EQUINE VETERINARY JOURNAL
Equine vet. J. (2004) **36** (6) 513-519

Horse-level risk factors for fatal distal limb fracture in racing Thoroughbreds in the UK

T. D. H. PARKIN*, P. D. CLEGG, N. P. FRENCH, C. J. PROUDMAN, C. M. RIGGS†, E. R. SINGER, P. M. WEBBON‡ and **K. L. MORGAN**

Department of Veterinary Clinical Science, University of Liverpool Veterinary Teaching Hospital, Leahurst, Neston, Wirral CH64 7TE and ‡The Jockey Club, 42 Portman Square, London W1H 0EN, UK.

Keywords: horse; Thoroughbred; racing; distal limb; fractures; risk factors

Summary

Reasons for performing study: **Fractures below the level of the radius or tibia (distal limb fractures) are the most common cause of equine fatality on UK racecourses; however, little is known about their epidemiology or aetiology. Identification of risk factors could enable intervention strategies to be designed to reduce the number of fatalities.**

Objectives: **To identify horse-level risk factors for fatal distal limb fracture in Thoroughbreds on UK racecourses.**

Methods: **A case-control study design was used. Fractures in case horses were confirmed by *post mortem* examination and 3 matched uninjured controls were selected from the race in which the case horse was running. One hundred and nine cases were included and information was collected about previous racing history, horse characteristics and training schedules. Conditional logistic regression was used to identify the relationship between a number of independent variables and the likelihood of fracture.**

Results: **Horses doing no gallop work during training and those in their first year of racing were at significantly increased risk of fracture on the racecourse. Case horses were also more likely to have trained on a sand gallop, i.e. a gallop described by trainers as being primarily composed of sand.**

Conclusions: **Modifications to training schedules, specifically within the first year of racing, may have a large impact on the risk of fatal distal limb fracture on the racecourse. Horses should do some gallop work in training and our results suggest that the minimum distance galloped should be between 805–2012 m (4–10 furlongs)/week.**

Potential relevance: **The information from this study can be used to alter training schedules in an attempt to reduce the incidence of fatal distal limb fracture in Thoroughbred racehorses. Training should include some gallop work, and further studies, recording the exact level of work, will help to identify an optimum range of training speeds and distances which will reduce the liklihood of catastrophic fracture on the racecourse.**

Introduction

In the UK, approximately 60% of racecourse fatalities are associated with a fracture (Vaughan and Mason 1976) and the distal limb is the most commonly affected site in all types of race (McKee 1995). Research has focused on the effect of training on bone strength (Nunamaker *et al.* 1990) and the effect of different surfaces on injury rates (Zebarth and Sheard 1985; Moyer *et al.* 1991). However, these approaches investigate only one area of interest, rather than the combined effect of multiple potential risk factors. Multivariable techniques have been used more widely in recent years, enabling the effect of each variable to be quantified while accounting for the effect of others. Risk factors that have been identified by studies conducted in Australia and the USA have included age (Mohammed *et al.* 1991; Estberg *et al.* 1996b,1998b; Cohen *et al.* 1997, 2000; Bailey *et al.* 1998), sex (Estberg *et al.* 1996b, 1998b; Hernandez *et al.* 2001), shoe type (Kane *et al.* 1996) and quality of horse (Kobluk *et al.* 1990; Estberg *et al.* 1998a; Cohen *et al.* 2000). The risk of injury has also been associated with both an increased (Estberg *et al.* 1996a) and decreased (Cohen *et al.* 2000) intensity of racing and a break from racing of more than 33 days (Hernandez *et al.* 2001).

There are clear differences in the UK racing industry, compared to the USA and Australia, which mean that not all of these risk factors may be applicable to distal limb fractures in this country. For example, in the UK most racing is on turf and more than one-third of all starts are over jumps, whereas the majority of previous work has focused on flat racing on dirt. In addition, there have been a number of different case definitions used in previous studies, ranging from catastrophic musculoskeletal injury through to 6 months off racing. In the current study, distal limb fracture necessitating euthanasia was used as the case definition, as it is focused, explicit and easily verified.

The objective was to identify risk factors associated with fatal distal limb fracture in horse racing in the UK, to enable modification of significant risk factors and the design of rational intervention strategies to reduce the number of equine fatalities on UK racecourses.

Materials and methods

Case definition and control selection

Cases were defined as horses that sustained a fracture of any bone distal to the radius or tibia that required euthanasia, at any of the 59 racecourses in the UK. Cases were confirmed by *post mortem*

*Author to whom correspondence should be addressed. †Present address: The Hong Kong Jockey Club, Sha Tin Racecourse, N.T., Hong Kong.
[Paper received for publication 06.06.03; Accepted 24.09.03]

TABLE 1: Complete list of racing history, horse detail and training variables investigated

Previous racing history and horse details	Training details
Horse details • Country in which horse was bred • Sire • Dam • Gender (colt, gelding, female) • Age • Age at first race • Country where first raced • First race type of career • No. years in racing • Current British Horseracing Board rating **Racing intensity** • No. starts in last month, 3 months, 6 months, 12 months, whole career • Total distance raced in last month, 3 months, 6 months, 12 months, whole career **Since last race** • No. days • Change in race type • Change in racing surface • Change in distance • Change in going • Change in weight carried • Change in class of race **Over whole career** • Change of race type • Change of racing surface • Longest interval between races • No. wins • Wins as percentage of starts • No. starts on current racecourse • Highest class of race • Mode going **In current race** • Change from mode going • Use of blinkers, visors, tongue straps • Weight carried	**Training regimen** • Types of training gallop used (turf, woodchip, fibresand, sand, polytrack, equitrack, other)* • Distance walked per week on tarmac • Distance trotted per week on tarmac • No. days since started canter work this season • No. days since started gallop work this season • Average distance cantered per week • Average distance galloped per week • Total distance cantered this season • Total distance galloped this season • No. times schooled over hurdles or steeplechase fences in last 3 months • Use of swimming facilities • Use of water treadmills • Approximate weight of riders used during training **Nutrition** • Amount and type of forage, concentrates and supplements **Medical history** • Trainer reported episodes of lameness and other medical events, resulting in periods of reduced work or complete box-rest **Prerace preparation** • Time taken to get to racecourse on day of race • Behaviour on arrival at the racecourse and in parade ring prior to race • Use of stabling at the racecourse

*Trainers were asked which surfaces horses were trained upon. The 6 named types of gallop were selected as the most common surfaces after consultation with trainers prior to the start of the study. Any gallop description which did not match one of these 6 was classified as 'other'.

examination at the University of Liverpool. Three control horses were selected randomly from uninjured horses in the same race, which reached the same part of the course as the injured horse. The point of injury was identified from the race reports and horses that were pulled up, fell or unseated their jockey before this point were excluded from the control selection process. Controls were selected using random number generation. Case and control horses were matched on race due to our specific interest in horse-level risk factors and because the going, affected by rainfall and time of year, is associated with the risk of musculoskeletal injury (Cheney *et al.* 1973; Bailey *et al.* 1998).

Previous racing history and horse details

Details were purchased from Raceform (Newbury, UK) as a disk-based programme, updated weekly, which included information on all races run in the UK. A comprehensive list of variables were investigated that related to breeding, age, gender, number of years in racing, number of starts and total distance raced, length of periods without racing, racing ability and use of head gear/tongue straps. Changes in distance, surface, race type, going and weight carried since the last race and compared to career averages were also recorded. Table 1 contains the complete list of variables investigated.

Training information

Telephone interviews were conducted with the trainers of case and control horses using a structured questionnaire designed to gather information about training practices. Variables investigated included the types of gallops used, distances trotted or walked on tarmac, distance cantered and galloped per week and since start of training season, use of swimming pools or water treadmills and schooling for National Hunt horses. Details about nutrition, medical history and prerace preparation were also recorded. Table 1 contains the complete list of variables investigated. A copy of the questionnaire is available from the senior author.

External validation of training data

Data from a cohort study of fractures in training at 13 flat training yards in the UK provided a source of external validation (K. Verheyen *et al.*, personal communication). During this study, personnel at each yard made daily records of training routines for a sample of horses in the yard. Nine of the controls from the current study were part of the Verheyen cohort study. The mean difference and range of differences between the paired sets of data were calculated by subtracting the values given in the Verheyen data from the estimates made in the current study.

TABLE 2: Univariable and quadratic relationships between independent variables, associated with racing and training history and fatal distal limb fracture (P≤0.25)

Variable	Odds ratio	95% CI	d.f.	P value	LRS P value
No. years in racing (quadratic)					
Years in racing	0.79	0.64–0.98		0.03	
Years in racing squared	1.09	1.03–1.14	2	0.001	0.004
Years in racing (categorical - quintiles)					
1 (i.e. first year)*	1				
2	0.57	0.25–1.27		0.17	
3	0.61	0.23–1.56		0.30	
4–5	0.34	0.13–0.92		0.03	
6–10	0.66	0.24–1.86	4	0.44	0.25
Distance galloped in training per week (piecewise linear)†	0.87	0.78–0.96	1	0.006	0.006
Distance galloped in training per week (quadratic)					
No. metres	0.96	0.93–1.00		0.05	
No. metres squared	1.004	1.00–1.01	2	0.005	0.015
Distance galloped in training per week (categorical - quintiles)					
0	3.13	1.10–8.91		0.03	
402–1408 m (2–7 furlongs)*	1				
1609–2414 m (8–12 furlongs)	1.06	0.53–2.09		0.87	
2615–3219 m (13–16 furlongs)	0.70	0.30–1.64		0.41	
3420–7443 m (17–37 furlongs)	1.06	0.46–2.47	4	0.89	0.09
First race of career					
No*	1				
Yes	2.09	0.84–5.22	1	0.11	0.12
Gender					
Colt*	1				
Gelding	0.5	0.23–1.09		0.08	
Female	0.6	0.27–1.36	2	0.22	0.22
Change of race type ever in career					
No*	1				
Yes	0.52	0.27–0.99	1	0.05	0.04
Change of surface since last race					
No*	1				
Yes	2.01	0.70–5.76	1	0.20	0.20
Use of woodchip training gallop					
No*	1				
Yes	1.47	0.91–2.37	1	0.12	0.11
Use of sand training gallop					
No*	1				
Yes	1.91	0.97–3.78	1	0.06	0.07

95% CI = 95% Confidence interval; d.f. = degrees of freedom; LRS = Likelihood ratio statistic; *Reference category; †Linear reduction in risk from 0 to 1609 m (0–8 furlongs) galloped per week, after which the risk levels off.

Statistical methods

Conditional logistic regression, which accounts for matching of cases and controls, was used to analyse the data. The univariable relationships between all the independent variables and fatal fracture were estimated by including them individually in a model with fatal fracture as the dependent variable. Continuous variables were also categorised into the quintiles of the distribution of that variable. Quadratic, cubic and piecewise linear terms were also derived for each continuous variable to determine which would best describe the shape of the relationship between the variable and fracture. Piecewise linear terms were used to describe relationships which have 2 (or more) linear components. In the case of distance galloped per week, the piecewise linear form was composed of an initial linear decrease in risk, up to a certain number of metres, after which the risk levelled off. The point or number of metres at which the risk levelled off was determined by assessment of the fit of a range of piecewise linear forms, each with a slightly different initial linear decreasing risk component. The upper distances assessed for this component were 402–3017 m (2–15 furlongs).

Multivariable models were created using the forward stepwise procedure. Variables that had P values ≤0.25 from the univariable analysis were considered for inclusion in the final models. Variables were retained if they significantly reduced the residual deviance of the model (likelihood ratio statistic; LRS; P<0.05). Goodness-of-fit was assessed graphically by plotting the deviance residuals versus the individual observations. Case-control sets that appeared to have extreme values during visual examination of these plots were excluded from the analysis to evaluate their influence on estimated odds ratios and the variables included in the models. The statistical packages Epi-info[1] and EGRET[2] were used.

Results

Univariable analysis and assessment of quadratic terms

The univariable relationships between independent variables and fracture, with P values ≤0.25, are shown in Table 2. The likelihood of fracture was strongly associated with the number of years in

TABLE 3: Multivariable conditional logistic regression model of fatal distal limb fracture (No. metres galloped per week included as a quadratic relationship) (likelihood ratio statistic = 23.22 [5 d.f.]; P<0.001)

Variable	Coefficients	Standard error	Odds ratio	95% Ci	d.f.	P value
No. years in racing (quadratic)						
Years in racing	-0.28	0.12	0.76	0.6–0.95		0.01
Years in racing squared	0.08	0.03	1.09	1.04–1.15	2	0.001
Distance galloped in training per week (quadratic)						
No. metres	-0.04	0.02	0.96	0.93–1.0		0.06
No. metres squared	0.004	0.001	1.004	1.0–1.01	2	0.004
Use of sand training gallop						
No*			1			
Yes	0.76	0.37	2.14	1.03–4.45	1	0.04

95% Ci = 95% Confidence interval; d.f. = degrees of freedom; *Reference category.

racing, the risk being highest for horses in their first year (quadratic relationship; P = 0.004). The average distance galloped per week was also associated with the risk of fracture, the risk being highest for those doing no gallop work. Both the piecewise linear (P = 0.006) and quadratic (P = 0.015) forms of this relationship were strongly associated with fatal fracture. The risk may therefore level off above 1609 m (8 furlongs)/week (piecewise linear) or increase again at very long distances (quadratic). The categorical form of the same variable was less strongly associated with the likelihood of fracture (P = 0.09); however, it also showed that the risk was highest for those doing no gallop work. A change of race type during the horse's career was associated with a reduced risk of fracture (P = 0.04). Other variables less strongly associated with an increased risk of fracture were first race of career (P = 0.12), being a colt (P = 0.22), change of surface since last race (P value = 0.2) and the use of woodchip (P = 0.11) or sand (P = 0.07) training gallops.

Multivariable analysis

The similar strength of the relationships between the 2 forms of the distance galloped variable and fracture suggested that either could represent the true situation. Two models were therefore produced, the first using the quadratic form and the second using the piecewise linear form of this variable. In the first model, 3 variables were associated significantly with the risk of fracture; the number of years in racing, the average distance galloped per week in training and the use of sand gallops (Table 3). Inclusion of further variables failed to improve the fit of this model significantly.

The relationship with number of years in racing was best described by a quadratic curve. The highest risk was in the first year in racing with a decline in risk for those horses in years 2–5. However, after 5 years in racing the risk appeared to increase again (Table 2). The relationship with the number of metres galloped per week in training was also described by a quadratic curve, suggesting that the risk was highest for horses doing no gallop work, initially decreased and then increased again for horses galloping longer distances. Inclusion of the variable describing the use of sand training gallops marginally improved the fit of the model (LRS = 3.95; P = 0.047). Case horses were twice as likely to have used a sand gallop than control horses.

In the second model, using the piecewise linear form of distance galloped per week in training, only this and the number of years in racing were associated with the risk of fracture (Table 4). In this model, inclusion of the variable describing the use of sand gallops did not significantly improve the fit (LRS = 3.71; P = 0.056). The association with number of years in racing was very similar to that in the first model. The piecewise linear term for the distance galloped per week in training indicated that the risk was highest for those horses doing no gallop work. There was a linear decline in risk up to 1609 m (8 furlongs)/week followed by no significant alteration in risk if the training schedule included more than 1609 m/week, up to a maximum of 7443 m (37 furlongs)/week. A cut off set at 1609 m (8 furlongs) provided the best fit for the model, i.e. the lowest residual deviance; however, fitting the same model with cut-offs within the range 805–2012 m (4–10 furlongs) did not significantly reduce the overall fit of the model. Due to the matched study design, it is not possible to plot this piecewise linear term. However, the plot of the categorical form of the same variable (Table 2) provides a graphical indication of the shape of the relationship (Fig 1). Removal of data sets with the largest residuals altered the odds ratios by less than 10% and had no effect on which variables were included in the final models.

Trainer compliance

Ninety-five percent (104/109) of trainer questionnaires were completed for case horses. Ninety-four percent (309/327) of trainer questionnaires were completed for control horses.

TABLE 4: Multivariable conditional logistic regression model of fatal distal limb fracture (No. metres galloped per week included as a piecewise linear relationship) (likelihood ratio statistic = 17.36 [3 d.f.]; P<0.001)

Variable	Coefficients	Standard error	Odds ratio	95% CI	d.f.	P value
Years in racing	-0.24	0.11	0.79	0.63–0.98		0.04
Years in racing squared	0.08	0.03	1.08	1.03–1.14	2	0.002
No. metres galloped in training per week (piecewise linear)†	-0.13	0.05	0.87	0.79–0.97	1	0.01

95% CI = 95% Confidence interval; d.f. = degrees of freedom. †Linear reduction in risk from 0–1609 m (0–8 furlongs) galloped per week, after which the risk levels off.

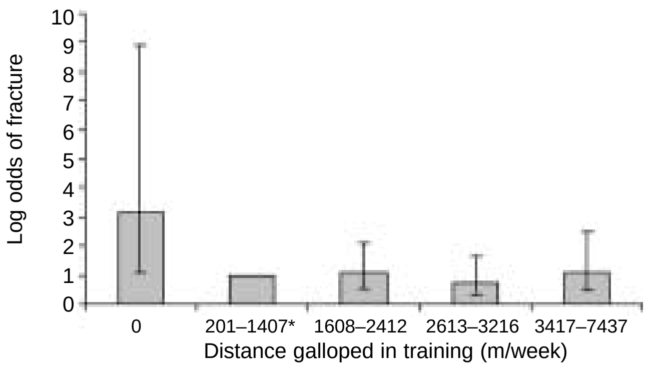

*Fig 1: Univariable relationship between the categorical form of distance galloped in training per week and the log odds of fatal distal limb fracture during racing (showing 95% confidence intervals; *reference category).*

Validation of training data

External validation of the data showed that 90% (57/63) of gallops used by horses which appeared in both data sets were consistently identified by trainers. The mean difference between the paired data for the number of days cantered and galloped since the start of the season was 29.4 (range 1–117) and 43.1 (range 4–130), respectively. The mean difference between the paired data for the average number of metres cantered and galloped per week was 6.1 (range -6 to 15) and -1.4 (range -8 to 2), respectively.

Discussion

This study was conducted to identify horse-level risk factors for fatal distal limb fractures occurring during racing in the UK. Results from the study indicated that horses that did no gallop work during training, were in their first year of racing and used sand training gallops were at increased risk of fatal distal limb fracture during racing.

The data were modelled in 2 ways. In the first, a quadratic relationship between distance galloped and risk of fracture was used. In the current data set there were, however, very few horses doing long-distance gallop work, resulting in a high level of uncertainty associated with the increased risk, suggested by this shape of relationship, for these horses. It was for this reason that the piecewise linear relationship, in which there was no increase in risk for horses doing long-distance gallop work, was used in the second model.

In both models, there was a strong association between those horses doing no gallop work and the risk of fracture. This effect concurs with other studies which indicate that the structure and mass of bone is influenced by adaptation to the stress it is placed under (Rubin and Lanyon 1985; Lanyon 1987; Riggs *et al.* 1993). Such adaptations achieve a biological optimum for bone under a particular mechanical environment (Loitz and Zernicke 1992; Riggs *et al.* 1993). In the racehorse, this is principally influenced by the training regimen to which the horse is exposed. Nunamaker *et al.* (1990) showed that different exercise patterns induce different loads on the third metacarpus; slower speeds result in tension at the dorsal cortex, whereas galloping at greater speed results in compression of this surface. We therefore hypothesise that the bones of horses in our study which were doing no gallop work were not optimally adapted to the loads they would experience under racing conditions and were therefore more likely to fail. Another possible explanation is that horses doing only slower work were unable to do faster work in training due to pre-existing injury. Of 13 trainers who said that horses did no gallop work, 8 were questioned about more than one horse. Of those 8 trainers, 5 also trained horses which they said did some gallop work, possibly indicating that they were training individual horses at slow speeds due to injury. Without reliable medical histories, however, it is not possible to verify whether this was the case.

Results from a study by Estberg *et al.* (1996a) indicated that long distances of high-speed exercise increase the risk of fatal breakdown in Thoroughbreds, suggesting that the quadratic relationship observed in the current study may be in fact be the best representation of the association between distance galloped in training and racecourse fracture. Cyclic loading or repeated deformation of bone within its elastic limit can result in fatigue damage, which may ultimately lead to complete failure (Lanyon 1987; Riggs *et al.* 1993). The degree of deformation or strain at each cycle is partially a function of the magnitude of load and the fatigue-life (the number of load cycles before failure) is logarithmically related to strain at each load cycle (Nunamaker *et al.* 1990); as the load increases, so the fatigue-life decreases. Therefore, bones of horses undergoing a greater number of high-load cycles, i.e. more fast work, are more likely to reach a point of failure sooner than those doing fewer high-load cycles. Rubin and Lanyon (1984) demonstrated that relatively few load cycles are required to produce an adaptive response. Boston and Nunamaker (2000), although using data from only 5 separate trainers, suggested that horses that underwent regular short-distance periods of faster work were less likely to develop dorsal metacarpal disease. The results from the current study also suggest that short distances of high-speed exercise reduce the risk of fracture and that this distance may be as short 805–2012 m (4–10 furlongs) per week. Further studies, recording the exact level of work, should help to identify an optimum range of training speeds and distances to reduce the risk associated with common types of catastrophic fracture during racing.

Horses in the first year of racing were at greater risk than horses in any other year. After the first year the risk initially decreased, but then appeared to increase again after 5 years (Table 2). We hypothesise that the increase in exercise intensity associated with entering training for the first time may be responsible for the high level of risk early in a horse's career. Collection of cases is continuing and when numbers suffice it will be possible to examine further the association between exercise levels and the likelihood of racing fracture for those horses in their first year of racing. It is important to note that the number of years in racing is not simply a measure of the age of the horse. Age was included in the current study and was not associated with the risk of fatal fracture. This may have been due to a partial matching on age in the control selection process, as some races are open only to certain age groups. However, Mohammed *et al.* (1991) also showed that, irrespective of age, horses in their first year of racing were at significantly higher risk of musculoskeletal breakdown. There has been a long-held concern that racing young horses presents them with a greater risk of injury. These results suggest that it is not the age of the horse but the first year of training which increases their risk. Wood *et al.* (2000) demonstrated that horses that start flat racing as 2-year-olds, compared to those that start at older ages, are at reduced risk of death later on in their racing careers. We could not substantiate this finding for distal limb fracture fatalities, but this may be due to the fact that Wood *et al.* (2000) analysed all causes of death, or that we analysed all race types together.

The quadratic shape of the relationship suggested that there was an increase in risk for horses which had been racing longest (>5 years). It is important to note that the horses in this category included a wide age range and this reflected the small number of older horses. Only 8% (34/436) of horses in the current data set had completed 5 or more years in racing; therefore, an increase in risk may be of little significance in terms of the whole racehorse population. A reduction in the risk of fracture in these horses would have little impact on the total number of horses sustaining fatal fractures on racecourses. This finding demonstrates that resource planning is another valuable product of this type of study. In order to have greatest impact on the total number of equine fatalities, further research effort should be focused on reducing the high level of risk associated with horses in their first year of racing.

The finding that horses in their first year of racing are at greater risk may partially explain the greatly increased risk seen in National Hunt flat (NHF) racing (McKee 1995; Parkin *et al.* 2003). National Hunt flat races are intended to introduce future jump horses to racing and, therefore, most horses participate in these races during the first year in training. In the current database, significantly more horses competing in NHF races were in their first year (67% [24/36]) compared to those competing in hurdle races (17% [20/120]; $\chi^2 = 41.7$; $P<0.001$) or steeplechase races (9% [10/120]; $\chi^2 = 59.8$; $P<0.001$).

There was evidence that the training surface might be important in reducing the risk of fracture. In the first multivariable model, there was an association between fracture and the use of sand gallops. This may have been due to residual confounding attributable to the slightly poorer fit of the quadratic form of distance galloped or it may be a real effect. Several other studies have indicated that the rate of injury during racing is greater on dirt than on turf (Hill *et al.* 1986; Mohammed *et al.* 1991; Wilson and Robinson 1996). Zebarth and Sheard (1985) suggested that this difference is due to the greater cushioning effect of turf compared to dirt, reducing the impact on the bony skeleton. A similar explanation was given by Moyer *et al.* (1991), who demonstrated that the incidence of dorsal metacarpal disease during training was significantly greater in horses trained on dirt compared to those trained on wood fibre. The finding from the current study suggests that the repetitive use of sand gallops may result in a greater degree of pathology, which translates into a greater risk of catastrophic injury on the racecourse. The most studied form of fatigue or repetitive strain injury is dorsal metacarpal disease. Norwood (1978) and Moyer *et al.* (1991) indicated that the incidence of this disease was directly attributable to the type of surface on which horses trained or raced. There is evidence to suggest that the most common type of fracture observed in the current study, i.e. condylar fractures of the third metacarpus or metatarsus, are also fatigue-related (Riggs *et al.* 1999). It is therefore possible that such fractures are the result of previous pathology, the degree of which may be influenced by the surface on which horses are trained. The physical properties of the sand training surface that may induce such pathology are unclear. Factors such as the level of maintenance or the depth of sand may be important, as suggested by Cheney *et al.* (1973) and Norwood (1978) with reference to dirt surfaces. This finding, together with the increased risk associated with all-weather racing surfaces (Parkin *et al.* 2003), suggests that identifying or modelling the way the hoof interacts with racing and training surfaces is an important area for further research.

In the univariable analysis, a change in race type during a horse's career was strongly associated with the likelihood of fracture. It appeared that horses that had changed their race type were less likely to sustain a fracture. However, in multivariable analysis the strength of this association was not maintained. The reason for this is that a change in race type was confounded by the number of years in racing, i.e. horses that had a longer racing career were more likely to have changed race type. From the data in the current study, only 6% (19/181) of horses in their first 2 years of racing had changed race type, whereas of those horses that had completed 3, 4 or 5 years of racing, 81% (84/104) had changed race type.

In the current study design, case and control horses were selected from the same race in order to account for other factors, such as the going or race distance, which may affect the likelihood of fracture. Such matching may have reduced the power to detect associations between the risk of fracture and variables such as age and sex, due to race entry restrictions. Some races are open only to certain age groups or sexes and the selection of controls from the same race therefore resulted in a partial matching on these factors. In order to address this specific problem, a further analysis will be performed only on races which have no such restrictions.

The use of telephone questionnaires to obtain training information ensured a very good response rate. This method was chosen after lengthy consultation with trainers prior to the start of the study. The majority indicated that they would prefer to be interviewed by telephone rather than complete lengthy postal or faxed questionnaires. In order to address concerns over the accuracy of data gathered by telephone questionnaire, external validation was performed. The results of this assessment suggested that, during telephone questionnaires, trainers consistently overestimated the amount of time horses had been both cantering and galloping that season. In contrast, the number of metres (furlongs) cantered and galloped per week were not consistently over- or underestimated by telephone questionnaire. The means of differences, however, suggested that distance cantered per week was more likely to be overestimated, whereas distance galloped per week was more likely to be slightly underestimated. Only distance galloped per week was significantly associated with the risk of fracture. It is possible that the level of inaccuracy observed with other variables reduced the power to detect associations with fracture. Further validation of these and other training variables will therefore be carried out by way of interviews conducted with a selection of trainers at their training yards.

This study has identified several risk factors for fatal distal limb fracture at the level of the horse. The results from this work have been presented to racehorse trainers, owners and veterinary surgeons. Suggestions have been made with respect to distances cantered and galloped in training, and it is hoped that the rate of fatal distal limb fracture on UK racecourses will be reduced. Further collection of cases will allow validation of the current findings and also enable risk factors for the most common types of fracture in individual types of race to be identified.

Acknowledgements

The help provided by the Jockey Club Veterinary Officers was essential to the success of this work. The cooperation of the local racecourse vets, clerks, racehorse owners and trainers is gratefully acknowledged. The authors would like to thank Kristien Verheyen and James Wood at the Animal Health Trust for the provision of data from their study. The authors would also like to thank Jo Cotton and Ron Cook at the University of Liverpool and Sebastian Garner from Racehorse Ambulance Services Ltd. This work and Tim Parkin's position at the University of Liverpool were funded by the Horserace Betting Levy Board.

Manufacturers' addresses

[1]CDC, Atlanta, Georgia, USA.
[2]Cytel Software Corporation. Cambridge, Massachusetts, USA.

References

Bailey, C.J., Reid, S.W., Hodgson, D.R., Bourke, J.M. and Rose, R.J. (1998) Flat, hurdle and steeple racing: risk factors for musculoskeletal injury. *Equine vet. J.* **30**, 498-503.

Boston, R.C. and Nunamaker, D.M. (2000) Gait and speed as exercise components of risk factors associated with onset of fatigue injury of the third metacarpal bone in 2-year-old Thoroughbred racehorses. *Am. J. vet. Res.* **61**, 602-608.

Cheney, J.A., Shen, C.K. and Wheat, J.D. (1973) Relationship of racetrack surface to lameness in the thoroughbred racehorse. *Am. J. vet. Res*. **34**, 1285-1289.

Cohen, N.D., Berry, S.M., Peloso, J.G., Mundy, G.D. and Howard, I.C. (2000) Association of high-speed exercise with racing injury in thoroughbreds. *J. Am. vet. med. Ass.* **216**, 1273-1278.

Cohen, N.D., Peloso, J.G., Mundy, G.D., Fisher, M., Holland, R.E., Little, T.V., Misheff, M.M., Watkins, J.P., Honnas, C.M. and Moyer, W. (1997) Racing related factors and results of prerace physical inspection and their association with musculoskeletal injuries incurred in thoroughbreds during races. *J. Am. vet. med. Ass.* **211**, 454-463.

Estberg, L., Gardner, I.A., Stover, S.M. and Johnson, B.J. (1998a) A case-crossover study of intensive racing and training schedules and risk of catastrophic musculoskeletal injury and lay-up in California thoroughbred racehorses. *Prev. vet. Med.* **33**, 159-170.

Estberg, L., Stover, S.M., Gardner, I.A., Johnson, B.J., Jack, R.A., Case, J.T., Ardans, A., Read, D.H., Anderson, M.L., Barr, B.C., Daft, B.M., Kinde, H., Moore, J., Stoltz, J. and Woods, L.W. (1998b) Relationship between race start characteristics and risk of catastrophic injury in thoroughbreds: 78 cases (1992). *J. Am. vet. med. Ass.* **212**, 544-549.

Estberg, L., Stover, S.M., Gardner, I.A., Drake, C.M., Johnson, B. and Ardans, A. (1996a) High-speed exercise history and catastrophic racing fracture in thoroughbreds. *Am. J. vet. Res.* **57**, 1549-1555.

Estberg, L., Stover, S.M., Gardner, I.A., Johnson, B.J., Case, J.T., Ardans, A., Read, D.H., Anderson, M.L., Barr, B.C., Daft, B.M., Kinde, H., Moore, J., Stoltz, J. and Woods, L.W. (1996b) Fatal musculoskeletal injuries incurred during racing and training in thoroughbreds. *J. Am. vet. med. Ass*. **208**, 92-96.

Hernandez, J., Hawkins, D.L. and Scollay, M.C. (2001) Race-start characteristics and risk of catastrophic musculoskeletal injury in Thoroughbred racehorses. *J. Am. vet. med. Ass.* **218**, 83-86.

Hill, T., Carmichael, D., Maylin, G. and Krook, L. (1986) Track condition and racing injuries in thoroughbred horses. *Cornell Vet*. **76**, 361-379.

Kane, A.J., Stover, S.M., Gardner, I.A., Case, J.T., Johnson, B.J., Read, D.H. and Ardans, A.A. (1996) Horseshoe characteristics as possible risk factors for fatal musculoskeletal injury of thoroughbred racehorses. *Am. J. vet. Res.* **57**, 1147-1152.

Kobluk, C.N., Robinson, R.A., Clanton, C.J., Trent, A.M., Ames, T.R. and Gordon, B.J. (1990) Comparison of the exercise level and problem rate of 95 Thoroughbred horses: a cohort study. *Proc. Am. Ass. equine Practnrs*. **36**, 471-475.

Lanyon, L.E. (1987) Functional strain in bone tissue as an objective and controlling stimulus for adaptive bone remodelling. *J. Biomech.* **20**, 1083-1093.

Loitz, B.J. and Zernicke, R.F. (1992) Strenuous exercise-induced remodelling of the mature bone: relationships between *in vivo* strains and bone mechanics. *J. expt. Biol.* **170**, 1-18.

McKee, S.L. (1995) An update on racing fatalities in the UK. *Equine vet. Educ*. **7**, 202-204.

Mohammed, H.O., Hill, T. and Lowe, J. (1991) Risk factors associated with injuries in thoroughbred horses. *Equine vet. J.* **23**, 445-448.

Moyer, W., Spencer, P.A. and Kallish, M. (1991) Relative incidence of dorsal metacarpal disease in young Thoroughbred racehorses training on two different surfaces. *Equine vet. J.* **23**, 166-168.

Norwood, G.L. (1978) The bucked shin complex in Thoroughbreds. *Proc. Am. Ass. equine Practnrs.* **24**, 319-336.

Nunamaker, D.M., Butterweck, D.M. and Provost, M.T. (1990) Fatigue fractures in thoroughbred racehorses: relationships with age, peak bone strain, and training. *J. orthop. Res.* **8**, 604-611.

Parkin, T.D.H., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2003) Level of risk and distribution of fatal distal limb fractures affecting Thoroughbreds racing in the UK. *Vet. Rec.* **154**, 493-497.

Riggs, C.M., Lanyon, L.E. and Boyde, A. (1993) Functional associations between collagen fibre orientation and locomotor strain direction in cortical bone of the equine radius. *Anat. Embryol.* **187**, 231-238.

Riggs, C.M., Whitehouse, G.H. and Boyde, A. (1999) Pathology of the distal condyles of the third metacarpal and third metatarsal bones of the horse. *Equine vet. J.* **31**, 140-148.

Rubin, C.T. and Lanyon, L.E. (1984) Regulation of bone formation by applied dynamic loads. *J. Bone Joint Surg. Am.* **66A**, 397-402.

Rubin, C.T. and Lanyon, L.E. (1985) Regulation of bone mass by mechanical strain magnitude. *Calcif. Tissue Int.* **37**, 411-417.

Vaughan, L.C. and Mason, B.J.E. (1976) *A Clinico-pathological Study of Racing Accidents in Horses. A Report of a Study on Equine Fatal Accidents on Racecourses*, Horserace Betting Levy Board, London, UK.

Wilson, J.H. and Robinson, R.A. (1996) Risk factors for equine racing injuries. *Comp. cont. Educ. pract. Vet.* **18,** 682-690.

Wood, J.L.N., Harkins, L.S. and Rogers, K. (2000) A retrospective study of factors associated with racehorse fatality on British racecourses from 1990-1999. In: *Proceedings of the 13th International Conference of Racing Analysts and Veterinarians*, Eds: R.B. Williams, E. Houghton and J.F. Wade, R&W Publications Ltd, Newmarket. pp 274-277.

Zebarth, B.J. and Sheard, R.W. (1985) Impact and shear resistance of turf grass racing surfaces for Thoroughbreds. *Am. J. vet. Res.* **46**, 778-784.