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Fifteen risk factors associated with sudden death in Thoroughbred racehorses in North America (2009–2021)

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OBJECTIVE
To identify risk factors associated with race-related sudden death in Thoroughbred racehorses in the US and Canada.

ANIMALS
4,198,073 race starts made by 284,387 Thoroughbred horses at 144 racetracks in the US and Canada between 2009 and 2021.

PROCEDURES
Study data were extracted from the Equine Injury Database, which contains detailed records of 92.2% of all official race starts made in the US and Canada during the study period. Forty-nine potential risk factors were analyzed using univariable and multivariable logistic regression. Cases were defined as race starts that resulted in fatality within 3 days of racing, in which at least 1 of 5 codes relating to sudden death was recorded. Fatalities due to catastrophic musculoskeletal injury were omitted from the study cohort.

RESULTS
536 race starts resulted in sudden death, an incidence rate of 0.13/1,000 starts. Fifteen risk factors were significantly associated with sudden death, including horse age and sex, season and purse of race, race distance, and horses' recent history of injury and lay-up. Horses racing while on furosemide medication were at 62% increased odds of sudden death.

CLINICAL RELEVANCE
Associations found between previous injury and sudden death suggests preexisting pathology could contribute in some cases. The association between furosemide and sudden death prompts further study to understand which biological processes could contribute to this result.

Previous studies of Thoroughbred racehorse fatalities have defined 2 broad types of fatality. The most common fatality type is fatality due to catastrophic musculoskeletal injury and has been subject to relatively abundant study in the literature.[1–24] Much of the focus of prior studies has been on multivariable modeling to understand risk factors that contribute to increased likelihood of injury or fatality, with the goal of reducing these deleterious outcomes.[25–28] The less common fatality type is sudden death, which is a very rare outcome, with incidence rates of the order of 1 sudden death/10,000 horse starts. An apparently otherwise healthy horse could experience sudden death, but without a full postmortem examination it is often difficult to establish the exact cause of death. Studies with a primary focus on sudden death outcomes are few, but associations have been demonstrated between sudden death and several risk factors, including age of the horse, race distance, race type, time of year, and recent racing history.[29–32] Other prior work has focused on both musculoskeletal and sudden death fatalities,[33] including the impact of such outcomes on injuries to jockeys.[34,35]

This study of a retrospective cohort aimed to investigate risk factors associated with race-related sudden death in Thoroughbred flat racing in the US and Canada. The data investigated were collected by The Jockey Club in a census-level survey of almost all Thoroughbred racing in the US and Canada called the Equine Injury Database (EID).[36] The all-cause risk of fatality among the cohort has reduced significantly since 2009, but the risk of fatality by sudden death within 3 days of racing has remained steady over the same time period.[37] It was hypothesized that risk factors at the horse and course levels would be found to be associated with the likelihood of a horse experiencing sudden death.

Materials and Methods

The data set used for this study was the full EID, which contains records of 4,562,746 horse starts made by 294,364 individual horses between January 1, 2009, and December 31, 2021. Of these recorded starts, 4,204,757 (92.2%) horse starts were made at tracks that reported injuries and fatalities to the EID; these starts were made by 284,714 (96.7%) individual horses. The study cohort was every horse start that was made at a fully reporting track during the time period investigated. Horse starts that resulted in fatality due to catastrophic musculoskeletal injury (n = 6,754 starts) were excluded from the study cohort. The final study cohort was 4,198,073 horse starts made by 284,387 individual horses at a total of 144 racetracks that reported to the EID during the study period. Potential risk factors were developed from records in the EID. The recorded data were mined to calculate individual histories of horses and jockeys. Additional data recorded by The Jockey Club were used to create new potential risk factors. One such data source was the "vet list," a register of horses that have been established as ineligible to race by a racing regulatory veterinarian for illness, injury, unsoundness, or other adverse health condition. When horses are added to the vet list, it is for a finite amount of time specified by the regulatory veterinarian, after which they can be removed from the list following a confirmatory veterinary examination.

The inclusion criteria for a case of sudden death was any horse that was recorded as a fatality within 3 days of racing, along with one or more of the following fatal injury descriptions or (presumptive) diagnosis, as provided by each participating track to the EID: (1) sudden death (recorded as "SUD" in the EID), (2) pulmonary hemorrhage, (3) exercise-induced pulmonary hemorrhage (EIPH), (4) postexertional distress/heatstroke (PED), and (5) cardiac arrhythmia. The definition of sudden death used in this study was broader than simply those horses recorded as SUD in the EID. This was for 2 reasons: (1) several records included multiple codes either alongside or instead of SUD, and (2) with the true cause of sudden death being very difficult to confirm, even when full postmortem examinations are conducted,[30] it would be reasonable to assume that several of the listed codes would not be accurate or would be at best regarded as presumptive diagnoses. Therefore, restricting the case definition used in this study to only those horses coded as SUD would have resulted in the exclusion and misclassification of a number of sudden death cases and also reduced statistical power.

These data were used to build a multivariable logistic regression model in a bespoke code written in R version 4.1.2 (R Foundation for Statistical Computing). Potential risk factors were analyzed in univariable form first, and those with a *P* value of < .2 were carried forward into the multivariable stage. Continuous risk factors were tested in both continuous and transformed (including categorical) form to find the form that produced the best-fitting model. Transformed variables included season of race (transformed from date of race), purse size, and days since last start, among others. The final multivariable model was constructed using a stepwise forward bidirectional process, with the Akaike information criterion (AIC) used to assess the model fit at each step.[38] At each step the model with the lowest AIC value was selected to progress to the next iteration. The model was finalized by testing for confounding and examining biologically plausible interaction terms.[39] Track, trainer, and horse were tested as random effects individually and together in a series of mixed-level models, and the overall fit of the single-level final model was tested using the Hosmer-Lemeshow goodness-of-fit test.[40] Post hoc power calculations based on the study cohort indicated that, for variables in continuous form, the final model had at least 80% power to detect ORs of 1.13 or above, with 95% confidence. For variables in binary categorical form, the final model had at least 80% power to detect ORs of 1.26 or above, with 95% confidence.

The authors note the following on interpreting the final models: the odds of an outcome given exposure to a risk factor are the ratio of the probability (or risk) of the outcome occurring to the probability of the outcome not occurring. The OR from exposure to a risk factor is the ratio of odds between the exposed and unexposed populations. It is a statistical measure of association of increased (or decreased) likelihood of the outcome occurring in a group exposed to a risk (protective) factor compared to an unexposed group.

Results

Of 4,198,073 horse starts made between 2009 and 2021 at the 144 tracks that reported injuries and fatalities to the EID, 536 were recorded as fatalities with one or more of the fatal injury descriptions matching the inclusion criteria and therefore classified as a form of sudden death. Of the 536 cases of sudden death, 462 (86.2%) included SUD in their fatality description, 58 (10.8%) included pulmonary hemorrhage, 49 (9.1%) included EIPH, 21 (3.9%) included PED, and 12 (2.2%) included cardiac arrhythmia. Note that, due to cases with multiple codes, the total number of all codes reported here adds up to more than 536. The overall case incidence rate was 0.13 sudden deaths/1,000 starts. Among the individual horses that raced during the time period studied, 0.2% experienced sudden death during racing. The total number of fatalities by all causes recorded (including sudden death) over the same period of time was 7,220, an incidence rate of 1.72/1,000 starts, or 2.5% of individual horses.

Forty-nine risk factors were selected for inclusion at the univariable stage of model building **(Supplementary Table 1)**. Following the univariable stage, 33 risk factors were carried forward into the multivariable analysis **(Supplementary Table 2)**. The final multivariable model retained 15 risk factors associated with sudden death **(Tables 1 and 2)**. The following 4 risk factors were retained in the final model despite statistical significance at the 90% confidence level rather than the 95% level: season of race, track surface, horse starts in the previous 90 to 180 days, and horse's first start as a claimer. The inclusion of these variables improved the overall fit of the model according to AIC, in accordance with the study design described above. Furthermore, some confounding was detected involving these variables, which will be discussed below.

Table 1—Descriptive statistics and results of the final multivariable model examining the association between sudden deaths and Thoroughbred racing starts in the US and Canada between 2009 and 2021.

Risk factor	Horse starts	Sudden deaths	Incidence/1,000 starts	OR	95% CI	*P* value
Season of race						
Summer*	1,357,738	190	0.14	1	—	—
Autumn	1,116,397	135	0.12	0.94	0.75–1.18	.606
Winter	764,453	86	0.11	0.78	0.6–1.01	.055
Spring	959,485	125	0.13	0.85	0.68–1.07	.17
Surface						
Dirt*	3,073,391	416	0.14	1	—	—
Synthetic	452,113	46	0.1	0.75	0.55–1.02	.067
Turf	672,569	74	0.11	0.82	0.63–1.07	.148
Race distance (furlongs)						
Per additional furlong	Median = 6.5	IQR = 2	—	0.87	0.81–0.93	< .001
	Min = 0.7	Max = 18	—			
State-bred race						
No*	3,506,076	469	0.13	1	—	—
Yes	691,997	67	0.1	0.71	0.54–0.93	.011
Purse value ($1,000)						
≤ 10*	1,116,343	130	0.12	1	—	—
> 10, up to 15	873,094	132	0.15	1.51	1.18–1.93	.001
> 15, up to 30	1,233,352	166	0.13	1.47	1.14–1.88	.002
> 30	975,284	108	0.11	1.35	1–1.82	.048
Horse sex						
Female*	1,831,388	206	0.11	1	—	—
Gelding	1,863,880	257	0.14	1.11	0.92–1.34	.294
Stallion	502,805	73	0.15	1.39	1.06–1.83	.018
Horse racing age						
Per additional year	Median = 4	IQR = 2	—	1.2	1.12–1.28	< .001
	Min = 2	Max = 14	—	—	—	—

For each risk factor in categorical form, an asterisk indicates the reference category. This table shows 7 of 15 risk factors identified. ***See*** Table 2 for the other 8 risk factors.

Table 2—Descriptive statistics and results of the final multivariable model examining the association between sudden deaths and Thoroughbred racing starts in the US and Canada between 2009 and 2021.

Risk factor	Horse starts	Sudden deaths	Incidence/ 1,000 starts	OR	95% CI	*P* value
Horse distance raced in career						
Per additional 10 km	Median = 12.9	IQR = 22.1	—	0.92	0.85–0.99	.031
	Min = 0	Max = 203.1	—			
Horse previous wins in career						
Per additional win	Median = 1	IQR = 3	—	1.05	1–1.09	.04
	Min = 0	Max = 44	—			
Horse starts in previous 0–30 d						
Per additional start	Median = 1	IQR = 1	—	0.86	0.75–0.99	.04
	Min = 0	Max = 6	—			
Horse starts in previous 90–180 d						
0*	1,610,654	214	0.13	1	—	—
1	561,963	88	0.16	1.13	0.87–1.46	.364
≥ 2	2,025,456	234	0.12	0.84	0.68–1.03	.092
Horse first start as a claimer						
No*	3,964,646	499	0.13	1	—	—
Yes	233,427	37	0.16	1.38	0.96–1.99	.081
Days since horse was last in lay-up						
Never been in lay-up*	1,375,539	132	0.1	1	—	—
0–30	849,777	145	0.17	1.37	1.05–1.77	.019
≥ 31	1,972,757	259	0.13	1.17	0.91–1.5	.22
Horse has ever previously been on the vet list						
No*	3,030,566	337	0.11	1	—	—
Yes	1,167,507	199	0.17	1.31	1.09–1.59	.005
Horse on furosemide this race day						
No*	233,276	18	0.08	1	—	—
Yes	3,964,797	518	0.13	1.62	1.01–2.61	.047

For each risk factor in categorical form, an asterisk indicates the reference category This table shows 8 of the 15 risk factors identified. ***See*** Table 1 for the other 7 risk factors.

At race level, 5 risk factors were retained in the final model. Compared to horses racing in summer, those racing in winter were at a 28% (1/0.78) reduced risk of sudden death. The risk of sudden death for starts made in the spring and autumn was not significantly different to the risk for starts made in the summer. Starts made on synthetic track surfaces were at 33% (1/0.75) reduced odds of sudden death compared to starts made on dirt tracks. There was no difference detected between the risk on turf compared to dirt.

Longer race distances were associated with a significantly reduced risk of sudden death. Horses in races at or above the third quartile in distance (8 furlongs) were approximately 32% (1/0.76) less likely to experience sudden death compared to horses in races at or below the first quartile in distance (6 furlongs). Horse starts in state-bred races (in which only state-bred horses were permitted to race) were approximately 41% (1/0.71) less likely to experience sudden death than horses in other races. Horse starts in races with purse values > $10,000 were at approximately 40% (ORs between 1.35 and 1.51) greater risk of sudden death compared to starts in races with purse values < $10,000.

A total of 10 risk factors at the horse level were retained in the final model. Compared to female horses, geldings were not significantly different with respect to their risk of sudden death, but intact male horses were at 39% increased risk of sudden death. Older horses were at increased odds of sudden death compared to younger horses, with horses at or above the third quartile in age (5 years) at 44% increased risk relative to horses at or below the first age quartile (3 years).

For each additional race start made in the previous 0 to 30 days, individual horses were at reduced risk of sudden death. Horses at or above the third quartile (2 starts) were approximately 16% (1/0.86) less likely to experience sudden death compared to horses at or below the first quartile (1 start). Horses that had made ≥ 2 race starts in the period 90 to 180 days before the current race were at 19% (1/0.84) decreased risk of fatality compared to horses that had made 0 or 1 start in the same time period.

Horses making their first start as a claimer (ie, having never raced in a claiming race before in their careers) were at 38% increased odds of sudden death compared to horses that were not or had previously been claimers.

Compared to horses that had never had a lay-up (defined as a period of longer than 60 days with no race starts), horses whose previous lay-up was within 30 days of the current start were at 37% increased odds of sudden death. With respect to the risk of sudden death, horses that had finished their previous lay-up > 30 days before the current start were not significantly different to horses that had never had a lay-up. Horses that had previously been added to a vet list were at 31% increased odds of sudden death compared to horses that had never been on a vet list before.

Two factors related to an individual horse's entire history were retained in the final model. Horses that had raced a longer cumulative distance in their prior career were at reduced odds of sudden death compared to those with less cumulative distance. Those horses at or above the third quartile (26.9 km) were at approximately 20% (1/0.83) reduced odds compared to horses at or below the first quartile (4.8 km). Horses with more previous wins in their prior career were at increased odds of sudden death, and those at or above the third quartile (3 wins) were at 16% increased odds compared to those at or below the first quartile (0 wins).

Compared to horses who were not racing on furosemide, horses that were recorded as receiving furosemide medication on race day were at 62% increased odds of sudden death.

No confounding was detected among the variables rejected during model building. However, some confounding was found to be present in the final model during validation processes. Removing the variable "horse starts in the last 90 to 180 days" changed the significance of the variables "season of race" and "furosemide this race." Removing "season of race" changed the significance of "horse starts in the last 90 to 180 days" and "furosemide this race." Removing "furosemide this race" did not change the significance of the other 2 variables but resulted in a far worse overall fit for the model than any other configuration. The final model retained all 3 variables because it was deemed to be the best overall fit according to AIC. This demonstrates the challenge of investigating a very rare outcome while 1 variable in particular—furosemide this race—had 94% prevalence among the study cohort.

No biologically plausible second-order interaction terms were retained in the final model. Mixed-effects model with track as a random effect showed that track contributed 17% of the total variance as measured by R^2. Compared to the fixed-effects model, including track as a random effect altered the model estimates for the variables state-bred race and purse by more than 10% and did not change the significance of any variables. Trainer as a random effect accounted for 14% of the total model variance as measured by R^2 and did not alter any model estimates by > 10% or change any variable significances. Including horse ID as a random effect accounted for 5% of total model variance as measured by R^2, did not alter any model estimates by > 1%, and did not change any variable significances. There was no evidence of a lack of fit found with the Hosmer-Lemeshow test with 10 degrees of freedom (P = .9).

Discussion

This study identified 15 risk factors at the levels of the race and horse that were significantly associated with increased risk of sudden death in Thoroughbred racehorses in the US and Canada. Some of the factors identified suggest that the possibility exists to identify at-risk horses well before they experience sudden death. Further work is required to determine which, if any, clinical signs are potential indicators and indeed whether such a rare outcome could be reliably predicted. The thoughtful application of big data predictive modeling would be helpful here; routine biometric monitoring of racehorses throughout their training and racing careers could provide valuable insights into horses' physical well-being. Adding data of this nature to existing risk profile development would allow the possibility for greater understanding of conditions such as cardiac arrhythmia, including potential associations between certain kinds of arrhythmia and sudden death. Future studies of this type would also enable the investigation of the effects of medication—including furosemide—at a physiologic level during training and racing.

The strictest limitation to this study was the very low incidence of the outcome, as 0.13 race starts/1,000 resulted in sudden death. Therefore, even with a very large data set such as the EID, few cases were available to be studied.

In a similar multivariable study, Lyle et al[31] reported associations between horse age and starts in the last 60 days that were consistent with the results found in the present study. Both studies demonstrated that older horses were at increased odds of sudden death compared to younger horses and horses with more race starts in recent months were at reduced odds of fatality compared to horses with fewer recent starts. Lyle et al[31] also reported an association between increased race distances and increased likelihood of sudden death. In the current study, the result with respect to race distance was in the opposite direction. This could be because the Lyle et al[31] study included both flat and jumps races, while the present study only included flat racing. The range of distances over which these 2 types of races were conducted are quite different. Many races in North America are held over shorter distances. The median race distance in this study was 6.5 furlongs, and > 1% of races in the study cohort were held over a distance longer than 9 furlongs (1 mile and 1 furlong).

Horse starts in summer are likely to have been in warmer conditions than those in winter, so it may be reasonable to speculate that heat stress could contribute to metabolic processes leading to sudden death. Indeed, the prevalence of sudden death cases coded as PED was disproportionately higher in summer, with 0.009 cases/1,000 starts (n = 12). This is compared to a prevalence of 0.003 PEDs/1,000 starts (n = 9) in other seasons, which is statistically significantly different according to the Fisher exact test ($P = .02$). However, with such low absolute numbers of case codes, it is difficult to draw firm conclusions, particularly given the difficulties in determining an exact cause of sudden death.

It has been previously reported that for catastrophic musculoskeletal injuries, accurately reporting data from the racecourse is challenging.[41] For sudden deaths, which have an incidence rate an order of magnitude lower than catastrophic musculoskeletal injuries, it is likely that it is even more challenging to ensure accurate records are made. As discussed by Lyle et al,[30] it can be difficult to ascertain the exact cause of sudden death, even with the use of a full postmortem examination. Even with the full EID available for the present study, there is a chance of misclassification within the outcome codes recorded. The present study accounted for this by widening the case inclusion criteria to include all outcomes the EID reporting protocol would regard as sudden death. To ensure quality of data, it is important to ensure that data reporting protocols at the racetrack are consistent and well-defined. At present, the EID protocols are consistent across all tracks that report, but perhaps further investigation into the specific definitions of each outcome code recorded would assist in making sure data are well-defined.

Previous studies have found that race starts made on synthetic track surfaces were at reduced odds of fatal musculoskeletal injury compared to starts made on dirt surfaces, in line with the results found here.[11] State-bred races by definition have less travel involved for many of the horses competing in those races, so it could be speculated that some horses are under reduced stress on race day in state-bred races compared to others. However, the variable reflecting whether horses "ship in" on the day of the race was not significant in this model, and if this explanation was the causative association behind this finding, one might have expected the "ship in" variable to have been included in the final model. This association is therefore somewhat difficult to explain. Higher purse-value races are by definition more competitive than lower purse-value races, potentially meaning horses are pushed harder to win these particular races than they might have been in lower value races. Similar results have been found in previous studies in North America and Australia.[3,11]

Horses that had been added to a vet list and those within 30 days of returning from a lay-up period were both at increased odds of sudden death. These suggest that if a horse is at increased risk of experiencing sudden death, there is the possibility of this presenting as clinical signs that can be observed well before death. However, much more investigation would be required to identify which veterinary diagnoses—if any—are associated with later sudden death. It should also be noted that lay-ups are not necessarily caused by injury or clinical issues; they could simply be a planned rest period or otherwise time spent training rather than competing. On the other hand, these variables could also indicate that there was a recent interruption to the horses' training schedules, meaning the horses would be less physically prepared for racing than if they had not had such an interruption. Further investigation would be required into the nature of lay-ups to definitively identify any underlying causes.

Horses with more previous career cumulative distance raced and horses with more previous career wins had the opposite direction of effect in the final model. The reduction in risk for horses with more career cumulative distance raced could be a healthy horse effect. However, the increase in risk for horses with more career wins could be an indication of competitive horses being pushed beyond their capacity. Further investigation into the exact causes of death would be required to draw any firm conclusions.

One association was found in the final model between race-day medication and increased odds of sudden death. Horses recorded as being medicated with furosemide on race day were at 62% increased odds of sudden death compared to horses that were not racing on furosemide. It should be noted here that 94% of horse starts in the cohort were recorded as being treated with furosemide on race day, so this is an extremely common risk factor. As such, identifying any potential causal link between furosemide administration and sudden death should be a priority. Furosemide administration, alongside water restriction, is common race-day practice for the management of EIPH and has been shown to also result in improvements in race performance.[42] Although evidence supports the use of furosemide to reduce the severity of EIPH,[42,43] the ethics of permitting any race-day medication is controversial and problematic for the sport.[43] Furosemide is a diuretic and reduces the severity of EIPH by reducing blood volume and hence blood flow and pulmonary arterial pressure.[44] The diuretic action results in a loss of sodium, potassium, and chloride into the urine and hence predisposes to electrolyte abnormalities.[45] In humans, these electrolyte disturbances may predispose to arrhythmias and arrhythmic death.[46] Therefore, it could be hypothesized that furosemide administration in horses may increase the risk of sudden death through fatal arrhythmogenesis. However, as the exact cause of sudden death (cardiac vs noncardiac) was not determined for the horses of this study, we can only speculate at possible mechanisms. Further investigation is required to understand which, if any, pathophysiologic mechanisms could underlie the association between furosemide use and sudden death, as this finding raises further concerns about the ethics of race-day administration.

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References

1. Allen SE, Rosanowski SM, Stirk AJ, Verheyen KLP. Description of veterinary events and risk factors for fatality in National Hunt flat racing Thoroughbreds in Great Britain (2000–2013). *Equine Vet J*. 2017;49(6):700–705.
2. Anthenill LA, Stover SM, Gardner IA, Hill AE. Risk factors for proximal sesamoid bone fractures associated with exercise history and horseshoe characteristics in Thoroughbred racehorses. *Am J Vet Res*. 2007;68(7):760–771.
3. Bailey CJ, Reid SWJ, Hodgson DR, Suann CJ, Rose RJ. Risk factors associated with musculoskeletal injuries in Australian Thoroughbred racehorses. *Prev Vet Med*. 1997;32(1-2):47–55.
4. Bailey CJ, Reid SWJ, Hodgson DR, Bourke JM, Rose RJ. Flat, hurdle and steeple racing: risk factors for musculoskeletal injury. *Equine Vet J*. 1998;30(6):498–503.
5. Boden LA, Anderson GA, Charles JA, et al. Risk factors for Thoroughbred racehorse fatality in jump starts in Victoria, Australia (1989–2004). *Equine Vet J*. 2007;39(5):422–428.
6. Boden LA, Anderson GA, Charles JA, et al. Risk factors for Thoroughbred racehorse fatality in flat starts in Victoria, Australia (1989–2004). *Equine Vet J*. 2007;39(5):430–437.
7. Bolwell C, Rogers C, Gee E, McIlwraith W. Epidemiology of musculoskeletal injury during racing on New Zealand racetracks 2005–2011. *Animals (Basel)*. 2017;7(8):62. doi:10.3390/ani7080062
8. Cohen ND, Berry SM, Peloso JG, Mundy GD, Howard IC. Association of high-speed exercise with racing injury in Thoroughbreds. *J Am Vet Med Assoc*. 2000;216(8):1273–1278.
9. Crawford KL, Ahern BJ, Perkins NR, Phillips CJC, Finnane A. The effect of combined training and racing high-speed exercise history on musculoskeletal injuries in Thoroughbred racehorses: a systematic review and meta-analysis of the current literature. *Animals (Basel)*. 2020;10(11):2091. doi:10.3390/ani10112091
10. Cruz AM, Poljak Z, Filejski C, et al. Epidemiologic characteristics of catastrophic musculoskeletal injuries in Thoroughbred racehorses. *Am J Vet Res*. 2007;68(12):1370–1375.
11. Georgopoulos SP, Parkin TDH. Risk factors associated with fatal injuries in Thoroughbred racehorses competing in flat racing in the United States and Canada. *J Am Vet Med Assoc*. 2016;249(8):931–939.
12. Hernandez J, Hawkins DL, Scollay MC. Race-start characteristics and risk of catastrophic musculoskeletal injury in Thoroughbred racehorses. *J Am Vet Med Assoc*. 2001;218(1):83–86.
13. Hernandez JA, Scollay MC, Hawkins DL, Corda JA, Krueger TM. Evaluation of horseshoe characteristics and high-speed exercise history as possible risk factors for catastrophic musculoskeletal injury in Thoroughbred racehorses. *Am J Vet Res*. 2005;66(8):1314–1320.
14. Hill WT. Survey of injuries in Thoroughbreds at The New York Racing Association tracks. *Clin Tech Equine Pract*. 2003;2(4):323–328. doi:10.1053/j.ctep.2004.04.004
15. Hitchens PL, Morrice-West AV, Stevenson MA, Whitton RC. Meta-analysis of risk factors for racehorse catastrophic musculoskeletal injury in flat racing. *Vet J*. 2019;245:29–40.
16. Parkin TDH, Clegg PD, French NP, et al. Analysis of horse race videos to identify intra-race risk factors for fatal distal limb fracture. *Prev Vet Med*. 2006;74(1):44–55.
17. Parkin TDH, Clegg RD, French NP, et al. Horse-level risk factors for fatal distal limb fracture in racing Thoroughbreds in the UK. *Equine Vet J*. 2004;36(6):513–519.
18. Parkin TDH, Clegg PD, French NP, et al. Race- and course-level risk factors for fatal distal limb fracture in racing Thoroughbreds. *Equine Vet J*. 2004;36(6):521–526.
19. Perkins NR, Reid SWJ, Morris RS. Risk factors for musculoskeletal injuries of the lower limbs in Thoroughbred racehorses in New Zealand. *N Z Vet J*. 2005;53(3):171–183.
20. Rosanowski SM, Chang YM, Stirk AJ, Verheyen KLP. Risk factors for race-day fatality in flat racing Thoroughbreds in Great Britain (2000 to 2013). *PLoS One*. 2018;13(3):e0194299. doi:10.1371/journal.pone.0194299
21. Sun TC, Riggs CM, Cogger N, Wright J, Al-Alawneh JI. Noncatastrophic and catastrophic fractures in racing Thoroughbreds at the Hong Kong Jockey Club. *Equine Vet J*. 2019;51(1):77–82.
22. Vallance SA, Case JT, Entwistle RC, et al. Characteristics of Thoroughbred and Quarter Horse racehorses that sustained a complete scapular fracture. *Equine Vet J*. 2012;44(4):425–431.
23. Verheyen KLP, Wood JLN. Descriptive epidemiology of fractures occurring in British Thoroughbred racehorses in training. *Equine Vet J*. 2004;36(2):167–173.
24. Zambruno T, Georgopoulos SP, Boden LA, Parkin TDH. Association between the administration of phenylbutazone prior to racing and musculoskeletal and fatal injuries in Thoroughbred racehorses in Argentina. *J Am Vet Med Assoc*. 2020;257(6):642–647.
25. Parkin TDH, Brown PE, French NP, Morgant KL. Cooking the books or simply getting the best out of the data? As-

sessing the nature of the relationship between variables. *Equine Vet J*. 2005;37(3):189–191.
26. Henley WE, Rogers K, Harkins L, Wood JLN. A comparison of survival models for assessing risk of racehorse fatality. *Prev Vet Med*. 2006;74(1):3–20.
27. Verheyen KLP. Reducing injuries in racehorses: mission impossible? *Equine Vet J*. 2013;45(1):6–7.
28. Palmer SE, McDonough SP, Mohammed HO. Reduction of Thoroughbred racing fatalities at New York Racing Association racetracks using a multi-disciplinary mortality review process. *J Vet Diagn Invest*. 2017;29(4):465–475.
29. Boden LA, Charles JA, Slocombe RF, et al. Sudden death in racing Thoroughbreds in Victoria, Australia. *Equine Vet J*. 2005;37:269–271.
30. Lyle CH, Uzal FA, McGorum BC, et al. Sudden death in racing Thoroughbred horses: an international multicentre study of post mortem findings. *Equine Vet J*. 2011;43(3):324–331.
31. Lyle CH, Blissitt KJ, Kennedy RN, et al. Risk factors for race-associated sudden death in Thoroughbred racehorses in the UK (2000–2007). *Equine Vet J*. 2012;44(4):459–465.
32. Brown CM, Kaneene JB, Taylor RF. Sudden and unexpected death in horses and ponies: an analysis of 200 cases. *Equine Vet J*. 1988;20(2):99–103.
33. Boden LA, Anderson GA, Charles JA, et al. Risk of fatality and causes of death of Thoroughbred horses associated with racing in Victoria, Australia: 1989–2004. *Equine Vet J*. 2006;38(4):312–318.
34. Hitchens PL, Hill AE, Stover SM. The role of catastrophic injury or sudden death of the horse in race-day jockey falls and injuries in California, 2007–2012. *Equine Vet J*. 2016;48(1):50–56.
35. Wylie CE, McManus P, McDonald C, Jorgensen S, McGreevy P. Thoroughbred fatality and associated jockey falls and injuries in races in New South Wales and the Australian Capital Territory, Australia: 2009–2014. *Vet J*. 2017;227:1–7. doi:10.1016/j.tvjl.2017.06.008
36. Equine Injury Database. The Jockey Club. Accessed February 4, 2021. https://jockeyclub.com/default.asp?section=Advocacy&area=10
37. Welfare and Safety of the Racehorse Summit. Grayson-Jockey Club Research Foundation. Accessed May 19, 2022. https://www.grayson-jockeyclub.org/WelfareSafety
38. Akaike H. Information theory and an extension of the maximum likelihood principle. In: Kotz S, Johnson NL, eds. *Breakthroughs in Statistics.* Vol 1. Springer; 1992:599–624.
39. Hosmer DW, Lemeshow S. *Applied Logistic Regression*. 2nd ed. John Wiley and Sons Inc; 2000:116–117, 167–183.
40. Dohoo I, Martin W, Stryhn H. *Veterinary Epidemiologic Research*. AVC Inc; 2003:18, 30, 72, 126–127, 140–141, 200, 220, 228, 236, 242, 274–275, 340, 349, 546.
41. Reardon RJM, Boden L, Stirk AJ, Parkin TDH. Accuracy of distal limb fracture diagnosis at British racecourses 1999–2005. *Vet Rec*. 2014;174(19):477. doi:10.1136/vr.102053
42. Hinchcliff KW, Couetil LL, Knight PK, et al. Exercise induced pulmonary hemorrhage in horses: American College of Veterinary Internal Medicine consensus statement. *J Vet Intern Med*. 2015;29(3):743–758. doi:10.1111/jvim.12593
43. Initiative focuses on racing integrity: AAEP's prescription for racing reform to seek non-race day EIPH treatments. AVMA. Accessed September 30, 2022. https://www.avma.org/javma-news/2015-09-15/initiative-focuses-racing-integrity
44. Hyyppä S, Pösö AR. Fluid, electrolyte, and acid-base responses to exercise in racehorses. *Vet Clin North Am Equine Pract*. 1998;14(1):121–136. doi:10.1016/s0749-0739(17)30215-8
45. Carlson GP, Jones JH. Effects of frusemide on electrolyte and acid-base balance during exercise. *Equine Vet J Suppl*. 1999;31(S30):370–374. doi:10.1111/j.2042-3306.1999.tb05250.x
46. Cooper HA, Dries DL, Davis CE, Shen YL, Domanski MJ. Diuretics and risk of arrhythmic death in patients with left ventricular dysfunction. *Circulation*. 1999;100(12):1311–1315.

Supplementary Materials

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