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Estimates of genetic parameters of distal limb fracture and superficial digital flexor tendon injury in UK Thoroughbred racehorses

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ABSTRACT

A retrospective cohort study of distal limb fracture and superficial digital flexor tendon (SDFT) injury in Thoroughbred racehorses was conducted using health records generated by the British Horseracing Authority (BHA) between 2000 and 2010. After excluding records of horses that had both flat and jump racing starts, repeated records were reduced to a single binary record per horse ($n = 66{,}507$, 2982 sires), and the heritability of each condition was estimated using residual maximum likelihood (REML) with animal logistic regression models. Similarly, the heritability of each condition was estimated for the flat racing and jump racing populations separately. Bivariate mixed models were used to generate estimates of genetic correlations between SDFT injury and distal limb fracture.

The heritability of distal limb fracture ranged from 0.21 to 0.37. The heritability of SDFT injury ranged from 0.31 to 0.34. SDFT injury and distal limb fracture were positively genetically correlated. These findings suggest that reductions in the risk of the conditions studied could be attempted using targeted breeding strategies.

Introduction

Musculoskeletal injuries are common in all forms of horseracing. Injury to the superficial digital flexor tendon (SDFT) and fractures of the distal limb are amongst the most prevalent musculoskeletal injuries in many racing jurisdictions (Ely et al., 2004; Parkin, 2008). Both of these injuries have serious consequences for equine welfare and the racing economy, and have been investigated in the past in attempts to identify modifiable risk factors that could be manipulated to reduce incidence (Hill et al., 2001; Parkin et al., 2004a and c; Perkins et al., 2005; Cogger et al., 2006; Lam et al., 2007; Ely et al., 2009; Kristoffersen et al., 2010; Jacklin and Wright, 2012).

Risk factors that have been found to be associated with racecourse fracture include the type of racing surface, trainer, going, age, race type and exercise history of the horse (Parkin et al., 2004a and c; Cogger et al., 2006; Kristoffersen et al., 2010). Risk factors found to be associated with injury to the SDFT include age, sex, previous exercise history, going and career length (Ely et al., 2004; Perkins et al., 2005; Jacklin and Wright, 2012). Only some of these risk factors for fracture and SDFT injury are realistically modifiable, and clear advice for stakeholders on injury prevention has not been forthcoming due to differences in case definitions and complicated relationships with risk factors such as exercise history. One previous study estimated the heritability of SDFT injury in the Thoroughbred to be 0.17–0.19 (Oki et al., 2008), but no studies have estimated the heritability of fracture in the racehorse and further work on the genetic risk of tendon injury has not to our knowledge been published to date. Identification of significant genetic risk should inform breeding decisions and environmental management to modify individual and population risk in a holistic manner.

In the UK, horses may compete in flat races or over obstacles in hurdle or steeplechase races. It has long been known that jump racing poses additional risks to horse health compared with flat racing, possibly through differences in the stresses placed upon musculoskeletal tissues during jumping compared to galloping on flat ground and due to increased risk of falling (Bailey et al., 1998; Parkin et al., 2004b). Although UK Thoroughbred racehorses may compete in any form of racing, at the start of its career each horse is trained for a specific discipline, with jump racing horses beginning their racing careers later, and racing to older ages. Recent studies identified a number of genes associated with conferring athletic ability and predilection for best racing distance in short or long races in the Thoroughbred (Hill et al., 2010; Suontama et al., 2012; Tozaki et al., 2012). However, no previous studies have attempted to identify whether

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Table 1
Description of dataset of Thoroughbred racehorses from the British Horseracing Authority.

	All	Male (%)	Female (%)
Total number of horses	66,507	41,002 (62)	25,505 (38)
Distal limb fracture cases	630	476 (76)	154 (24)
SDFT injury cases	1,524	1,232 (81)	292 (19)
Number of flat racers	38,016	19,340 (51)	18,676 (49)
Number of jump racers	28,491	21,662 (76)	6,829 (24)
Distal limb fracture cases in flat racers	252	172 (47)	80 (53)
Distal limb fractures in jump racers	378	304 (80)	74 (20)
SDFT injuries in flat racers	142	110 (77)	32 (33)
SDFT injuries in jump racers	1,382	1,122 (81)	260 (19)

SDFT, superficial digital flexor tendon.

flat and jump racing horses are genetically distinct with regard to their susceptibility to musculoskeletal injury.

The aims of this study were twofold: (1) to estimate the heritability of distal limb fracture and SDFT injury at the racecourse, and (2) to identify whether differences exist in disease heritability between flat and jump racing horse populations. This would be an important consideration in how to manage the racing population and conduct future risk factor analyses in Thoroughbred racehorses.

Materials and methods

Data

Information on all equine injuries reported at all of the UK's 60 racecourses between January 2000 and January 2010 was available from the British Horseracing Authority (BHA) in a Microsoft Excel spreadsheet (900,775 records). Every race in the UK is compulsorily attended by two racecourse veterinary surgeons (three for jump races), and every equine medical event must be recorded using a Racecourse Veterinary Consultation Form. A BHA veterinary official must also be present at every race meeting, and it is the official's responsibility to upload the medical information into a central BHA database following every meeting. Each medical event is categorized using one or more tick-boxes available from a large set of possible diagnoses in the BHA database. Diagnoses are made using clinical examinations on site or post-mortem examinations, without extensive use of diagnostic aids such as radiography or ultrasound in many cases. The definition of distal limb fracture used here was inclusive of the carpus or tarsus.

Due to difficulties with the use of repeated records for binary data, the initial repeated records dataset was reduced to include only one record per horse. Records for horses that competed in both flat and jump races were excluded from analyses. Cases of distal limb fracture and SDFT injury were identified, and a binary profile for each horse was created, whereby a horse was coded '1' as a case if it had ever been diagnosed with a distal limb fracture, or with an SDFT injury, and '0' if it had never received such a diagnosis. Each diagnosis was also analysed within both the flat and jump racing populations separately. The number and percentage of male and female horses that received such diagnoses are described in Table 1. Information on 66,507 horses was available, of which 41,002 (61.7%) were male (Table 1). Flat racing horses started between one and 177 races each and jump racing horses started between one and 102 races each.

Model building and heritability analysis

Multivariable animal logistic regression models were built for both distal limb fracture and SDFT injury. Sex and the number of starts for each horse were used as non-genetic effects in each model.

The final models for distal limb fracture and SDFT injury were analysed using ASReml v.3 genetic analysis software (VSN International) and heritabilities were estimated from the variance components. The general logistic model form was:

$$\log\left(\frac{p}{1-p}\right) = Xb + Za + e$$

where X and Z are known incidence matrices, b is the vector of fixed effects, a is the vector of random additive genetic effects with the distribution assumed to be multivariate normal with parameters $(0, \sigma_a^2 A)$, e is the vector of residuals with multivariate normal distribution and parameters $(0, \sigma_e^2 I)$, A is the numerator relationship matrix, I is an identity matrix, σ^2 denotes variance, and where p denotes the probability of the condition in the population. Residual variance in logistic models was set to $\frac{\pi^2}{3}$.

Table 2
Heritability estimates of distal limb fracture and SDFT injury at the racecourse, h^2 is heritability on the logistic scale (s.e. denotes standard error).

	h^2 (s.e.) distal limb fracture	h^2 (s.e.) SDFT injury
All horses	0.2065 (0.0527)	0.3105 (0.0238)
Flat racers	0.3293 (0.0844)	0.3283 (0.1391)
Jump racers	0.3711 (0.0565)	0.3405 (0.0242)

Heritability was determined by:

$$h^2 = \frac{\sigma_a^2}{\sigma_p^2}$$

where σ_a^2 is animal variance and $\sigma_p^2 \sigma_a^2 \sigma_a^2$ is phenotypic variance. Bivariate linear mixed model analyses were conducted using distal limb fracture and SDFT injury to assess the genetic correlation between the two deleterious outcomes. Odds ratios (OR) and their confidence intervals (CI) were calculated using R statistical software version 2.15.1 (Bates et al., 2012; Kohl, 2012).

Results

The number of horses that competed exclusively in flat or jump races was 38,016 (57.2%) and 28,491 (42.8%), respectively. During the time period over which these data were collected, 84,380 races were run over 3463 days. All horses were born between April 1983 and June 2007 and were descended from 2982 sires and 36,187 dams. Each sire contributed between one and 552 offspring to the dataset (mean 22.3, median 4, mode 1), and each dam contributed between 1 and 13 offspring (mean 2, median 1, mode 1). Pedigree information included 118,138 horse identities and up to four generations of information per horse.

Distal limb fracture was twice as likely to occur in jump racing compared to flat racing horses (OR 2.0, 95% CI 1.7–2.4). SDFT injury was found to be over 13 times more likely to occur in jump racing compared with flat racing (OR 13.6, 95% CI 11.4–16.2).

Table 2 contains estimates of the heritability of distal limb fracture and SDFT injury in all horses, and in flat racing or jump racing horses exclusively. The heritability of distal limb fracture in all horses was significantly different from zero. Horses that competed in jump races had a higher estimated heritability for distal limb fracture compared with those that competed only in flat races, but this difference was not significant. SDFT injury heritability was estimated to be 0.31 when all horses were considered together, and this estimate rose to 0.34 for jump racing horses (Table 2). Again, the heritability of this condition appeared to be higher in jump racing compared with flat racing, but this difference was not statistically significant.

Table 3 contains estimates of genetic, phenotypic and residual correlations between SDFT injury and distal limb fracture. A significant positive genetic correlation was found between distal limb fracture and SDFT injury amongst all horses (0.44 ± 0.10, $P < 0.001$). No significant genetic correlation was found between these conditions within the flat racing population. However, within the jump racing population, there was a large significant genetic correlation between SDFT injury and distal limb fracture (0.72 ± 0.05, $P < 0.001$). A small but significant negative phenotypic correlation was found between distal limb fracture and SDFT injury was found in the racehorse population as a whole.

Table 3
Genetic (r_g), phenotypic (r_p), and residual (r_e) correlations between SDFT injury and distal limb fracture at the racecourse (s.e. denotes standard error).

	r_g (s.e.)	r_g P-value	r_p (s.e.)	r_e
All horses	0.4422 (0.0970)	<0.001	–0.0109 (0.0039)	–0.0319
Flat racers	0.3646 (0.1879)	0.07	–0.0034 (0.0039)	–0.0074
Jump racers	0.7239 (0.0536)	<0.001	–0.0033 (0.0040)	–0.0665

Discussion

This study is one of the first to identify a significant genetic component to the risk of fracture and SDFT injuries in Thoroughbred racehorses (Oki et al., 2008). The data used represent an excellent resource for the genetic analysis of these conditions. Diagnoses were made by experienced racecourse veterinarians without the use of diagnostic imaging, thus there may have been some loss of case specificity. Additionally, a degree of autoregression is inevitably present in these data due to the serious nature of the conditions studied, whereby diagnosis of a serious musculoskeletal condition is likely to result in the removal of the injured horse from the pool of susceptible horses in the future. Heritability estimates for these binary data analysed using logistic regression models were large.

The heritability of distal limb fracture and SDFT injury were not consistent between flat and jump racing populations, which may suggest different underlying mechanisms of genetic risk between these populations, although the differences were not statistically significant. The estimates of additive genetic variance for each condition in flat and jump racing horses did not differ significantly (data not shown), therefore, based on these findings the genetic risk of distal limb fracture and SDFT injury in flat and jump racing horse populations could be expected to alter at a similar rate if selective breeding strategies were to be implemented.

Distal limb fracture is a very important cause of compromise to racehorse welfare and features in many types of racing. In the current study the heritability of distal limb fracture was found to be significantly greater than zero. The significant proportion of risk conferred through the pedigree could signify that some reduction in fracture incidence could be achieved in the future if the mating of genetically susceptible individuals were to be avoided. Targeted selective breeding strategies based on estimated breeding values for distal limb fracture, coupled with a vigilant approach to the identification of at-risk individuals and use of frequent distal limb imaging to identify bone-level adaptation or pathology before catastrophic breakdown occurs could all be implemented to reduce future incidence. The heritability of distal limb fracture in the flat racing portion of the current dataset was not statistically different from the jump racing portion. Jump racing horses were found to be twice as likely to suffer a distal limb fracture as flat racing horses, suggesting that environmental risks rather than genetic differences play an important part in the difference in prevalence of distal limb fracture between flat and jump racing populations. Jump racing has been found to be a risk factor for fracture in previous studies and the results reported here support this finding (Bailey et al., 1998; Parkin, 2008).

Injury to the SDFT is also an important diagnosis in racing horses. Much work has been done to ascertain important modifiable environmental risk factors for this condition, but little attention has previously been given to genetic influences, with the exception of a study by Oki et al. (2008). In that paper, the authors used a Gibbs sampling approach to estimate heritability of SDFT injury on a graded scale (no injury, subclinical injury, or clinical injury), from diagnoses of a Japanese racing cohort during training and racing activities. The estimates of heritability (0.17–0.19) were lower than those reported here, which was perhaps due to differences in population, methodology and grading of the outcome. Here, SDFT injury heritability amongst all horses was estimated to be high. This magnitude suggests that SDFT injury incidence could be reduced through targeted breeding approaches.

Amongst flat racing horses, the heritability of SDFT injury appeared lower than the heritability in the jump racing population but the difference was not statistically significant. Differences in heritability estimates, if real, may suggest that environmental influences play a greater part in susceptibility to SDFT injury in flat racing than they do in jump racing, however the genetic data shown here do not support this theory. Targeted breeding strategies based on SDFT injury estimated breeding values could be of use to affect change in genetic risk in the UK racing population. It should be noted that, unlike distal limb fractures, a greater proportion of SDFT injuries at the racecourse may not have been diagnosed due to a comparatively slow onset of clinical signs (which may be detected upon the horse returning home), thus reducing the number of cases artificially. Also, SDFT injuries that occurred in training may not have been detected due to subtle clinical signs, thus a small number of horses may have raced with pre-existing SDFT pathology, therefore raising their likelihood of becoming a case.

A bivariate analysis of SDFT injury and distal limb fracture revealed a significant positive genetic correlation of a moderate to large magnitude in the jump racing population and amongst all horses. This suggests that a proportion of risk genes is shared by these conditions, or are in linkage with each other, such that genetic susceptibility to one of these conditions is likely to occur concurrently with genetic susceptibility to the other condition. Of course, environmental influences mean that the two phenotypes may not occur concurrently as frequently as this may suggest. Indeed, no phenotypic correlation was found between the conditions amongst flat and jump racing horses, respectively, and a significant but small negative phenotypic correlation was found between them within the population of racehorses as a whole. A significant positive genetic correlation is of practical importance to breeders, as it implies that a forced reduction in the genetic risk of one condition will also reduce the genetic risk of the other, therefore selection of horses for breeding may only need to focus upon one condition, to benefit both.

Within the flat racing population, the moderate genetic correlation between SDFT injury and distal limb fracture was not statistically significant. This finding may suggest that there are underlying differences in the genetic architecture of SDFT injury and distal limb fracture between flat and jump racing horses, or may only suggest a lack of power of this study to detect a statistically significant correlation.

Conclusions

Distal limb fracture and SDFT injury at the racecourse are heritable conditions in the UK Thoroughbred population. Targeted breeding strategies could be implemented to affect a reduction in future genetic risk. There may be commonalities in the genetic architecture underlying the risk of SDFT injury and distal limb fracture in this population, as suggested by positive genetic correlations between these conditions, thus targeted breeding strategies may be able to reduce the genetic risks of both conditions concurrently.

Conflicts of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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