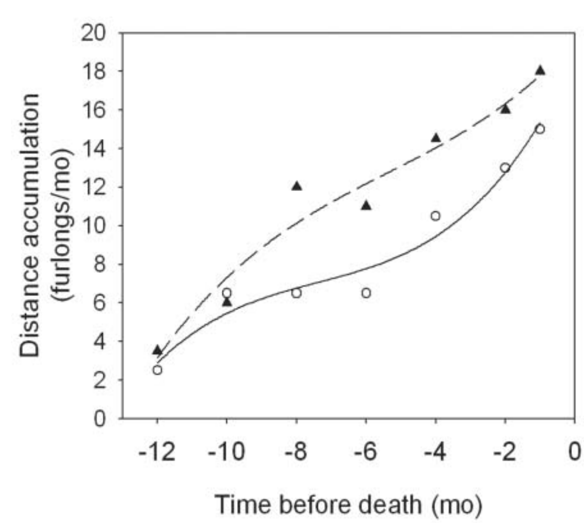

Figure 1—Monthly rate of distance accumulation for each of the time intervals during the 12 months prior to death for 269 deceased Thoroughbred racehorses with (triangles [n = 121]) and without (circles [148]) PSB fractures. Polynomial regression lines are illustrated for horses with (dashed line) and without (solid line) fracture of the PSB.

Time—The number of days a horse was active and the days since the last layup were greater for horses with PSB fractures than for horses without a PSB fracture (Table 7). Median layup time comprised 24% of

Table 8—Distribution of variables associated with horseshoes among deceased Thoroughbred racehorses without PSB fracture (control horses; n = 148), with any forelimb PSB fracture (121), or with forelimb midbody PSB fracture (75).

	No. of horses			PSB fracture			Midbody fracture		
Variable	Control	PSB fracture	Midbody fracture	OR	95% CI	*P* value	OR	95% CI	*P* value
Toe grab									
0 mm	23	16	11	0.75	0.34–1.63	0.613	1.08	0.43–2.70	0.988
> 0 to ≤ 4 mm	86	67	46	0.80	0.46–1.39	0.764	1.16	0.60–2.25	0.717
> 4 to ≤ 8 mm	39	38	18	Reference		Reference			
Rim									
Present	26	15	9	1.52	0.76–3.02	0.233	1.58	0.70– 3.56	0.274
Absent	122	106	66	Reference		Reference			
Pad									
Present	37	37	22	0.76	0.45–1.31	0.325	0.81	0.44–1.51	0.507
Absent	111	84	53	Reference		Reference			

See Tables 3 and 5 for key.

Table 9—Multivariable models for deceased Thoroughbred racehorses with any forelimb PSB fracture.

Variable	Hosmer-Lemeshow *P* value	*P* value	OR	95% CI	Adjusted OR	Difference in units
Female vs male	0.889	0.052	0.38	0.19–0.78		
Gelding vs male		0.194	0.43	0.21–0.88		
Distance 6 mo		< 0.001	1.02	1.01–1.03	1.699	23
Works		0.009	1.20	1.05–1.37	2.455	5
Work furlongs		0.009	0.96	0.93–0.99	0.473	19
Female vs male	0.446	0.063	0.42	0.21–0.86		
Gelding vs male		0.376	0.51	0.25–1.04		
Distance 6 mo		< 0.001	1.02	1.01–1.03	1.621	23
Races		0.083	1.22	0.98–1.52	1.481	2
Race furlongs		0.093	0.97	0.94–1.00	0.688	14
Female vs male	0.824	0.068	0.43	0.21–0.87		
Gelding vs male		0.384	0.52	0.25–1.05		
Distance 6 mo		< 0.001	1.02	1.01–1.03	1.643	23
Events		0.049	1.09	1.00–1.19	2.378	10
Event furlongs		0.050	0.98	0.97–1.00	0.522	40
Female vs male	0.918	0.039	0.39	0.98–0.78		
Gelding vs male		0.290	0.47	0.23-0.94		
Distance 2 mo		0.013	1.03	1.01–1.05	1.171	6
Works		0.030	1.16	1.01–1.32	2.070	5
Work furlongs		0.045	0.97	0.94–0.99	0.575	19
Female vs male	0.489	0.041	0.41	0.21–0.81		
Gelding vs male		0.402	0.51	0.26–1.01		
Distance 2 mo		0.011	1.03	1.01–1.05	1.170	6
Races		0.098	1.20	0.97–1.49	1.439	2
Race furlongs		0.162	1.00	0.95–1.01	0.742	14
Female vs male	0.609	0.046	0.43	0.22–0.84		
Gelding vs male		0.418	0.52	0.27–1.03		
Distance 2 mo		0.023	1.02	1.01–1.04	1.150	6
Events		0.093	1.07	0.99–1.16	2.011	10
Event furlongs		0.147	1.00	0.97–1.00	0.637	40

Male = Sexually intact male. Distance 6 mo = Accrued distance during the 6 months prior to death. Distance 2 mo = Accrued distance during the 2 months prior to death.
See Tables 3 and 5 for key.

median career time for horses with PSB fracture, compared with 34% of median career time for horses without PSB fracture. The number of days since last layup was greater for horses with a midbody PSB fracture than for horses without a PSB fracture.

Horseshoe characteristics—Toe grab data were collapsed from 5 to 3 categories (0 mm, > 0 to ≤ 4 mm, and > 4 to ≤ 8 mm) to obtain convergence of the univariable logistic regression model. Of 269 horses, 14% did not have horseshoe toe grabs, 57% had toe grabs ≤ 4 mm in height, and 29% had toe grabs ≥ 4 mm at the time of postmortem examination (**Table 8**). Fifteen percent of horses had shoes with rims, and 28% of horses had a shoe with a pad.

No significant differences ($P > 0.2$ for all comparisons) were detected in the distributions of toe grab heights, rims, or pads between horses with any PSB fracture or a midbody fracture of a PSB and horses without a PSB fracture.

Multivariable logistic regression—The best-fitting model for any PSB fracture included sex (female vs sexually intact male), total number of workouts, total workout distance, and distance accumulated in the 6 months prior to death (OR, 1.20, 0.96, and 1.02, respectively; **Table 9**). The OR adjusted for the difference between median values of horses with and without PSB fractures was 2.5 for 5 additional workouts, 0.47 for 19 additional workout furlongs, and 1.7 for 23 additional cumulative furlongs in the 6 months prior to death.

Because many exercise variables are highly correlated and previous studies[15,22] found relationships between high-speed distances acquired in the 2 months preceding injury or death, models with 2-month distance substituted for 6-month distance were also explored (Table 9). Workout and race incidence and rates are potential manageable factors, so models including these were also considered. The model that used distance at 2 months, number of workouts, and workout furlongs had the best fit.

The risk of PSB midbody fractures was lower (P = 0.003; OR, 0.2) for females and higher with greater accrued distance within 8 months prior to death (P < 0.001; OR, 1.014/furlong), compared with sexually intact males. The OR adjusted for a 31-furlong difference between horses with PSB midbody fractures and horses without PSB fractures was 1.52.

Discussion

This retrospective study provides useful insight into exercise factors that are associated with severe PSB fracture. However, retrospective studies alone do not provide direct evidence for cause-and-effect relationships. Evidence for a cause-and-effect relationship is strengthened by a logical and biological rationale for a relationship between exercise and fracture. Given that there was no direct external trauma or systemic bone disease (unlikely in the Thoroughbred racehorse population studied), exercise was required for PSB fracture to occur. Bone fractures secondary to repetitive exercise activities are well documented in equine athletes.[2,3,7,8] The associations between exercise and severe PSB fracture are interesting and potentially useful because exercise can be managed for injury prevention. A prospective, cohort study with findings similar to those of the present study would lend credence to a cause-and-effect relationship. Prospective studies require greater effort, expense, and time, but other factors related to both exercise and injury could confound either study.

Control horses were not intentionally matched by age or sex with case horses. By use of horses with fractures in any bone other than a PSB as control horses, results of the study identified factors specifically associated with PSB fracture, rather than identifying factors associated with general overtraining. Including horses with other fractures in the control group may have biased the results toward the null hypothesis because many control horses might have had the same training-related factors associated with repetitive overuse as case horses. Thus, the results were likely a conservative estimate of the association between racing and training and risk of PSB fracture. When data of the present study were analyzed by use of only the 47 horses without musculoskeletal injuries as control horses (data not reported), findings were similar to those reported. Reported associations for horses with PSB fracture must be interpreted relative to all horses in the control group. From this perspective, it is interesting that horses that died with PSB fracture had different exercise histories than horses that died from nonmusculoskeletal reasons or horses that died from a fracture of a bone other than the PSB. Further study is warranted to clarify the relationships with the live racehorse population.

The magnitude of risks observed in this study may be greater in the live racehorse population. Horses obtained for the present study from the CHRB Postmortem program were a subset of all horses that died or were euthanatized at racetracks because of musculoskeletal and nonmusculoskeletal causes. Sixty-two percent of control horses in the present study died from other skeletal fractures or suspensory apparatus failure (3%). Many of the same risk factors found in horses with a PSB fracture in the present study are also reported risk factors for all musculoskeletal injuries, compared with actively racing control horses. For example, in the present study, horses with a fatal PSB fracture had accumulated higher 2-month high-speed distances than horses without PSB fracture with any other fatal injury. In another study,[22] horses with any fatal musculoskeletal injury had higher 2-month high-speed distances than live, race-matched uninjured control horses.The observed exercise intensity risks in the 2 studies are likely additive because the control group for the first study was similar to the case group for the second study. Therefore, risks for PSB fracture in the present study are likely to be underestimates of risks for the live racehorse population.

Sexually intact male horses were 2.3 and 3.7 times as likely as female horses to incur any PSB fracture or midbody PSB fracture, respectively. No significant difference in distribution of PSB fractures was found for geldings, compared with females or sexually intact males. These findings are consistent with other studies[10,13,15,20,23] in which risk of musculoskeletal injury is lowest in females. Sex is likely confounding other more fundamental factors in the etiology of severe PSB fracture. In the study reported here, there was no evidence that sexually intact males participated in appreciably longer workouts or races than did females or geldings. Perceived horse value and postsurgical prognosis could influence decisions regarding treatment, salvage, and euthanasia. A larger proportion of females with mild to moderate injuries may be retired from racing to become broodmares and, thus, may not continue to accrue microdamage and injury risk. Alternatively, sexually intact males may be more aggressive and highly competitive, characteristics that may increase risk for injury and decrease chances for postoperative recovery from PSB fractures. Sex-related factors that affect perceived value could include race earnings potential and breeding earnings potential. Sex-related factors that affect assessment for surgical candidacy could include disposition of the horse and its management for recovery and rehabilitation.

Although age was not a measured risk factor for horses with PSB fractures in the present study, compared with horses that died of other causes, older horses that remain in racing may have increasing risk for musculoskeletal injury because of increasing event exposure. Alternatively, age-related remodeling and modeling changes in response to maturation and microdamage repair may reduce susceptibility of PSB to fracture. In the present study, distributions of PSB fractures and PSB midbody fractures were not different among horses from 2 to 5 years of age, regardless of whether age was treated as a continuous or categoric variable. Most prior studies[10,13,22-24] found an increase in musculoskeletal injury risk with age, whereas another found no age effect.[15] One possible explanation for the lack of an age relationship with PSB fracture in the present study and with suspensory apparatus failure in a related study[15] is that most control horses had musculoskeletal injuries of bones other than the PSB. Consequently, if the risk for most musculoskeletal injuries increases with horse age, then age effects are unlikely to be apparent in our comparisons of groups of horses with different musculoskeletal injuries. In fact, older horses were overrepresented in the present study, compared with the live racetrack population.

Median distance accumulation in workouts and in total events was higher in horses with PSB fractures than in horses without PSB fractures. For univariable analyses, cumulative workout furlongs and event (race plus workout) furlongs were significantly greater in horses with PSB fractures, compared with horses without PSB fractures. The paradoxical multivariate finding that greater workout distance was negatively associated with PSB fractures can be attributed to the specific statistical model. When considered simultaneously with factors such as age, sex, and additional exercise variables in the multivariable analysis, additional workout distance contributes simultaneously to 2 variables: workout distance and distance at 6 months. If a work furlong is added within an existing workout, the furlong is also added to distance at 6 months. The 2 regression coefficients in combination ($\beta = 0.02$ for 6 months and $\beta = 0.04$ for work furlongs) will always be negative. The only way for distance at 6 months to increase risk of injury is if furlongs are added via race furlongs or if furlongs are added via a new workout, rather than by extending an existing workout by an additional furlong. Horses with suspensory apparatus failure and lateral condylar fractures reported in a previous study of this data set also had higher median workout and event furlongs,[15] compared with horses without these injuries.

Horses with PSB fractures had higher rates of distance accumulation than horses without PSB fractures. In univariate results, the median rate of race distance accumulation per month was approximately 1.4 times greater for horses with PSB fractures, compared with horses without PSB fractures. Exercise intensity per month was highest at 1 month prior to death. In multivariable analysis, horses with PSB fractures had greater distance accumulation rates at 6 months prior to death, compared with horses without PSB fractures. The magnitude of the association was small by furlongs, but by use of the median difference between case and control horses in this study, a horse with 23 more cumulative training and racing furlongs (roughly 3 miles) during the 6-month period before death was 1.7 times as likely to sustain a PSB fracture.

Risks associated with exercise intensity may differ between horses racing inconsistently and horses racing on a regular basis. Similar to the present findings, exercise intensity was greater for California horses with nonspecific catastrophic musculoskeletal injury[22,25] as well as for horses with suspensory apparatus failure and lateral condylar fracture.[15] Case and control horses in the present study with a median of > 40 days between races might be considered to be inconsistent racers because a median of 17 days between races was reported for a control group of live racehorses in California.[22] Horses with and without forelimb PSB fracture entered a mean of 6 and 8 races/y, respectively, in the present study. In contrast, greater distance accrued during training for the 30 days prior to injury was not associated with risk for suspensory apparatus failure in New Zealand Thoroughbred racehorses.[13] Horses with greater distance accumulation during 1 to 2 months were at reduced risk for nonfatal, nonspecified musculoskeletal injuries at Florida[23] and Kentucky[26] racetracks. In a New York study,[24] horses that raced ≤ 6 times in a year were 3 times as likely to sustain a noncatastrophic injury that prevented racing for 6 months, compared with horses that raced 7 to 12 times in a year. However, in Florida, Thoroughbred racehorses were at greater risk for nonfatal and catastrophic musculoskeletal racing injuries if there were > 33 days between races.[21,23] Horses that have lower distance accumulation rates and fewer races per year probably have injuries that keep them from training and racing more often and are less physically fit, placing them at higher risk for acute injuries during a competitive high-speed event. Perhaps all horses in the present study were inconsistent racers and, thus, similar to the case horses in the Florida and Kentucky studies. Clearly, further consideration is needed to find a balance between achieving fitness for performance and overtraining, which leads to musculoskeletal injuries.

Comparisons among studies should be made with caution because outcomes, measured variables, sampling designs, and confounding variables differ among studies. Other factors not measured or considered, such as track condition, surface, and banking, could play additional roles in studies of injuries at different musculoskeletal locations. Exercise risk factors may be specific for different injury outcomes. A study[27] of humeral and pelvic fractures in California Thoroughbred racehorses found that horses that returned to training after a layup period of > 60 days were at greater risk for humeral fracture. Horses that sustained a complete pelvic fracture participated in more total number of continuous days in race training, compared with horses that sustained a complete fracture of the humerus.[27] In the present study, PSB fractures occurred after a long period of continuous activity. Horses with PSB fractures had a median of 107 more days of recent continuous racing and training than did horses without PSB fractures. Similarly, the time since a layup period in horses with suspensory apparatus failure and lateral condylar fracture was greater than that in horses without these injuries.[15]

Horses with PSB fractures had longer careers and more events than horses without PSB fractures; however, the median career lengths for horses with and without PSB fracture were only 1.3 and 1.2 years, respectively. Horses with PSB fractures spent more time in active training and racing (approx 1.3 months) and participated in higher numbers of workouts and combined workout-race events than did horses without PSB fractures. Horses that participated in a median of 5 more career workouts, the difference between case and control horses in this study, had 2.5 times the risk for PSB fractures. Horses with suspensory apparatus failure and lateral condylar fracture had significantly higher median active days in the prior study[15] of this data set. In that study, higher numbers of workouts were associated with increased risk for suspensory apparatus failure and lateral condylar fracture, and risk for suspensory apparatus failure was found to peak at 2 to 5 career races.

Many variables examined in the present study were interrelated. Variations of the multivariable model were explored to examine the associations between workouts, races, and total events with sex and cumulative distances at 2 and 6 months. The number of workouts and workout distance were significant factors in the original best-fit model. When the workout effects were substituted with races and total events, this produced reasonable but sometimes poorer model fit or less magnitude of association as measured by ORs. The interrelatedness between workout and race variables makes it difficult to separate workout and race-related risks for PSB fracture.

Horseshoe toe grab height should not be excluded as a potential risk factor for suspensory apparatus failure or PSB injuries. Toe grab height was identified as a risk factor for suspensory apparatus failure in a previous postmortem study[14] of Thoroughbred racehorses, in which horses shod with low toe grabs were 6.5 times as likely to have suspensory apparatus failure as horses without toe grabs and horses with regular toe grabs were 15.6 times as likely to have a suspensory apparatus failure, but not in a postmortem study[28] of mixed-breed racehorses. Although toe grab height was not a significant risk factor in the multivariable or univariable models in the present study, a prior related study,[15] and a Florida study,[23] the direction of the relationship between toe grab height and injury in both studies was consistent with higher risk with higher toe grabs. Furthermore, toe grab height is associated with the development of mild suspensory apparatus injury,[18] which is a risk factor for suspensory apparatus failure.[29] The use of high toe grabs has decreased in recent years,[30] and variability in toe grab height is associated with 10% to 16% of the variability in exercise variables,[15] perhaps making it more difficult to detect a significant toe grab effect in univariable and multivariable analyses, respectively. It is possible that a toe grab effect is also confounded by other factors; but in the absence of other known relationships, avoidance of use of high (≥ 4 mm) toe grabs is still recommended for injury prevention.

The associations between other horseshoe characteristics and risk of injury are less clear. In the present study, horses shod with rim or pad features were not at significantly greater risk for PSB fractures than were horses without rims or pads. A prior study[15] of a subset of this population of horses revealed that the use of horseshoe pads was associated with suspensory apparatus failure, although a causal relationship was not identified. High toe-hoof angle was also a risk factor for suspensory apparatus failure.[16,21]

There was no evidence that exercise history of horses with midbody fractures of the PSBs was different from that of horses with any PSB fracture. Proximal sesamoid bone midbody fractures were the most common PSB fracture.[19] Because PSB midbody fractures accounted for approximately 60% of all PSB fractures, it is not surprising that fewer risk factors were associated with fewer numbers of PSB midbody fractures. Horses with PSB midbody fractures had higher median accrued monthly distances prior to death and higher mean distance per race than did horses without any PSB fracture. In multivariable analysis, horses with PSB midbody fractures were significantly more likely to be sexually intact males and accumulate greater furlong distances in 8 months prior to death, compared with horses without PSB midbody fractures.

Exercise changes that reduce the incidence of PSB fractures may increase the incidence of other musculoskeletal injuries. Findings from the present study support the recommendation that limiting exercise intensity and continuous time spent in racing-speed activity during a racing career for Thoroughbred racehorses may lower the incidence of PSB fractures. Proximal sesamoid bone fracture occurred more frequently in limbs from actively exercising horses in an in vitro biomechanical study,[5] whereas soft tissue suspensory ligament rupture occurred more frequently in horses that were not trained (pasture only). However, limiting continuous time in activity may increase risk for humeral fractures that have been associated with longer layup time, shorter time since layup, and increased interval between races.[27] In addition, horses with fewer race starts per year were at higher risk for musculoskeletal injuries at New York racetracks.[24] Failure to consider possible effects of confounding factors may explain discrepancies in findings among risk factor studies. However, because PSB fractures are the most common catastrophic injury of Thoroughbred racehorses in the United States, a decrease in the incidence of PSB fractures by limiting exercise intensity and continuous time in activity, even if offset by an increase in other less frequent injuries, would likely decrease overall injury incidence. It is less clear how reduction in exercise intensity should be partitioned between works and races.

Exercise at slower gaits may contribute to development of musculoskeletal injury. Official racing-speed exercise records are only 1 component of the exercise history. However, this index captures the high physical loads that are likely to induce musculoskeletal damage. A recent study[31] examined cumulative distance during unofficial cantering and official racing-speed (gallop) recorded training sessions in 2-year-old racing Thoroughbreds in the United Kingdom. In multivariate analysis, accumulation of canter distance during the 30 days prior to detection of nonfatal pelvic and tibial stress fractures was an associated risk factor for these injuries, but not the distance accumulated during high-speed workouts. It is interesting that in the present study, workout-related factors, which are usually less physically demanding than races, had stronger associations in the multivariate analysis than did race-related factors.

Findings of the present study support the concept that microdamage of the PSBs likely develops in response to increased workloads associated with distance and number of events. Exercise and racing-speed activity, which is necessary to achieve and maintain athletic fitness and performance, must be balanced by sufficient time for bone repair and musculoskeletal adaptation to prevent injuries. Limiting exercise intensity and continuous time spent in racing-speed activity during a racing career is likely to decrease the incidence of PSB fractures in the forelimb of Thoroughbred horses.

a. Jockey Club Information Systems, Lexington, Ky.
b. SAS software, version 9.1.3, SAS Institute Inc, Cary, NC.

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Appendix 1

Definition of event variables used in risk-factor analyses.

Variable	Definition
Events	
Works	No. of works recorded
Races	No. of races performed
Events	No. of works plus races
Layups	A period with ≥ 60 days with no recorded event
Event rates	
Works/career y	No. of works divided by a career-period year
Races/career y	No. of races divided by a career-period year
Events/career y	No. of total races and works divided by a career-period year
Works/active y	No. of works divided by an active-period year
Races/active y	No. of races divided by an active-period year
Events/active y	No. of races and works divided by an active-period year

Works = Workouts. Events = Combined workouts and races.

Appendix 2

Definition of distance variables (in furlongs) used in risk-factor analysis.

Variable	Definition
Career distances	
Works	Distance of works
Races	Distance raced
Events	Distance raced plus distance of works
Accrued distance	
1 mo before death	Total distance during the 30 days prior to death or euthanasia
2 mo before death	Total distance during the 60 days prior to death or euthanasia
4 mo before death	Total distance during the 120 days prior to death or euthanasia
6 mo before death	Total distance during the 180 days prior to death or euthanasia
8 mo before death	Total distance during the 240 days prior to death or euthanasia
10 mo before death	Total distance during the 300 days prior to death or euthanasia
12 mo before death	Total distance during the 365 days prior to death or euthanasia
Distance/event	
Works	Distance of works divided by No. of works
Races	Distance raced divided by No. of races
Events	Total distance divided by the sum of No. of races plus No. of works
Distance rates	
Works/career mo	Total works distance divided by career-period months
Races/career mo	Total race distance divided by career-period months
Events/careermo	Total events distance divided by career-period months
Works/active mo	Total works distance divided by active-period months
Races/active mo	Total race distance divided by active-period months
Events/active mo	Total events distance divided by active-period months

See Appendix 1 for key.

Appendix 3 appears on the next page

Appendix 3

Definition of time variables used in risk-factor analysis.

Variable	Definition
Career days	Day of death minus day of first recorded event
Active (nonlayup) days	Career days minus layup days
Layup time	No. of days in 60-day intervals with no recorded event
Mean layup length	Layup days divided by number of layup periods
Days since last layup	Days since end of last layup; if no layup, then days since start of career
Days between works	Career days divided by No. of works for career
Days between races	Career days divided by No. of races for career
Days between events	Career days divided by No. of events for career (works plus races)
Days between works for active periods	Active days divided by No. of works
Days between races for active periods	Active days divided by No. of races
Days between events for active periods	Active days divided by No. of events (works plus races)
Days to 1 work furlong for career	Career days divided by total works distance (furlongs)
Days to 1 race furlong for career	Career days divided by total race distance (furlongs)
Days to 1 event furlong for career	Career days divided by total distance (works plus races)
Days to 1 work furlong for active periods	Active days divided by total works distance (furlongs)
Days to 1 race furlong for active periods	Active days divided by total race distance (furlongs)
Days to 1 event furlong for active periods	Active days divided by total distance (works plus races)

See Appendix 1 for key.