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AUTHORS: Anna Johnston, Anhad Sidhu, Christopher Riggs, Kristien Verheyen, Sarah Rosanowski

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MISS ANNA S JOHNSTON (Orcid ID : 0000-0003-2680-6208)

DR. CHRISTOPHER M RIGGS (Orcid ID : 0000-0002-9332-4789)

DR. SARAH ROSANOWSKI (Orcid ID : 0000-0002-7950-0029)

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The effect of stress fracture occurring within the first 12 months of training on subsequent race performance in Thoroughbreds in Hong Kong

A. S. Johnston[a]*, A. B. S. Sidhu[b], C. M. Riggs[c], K. L. P. Verheyen[d] and S. M. Rosanowski[a]

[a]*Centre for Applied One Health Research and Policy Advice, Jockey Club College of Veterinary Medicine and Life Sciences. City University of Hong Kong, 31 To Yuen Street, Tat Chee Avenue, Kowloon, Hong Kong SAR;* [b]*Equine Hospital, Royal (Dick) School of Veterinary Studies, University of Edinburgh, Midlothian, UK;* [c]*Veterinary Clinical Services, Equine Hospital, Hong Kong Jockey Club, Hong Kong SAR and* [d]*Veterinary Epidemiology, Economics and Public Health, Department of Pathobiology and Population Sciences, Royal Veterinary College, University of London, UK.*

*Corresponding author email: as.johnston@hotmail.com

Keywords: racehorse; nuclear scintigraphy; Thoroughbred; stress fracture; exercise; performance

Summary

Background: Racehorses are at an increased risk of stress fracture within the first 12 months of racing and when resuming training after a break. Research in these high-risk periods and on the effect of performance post-recovery is limited.

Objectives: To describe the occurrence of stress fractures, diagnosed by nuclear scintigraphy (NS), in racehorses' first 12 months training in Hong Kong, and their impact on racing performance and career length.

Study design: Retrospective 1:2 matched case-control study.

Methods: Clinical records of horses with NS-diagnosed stress fractures within 365 days of import between 2006 and 2018 were collated. Cases and controls were matched on import date. Univariable conditional logistic regression compared signalment, pre-fracture training and post-recovery racing performance between cases and matched controls. Shared Frailty Cox regression analysed time from import to fracture and total career length.

Results: Eighty-seven horses sustained a NS-diagnosed fracture within their first year in Hong Kong (incidence risk 1.7% (95% confidence interval (CI) 1.4-2.1%; N=5,180)). The humerus (42.0%; 95% CI 31.8-52.6%; n=39) and tibia (28.0%; 95% CI 19.1-38.2%; n=26) were most common stress fracture sites. Cases missed a median of 63 days (Interquartile range (IQR) 49-82) of training because of fracture. Within the 12 months following diagnosis, case horses had a median of four (IQR 2-4, p<0.0001) fewer race starts and were down HK$206,188 (IQR HK$0-436,800, p=0.007) in race earnings compared to controls. Career length did not significantly differ between cases and controls (median 2 years and 3 months; IQR 15.3-39.1 months; p=0.2).

Main limitations: Only stress fractures diagnosed by NS were included, hence, the study is not representative of all stress fractures occurring in racehorses in Hong Kong.

Conclusions: Racehorses sustaining a stress fracture within one year of entering Hong Kong lost significant time in training, earnings and race starts. However, overall career length was unaffected.

Introduction

Racehorses are at an increased risk of fracture in their first year of racing [1] and upon returning to training following a layup or spell from training [2–4]. Most of these injuries are a consequence of mechanical fatigue caused by repetitive, cyclical loading of bone at high peak strains [5]. Peak strains may be exceptionally high in bones of the appendicular skeleton of young horses, which have had insufficient time to undergo functional adaptation [5]. Strains may also be especially high in specific locations of bones in the limbs due to stress concentration created by localised, intense intra-cortical remodelling [6]. Focal targeting of remodelling under these circumstances may reflect a biological response to repair damaged bone and there is evidence that this process is significantly more active in horses that are resting compared to those in regular work [7]. Consequently, horses starting training and those returning to work after a short period (2 weeks to 3 months) of rest [2] are at higher risk of sustaining fatigue-related bone injuries, including stress fractures.

Stress fractures are diagnosed at varying stages of fatigue failure of bone, which is a progressive process that may culminate in complete and catastrophic fracture [7,8]. Early detection permits suitable case management, avoiding catastrophic fracture and facilitating recovery, with full healing through the physiological process of remodelling [6]. Nuclear scintigraphy (NS) is sensitive at detecting increased bone resorption/formation and is considered the gold standard imaging modality in horses for the early detection of stress fractures and other bone injuries [9–12]. The tibia and humerus are bones of the appendicular skeleton most commonly affected by stress fracture in racehorses in Hong Kong (HK) [9]. Comparisons between these two fractures have seldom been made [13], despite their clinical significance [9]. Furthermore, the cost of stress fractures in regard to training days lost, and reductions in racing performance has received little investigation [9,11,13].

The aims of this study were to describe the occurrence of stress fractures, diagnosed by NS in racehorses during their first year training in HK and to describe the racing performance of horses after recovering from a stress fracture. This was achieved through the following objectives; to describe the population of case horses in regard to signalment and exercise; to describe the recovery of horses after stress fracture in relation to training activity; to compare post-fracture racing performance between cases and matched controls; and to compare the effects of stress fracture within one year of import on career length between cases and matched controls.

Materials and Methods

Study Design

A 1:2 matched case-control study design was used. Training and racing data for all racehorses at the Hong Kong Jockey Club (HKJC) were retrospectively collected from January 2006 to June 2018. Data were collected from the date of import to 12 months after the date of stress fracture diagnosis. Additionally, notices of retirement up to the 31 October 2018 were recorded.

All Thoroughbred racehorses imported into HK within the study period formed the study population (N=5,180). From 2006 to 2018, between 340 and 500 racehorses were imported annually [14]. Prior to import, information regarding daily exercise was unknown, however the experience of these horses at import ranged from early training only, to having performed in multiple races. During the process of import, horses are subject to at least three weeks pre-export and two weeks post-arrival quarantine. Their opportunity for exercise during this period is usually greatly restricted. Race training commences approximately two weeks after completion of post-arrival quarantine. Consequently, racehorses imported to HK undergo approximately seven weeks of reduced exercise, which is comparable to a rest period. The time between import and starting training was recorded for each horse.

Case and control horses were matched on import date and consequently, country of origin. Matching controlled for the time horses spent in HK and their exposure to variables associated with training at the HKJC. Such variables included the time horses were training at the same facility, within the same stable complex and exposure to the same climate and weather conditions. Two controls with the same import date as cases were exclusively selected by simple random sampling. When two eligible controls were not available with the same date of import, controls were selected from a temporally proximate import group with the same country of origin.

Case and Control Definitions

Cases were Thoroughbred racehorses sustaining a stress fracture of the appendicular skeleton diagnosed by clinical signs of lameness associated with the corresponding limb and confirmed by NS, within the first 365 days after import into HK. Controls were Thoroughbred racehorses without clinical signs of stress fracture (diagnosed by any means) within the first 365 days after import into HK.

Nuclear Scintigraphy Protocol

Horses suspected to have a stress fracture were prepared for skeletal scintigraphic studies following intravenous injection of ^{99m}Tc methylene diphosphonate with a radioactive dose of 4.4×10^9 Bq. Scans were performed approximately four hours after injection using a gamma camera (MiE Equine Scanner H.R.)[a].

The lame and contralateral limbs were routinely scanned although in some cases whole body scans were performed.

Data Collection

Baseline information on age, sex, foaling date, country of origin, import type (i.e. imported for international sales with or without prior racing experience, or imported for private sales with or without prior racing experience) and whether horses had previously raced was collected for all horses (known as signalment). The number of previous race starts were recorded for horses with overseas racing form, available from HKJC online racing records [14].

Training and racing data were obtained from the HKJC's training and racing records, respectively. These are publicly available online (https://racing.hkjc.com/racing/information/english/Horse/SelectHorse.aspx). Daily training data included dates and exercise activities for each horse. Binary variables for training activity were categorised as to whether a horse: raced, barrier trialled, galloped, cantered, trotted or swum. Barrier trials were defined as training races, designed to prepare horses for race-day. A swimming session occurred when horses used the undercover equine swimming pool on site at Sha Tin training centre.

As well as separate categories for gallop, barrier trial and race activities, a single category comprising of these activities was generated to encompass all high-speed exercise events, henceforth referred to as "fast work" (1). Horses cantering and trotting were grouped at initial data collection which was referred to as "slow work" (0).

Racing records, including the date of races, finishing position and race earnings were recorded for all horses from import to 12 months following date of stress fracture (controls followed for 12 months after cases' date of stress fracture diagnosis). Data relating to stress fracture and retirement were collected from veterinary records available on the HKJC's Veterinary Management Information System (VMIS); a bespoke software whereby veterinarians are required to record all clinical findings and treatments administered during training [15]. These included; date of stress fracture diagnosis, affected limb, bone, and date and reason for retirement. Retirement was defined as a horse ceasing competitive racing at the HKJC and was officially recorded in VMIS. Notices of retirement up to 31 October 2018 were included in the study.

Outcome variables

From import, the number of days were calculated to horses' first slow exercise event, gallop, barrier trial and race (hereby referred to as training timings) for all horses. The days between horses' first slow work and first timed gallop were also calculated. For case horses, the time periods generated prior to stress fracture diagnosis included; date of import to date of diagnosis, date of last fast work to date of diagnosis, and date of last slow work to date of diagnosis. The total number of training days lost due to stress fracture was calculated as the time from the last recorded training activity prior to diagnosis to the first exercise event post-diagnosis. There is no set protocol for recovery from stress fracture, and trainers make decisions regarding recovery based on veterinary guidance. The first exercise event post fracture was defined as the first slow work (trot or canter) event from the date of stress fracture diagnosis. Time periods generated measuring recovery from stress fracture included; the date of diagnosis to first slow work, gallop, barrier trial and race. For all horses that were no longer in race-training, the total career length in HK was calculated, measured from the date of import to the date that training ceased.

For all horses, racing performance was measured for each three-month period following stress fracture diagnosis for the subsequent 12 months (hereby referred to as quarter: Q1, Q2, Q3 and Q4) by calculating the quarterly number of race starts, race earnings (prize money earned from race winnings, measured in Hong Kong Dollars [HK$]) and placing percentage. Placing percentage was defined as the percentage of top three placings out of the number of race starts. For control horses, racing performance was measured from the date of stress fracture diagnosis for the matched case, in order to control for the potential greater opportunity for performance from import for controls.

Data Analysis

The study population was described using summary statistics, presented based on data distributions. Continuous and ordinal data were summarised by mean and standard deviation (SD), or by median, range and interquartile range (IQR) for normally and non-normally distributed data, respectively. Data distribution was determined by visual assessment of histograms. Categorical variables were presented as frequencies and percentages with binomial exact 95% confidence intervals (CI).

Differences in signalment, training timings and career length between cases and matched controls, and between humeral and tibial stress fracture cases were compared using univariable conditional logistic regression and univariable logistic regression, respectively. Comparisons were made between signalment, training timings and career length. Shared Frailty Cox regression was used to analyse career length (days) between cases and matched controls. Differences in recovery milestones between case of humeral and tibial stress fracture were compared using non-parametric Wilcoxon rank-sum tests.

To account for the high frequency of zeros in the number of race starts, earnings and percentage placings, race performance data were analysed in two stages. Firstly, the odds of racing (0/1), gaining race earnings (0/1) or having top three placings (0/1) in each quarter after stress fracture diagnosis compared between cases and matched controls using univariable conditional logistic regression. Non-parametric K sample tests compared the median values for each variable out of horses that had raced, had gained race earnings or had top three placings between cases and controls. Additionally, comparisons were made between humeral and tibial stress fracture cases [16]. The overall difference in the median values of race starts and race earnings over the 12 months post stress fracture diagnosis between cases and controls, and between humeral and tibial stress fracture cases was calculated to estimate case horses' median fewer race starts and median lost race earnings attributable to stress fracture occurrence.

Values of $p<0.05$ were considered statistically significant. All data cleaning and analyses were conducted in Microsoft Excel (2016) and STATA 15.1 (StataCorp. 2017. *Stata Statistical Software: Release 15*. College Station, TX: StataCorp LLC).

Power

Assuming a type one error of 5% and n=87 total eligible horses as cases for the study, the odds ratios able to be detected as statistically significant were calculated based on a case:control study with 1:2 matching, using samplesize.sourceforge.net [17]. A power of 80% enabled odds ratios of 2.5 and above to be detected, providing at least 20% of controls were exposed to the explanatory variable under investigation. Odds ratios of 3.0 and above could be detected when at least 10% of controls were exposed to the explanatory variable under investigation.

Results

Descriptive Results

The study comprised of 261 imported racehorses; 87 cases and 174 matched controls. In total, 97.0% (95% CI 94.6-98.9%; n=254) of racehorses were geldings, with 5 colts and 2 fillies. The mean age at import was 3 years old (3.1 years; SD 0.6). Most horses were imported from Australia (47.0%; 95% CI 40.9-53.4%; n=123), New Zealand (27.0%; 95% CI 21.9-33.0%; n=71) and Great Britain (15.0%; 95% CI 11.2-20.3%; n=40). One third (34.0%; 95% CI 28.0-39.8%; n=88) of racehorses had raced prior to import, with a mean of six previous race starts (SD 3.4). Horses were trained by one of 27 trainers, with trainers having a minimum of one and maximum of 20 horses in the study population (median 9; IQR 4-14). Horses commenced recorded ridden exercise a median of 21 days after import (IQR 17-26; range 2-84) and spent a median of 20 days in training before their first recorded gallop (IQR 13-35; range 1-245). The median time between import and beginning fast work was 44 days (IQR 34-62; range 10-268). There were no significant differences between the signalment of horses or in training timings between cases and matched controls (Tables S1 and S2). Further, there was no significant differences between previous racing history, prior to import, between cases and controls. Of the cases, 64.4% (n=55) had not previously raced, compared to 64.9% (n=113) of controls (p=0.8). Of horses that had raced, cases ran a median of 5 times (IQR 2-6) and controls ran a median of 6 times (IQR 3-9).

Description of stress fracture cases

The incidence risk of horses sustaining a NS-confirmed stress fracture during their first year training in Hong Kong over the study period was 1.7% (95% CI 1.4-2.1%; N=5,180). The median time between import and diagnosis of a stress fracture was 112 days (IQR 55-221; range 25-354). Stress fractures occurred in 25.3% (95% CI 16.6-35.7%; n=22) of cases prior to undertaking fast work. The median age at the time of stress fracture diagnosis was 3.3 years (IQR 2.9-4.0; range 2.3-4.9).

A single stress fracture was recorded in 92.0% (95% CI 84.1-96.7%; n=80) of cases, however, seven horses sustained stress fractures at multiple sites on the first occasion of fracture (Table S3). The humerus was the most commonly affected bone, followed by the tibia (Table 1).

Of humeral stress fractures (n=39), 46.2% (95% CI 30.1-62.8%; n=18) were located in the left and 53.8% (95% CI 37.2-70.0; n=21) in the right forelimbs. Tibial stress fractures (n=25) occurred more frequently in the left hind (n=15) compared to the right hind (n=6) (p=0.01). One horse sustained a bilateral tibial stress fracture, and in two cases, the limb was not specified. Signalment and training timings did not differ between humeral and tibial stress fractures (Table S2).

Seventy-five percent (95% CI 64.3-83.4%; n=65) of case horses had undertaken fast work prior to stress fracture. In 20.7% (95% CI 12.7-30.7%; n=18) of cases, the horses' last work event before diagnosis was classified as fast work. The remainder of cases' last exercise event before diagnosis was classified as slow work (79.3%; 95% CI 69.3-87.3%; n=69).

The NS examination at which fracture was diagnosed was conducted a median of 12 days after the last fast-work event (IQR 8-21; range 0-141; n=65), and eight days after the last slow-work event (IQR 4-11; range 0-44; n=85). This did not differ significantly between humeral and tibial stress fractures. Two horses were diagnosed with a stress fracture (both involving the wing of ileum) prior to starting recorded exercise.

Stress fracture recovery

In total, 95.4% (95% CI 88.6-98.7%; n=83) of horses diagnosed with a stress fracture by NS within one year of entering HK returned to training. Horses returned to training after a mean of 58 days (SD 30; n=83), commenced gallop work after a mean of 96 days (SD 42; n=81), entered a barrier trial after a mean of 161 days (SD 61; n=76) and entered a race after a mean of 199 days (SD 72; n=68) after stress fracture. When absence from training prior to and post-diagnosis was considered, horses did not train for a median total of 63 days due to stress fracture (IQR 49-82; range 19-188).

When humeral and tibial stress fractures were considered separately, 94.9% (95% CI 82.7-99.4%; n=37/39) of humeral fracture cases and 70.8% (95% CI 48.9-87.4%; n=17/24) of tibial fracture cases returned to barrier trials within one year of stress fracture. Of cases sustaining a humeral or tibial stress fracture that did return to work, gallop, barrier trial and race within the 12 months post-diagnosis, there was no significant difference between the time to return to each training event.

Post-stress fracture racing performance

Over 78% of cases (95% CI 68.0-86.3%; n=68) and over 85% of controls (95% CI 79.5-90.5%; n=149) raced within 12 months following the date of stress fracture diagnosis (controls matched to cases' diagnosis date). Table 2 displays the summary statistics of racing performance for cases and controls.

The epidemiological odds of racing (Q1; OR 42.8, 95% CI 10.4-175.9, p<0.0001, Q2; OR 4.0, 95% CI 2.2-7.1, p<0.0001), being placed in the top three (Q1; not applicable, Q2; OR 2.5, 95% CI 1.2-5.2, p=0.007) and gaining race earnings (Q1; OR 28.5, 95% CI 3.9-209.2, p<0.0001, Q2; OR 3.1, 95% CI 1.7-5.7, p=0.0001) were significantly higher for controls compared to cases in Q1 and Q2. In Q3, control horses had increased odds of having race earnings compared to cases (OR 1.8, 95% CI 1.0-3.1, p=0.04), although there were no significant differences in the odds of racing or being placed in the top three. In Q4, there were no significant differences in the odds of racing, being placed in the top three or having race earnings between cases and controls.

Of horses that raced, gained race earnings and had top three placings, there were no significant differences between the median number of races run, earnings gained or placing percentage, respectively, between cases and controls in any quarter after the date of stress fracture diagnosis (Tables 2 and 3).

Overall, in the 12 months subsequent to stress fracture diagnosis, case horses had a median of four fewer race starts (IQR 2-4, p<0.0001) and earnt a median HK$206,188 (IQR HK$ 0-436,800, p=0.007) less than control horses (Table 3). No significant differences in lost race starts or earnings were found between cases with humeral or tibial stress fractures.

Retirement

At the time of analysis (data collection complete 31 October 2018), 71/87 (81.6%; 95% CI 71.9-89.1%) case horses and 134/174 (77.0%; 95% CI 70.0-83.0%) control horses had retired. There was no significant difference between the proportion of retirement between cases and controls (p=0.69), as depicted in Figure 1. Of case horses, four retired directly after stress fracture diagnosis, before returning to race-training: three horses retired as a result of stress fracture and one horse retired due to a tendon injury. Bone-related issues (including fracture, osteoarthritis, "degenerative changes" and "fetlock disease") were the most common reason for retirement for cases and controls in the study population (34.0%; 95% CI 27.4-41.1%; n=67/197), followed by tendon injury (23.9%; 95% CI 18.1-30.4%; n=47). Other retirement reasons included (but were not limited to) respiratory conditions (namely exercise induced pulmonary haemorrhage), ligament injury, poor/unacceptable performance and cardiac conditions. By the time horses were retired, case horses had 3.2 times the odds of retiring due to stress fracture compared to control horses that had not sustained a stress fracture within their first year in HK (95% CI 1.14-5.22; p=0.02; no. of cases retiring due to stress fracture= 12; no. of controls retiring due to stress fracture=1). There was no significant difference in the odds of retirement due to stress fracture between case horses sustaining stress fractures in multiple locations compared to those with a single fracture in the first stress fracture event.

Horses were in training for a median of 2 years and 3 months (IQR 15.3-39.1; range 0.3-97.1). There were no significant differences in career length between horses sustaining a stress fracture diagnosed by NS in their first year at the HKJC and control horses (p=0.2, Figure 1). This did not vary between multiple-site stress fracture cases and matched controls, or between horses sustaining humeral or tibial stress fractures.

Discussion

During the process of importation into HK, racehorses are effectively subject to several weeks of enforced rest. This provides a useful model for investigating the occurrence of stress fractures in a homogenous population of racehorses upon their return to race training following a period in which their appendicular skeleton is subject to relatively low strains. The current study showed that within the population of horses in their first year in HK, humeral and tibial sites of stress fracture were most common. Case horses missed a significant number of days in training and in the 12 months following fracture diagnosis, missed a significant number of race starts and race earnings compared to controls. Horses began training a median of 21 days after import (seven days after release from quarantine) and spent a median of 20 days in slow work before their first timed gallop- a median of 42 days after import. This timeframe did not differ significantly between cases and controls, indicating that the rate of introduction to exercise was not associated with stress fracture incidence. Racing starts prior to entering HK did not differ between cases and controls, however, prior exposure to exercise or training program may have been an influential factor associated with stress fracture occurrence, which was not considered in the current study.

The majority of horses with stress fractures returned to race training. However, when compared to controls, case horses missed approximately two months of race training (median 63 days), had fewer race starts and consequently won less prize money in the 12 months following stress fracture diagnosis. The effect was transient as by 12 months post-fracture, there were no significant differences in race performance outcomes between cases and controls. In addition, overall career length was not negatively affected by the occurrence of stress fracture, although overall, cases were three times more likely to retire due to stress fracture. These findings highlight the short term economic impact of stress fractures in racehorses and complements existing theory that providing adequate post-fracture management enables horses to fully recover with unimpaired long-term athletic performance [11,18]. However, it must be noted that the estimation of missed opportunities to race and earn prize money did not account for confounding factors, such as horse rating, trainer or race availability, factors that may have influenced the horses' performance following fracture. While there is evidence that trainer is associated with the risk of fracture [19,20], this was not able to be controlled for in the present analysis due to resulting data sparsity, which is also what prevented any further multivariable analysis. Despite this, time in HK (and therefore time in race training) was controlled for by matching controls to the same date of import as cases, which would have controlled for the time in the racing season and, to an extent, race availability, reducing the effect of some confounding factors.

One quarter of horses in the study sustained a stress fracture before partaking in timed gallops. It is unlikely that sufficient micro-damage accumulated from the relatively small volume and intensity of work in these cases to be the cause of fracture in its own right. Therefore, it is reasonable to conclude that these fractures arose in bone tissue that was significantly weakened through other means. Carrier *et al*. [2] identified that humeral stress fractures were most commonly sustained in horses starting increased exercise following a lay-up (spell from training) for two months or more. They theorised that this increase in fracture occurrence was due to a localised increase in porosity of cortical bone of the humerus during periods of reduced exercise. This significantly weakened the bone, predisposing it to fracture at relatively light loads upon commencing higher intensity exercise [2,21]. Further work to characterise the material properties of cortical bone from the humerus of racehorses in which callus associated with stress fracture was present provided strong evidence to substantiate this theory [22]. Cortical bone obtained from locations where stress fractures arise, in the presence of periosteal callus (indicating early stress fracture) was significantly weaker than tissue from bones without callus [29]. These findings all emphasise the need for close monitoring of horses on returning to work following a period of rest and support previous findings that even cantering is a significant risk factor for bone failure and stress fracture occurrence in at risk horses [19,23].

The stress fractures most commonly diagnosed by NS occurred in the humerus and tibia. These findings are in agreement with the distribution of fractures reported in previous studies conducted in HK [9] and in Australian racehorses [13]. Further, no significant differences were identified between the signalment and post-recovery performance of horses that sustained either humeral or tibial stress fractures. This is in contrast to findings from Australia where racehorses that sustained either stress or complete humeral fractures had a higher median age but less previous racing experience than cases with stress or complete tibial fractures [11,13]. These differences may be due to the current study investigating horses within their first year in training in HK, rather than investigating the whole racing population, the interruption to race-training associated with the importation process, or the difference in exposure to racing and age structure of the racehorse population in HK [9]. Furthermore, exposure of horses to preparatory training and racing prior to importation prevents direct comparison of our findings to studies investigating horses “naïve” to race-training [24].

The inclusion of only horses with stress fractures diagnosed by NS excluded cases diagnosed by other methods, as well as those horses that may have had no clinical signs of lameness (and therefore did not receive a NS scan) but did have evidence of stress fracture. This case definition reduced the sample size and, therefore, the power, of the study. Consequentially, selection bias was introduced, as cases with asymptomatic stress fractures and cases with stress fractures of specific anatomical sites, more likely to be diagnosed by clinical signs or other imaging modalities, were not included in analysis. However, NS is seen as the gold standard for early stress fracture detection [9–11], hence maximising sensitivity and specificity of case diagnosis, enabling analysis of horses sustaining a definitively diagnosed stress fracture within their first year training at the HKJC [7,9,11]. Additionally, veterinary regulation of racehorses at the HKJC is high, with routine recording of all clinical findings, diagnostic procedures and treatments. This resulted in a high negative predictive value, and high confidence that control horses were absent of fracture for the duration of the study period.

Conclusion

Horses sustaining a stress fracture during their first year in training at the HKJC had significantly fewer race starts and less race earnings in the 12 months following diagnosis compared to controls, however, overall career length was unaffected. This supports evidence that by ensuring appropriate management, racehorses can make a complete recovery from a stress fracture. Further research is required to identify exercise-related risk factors associated with stress fracture occurrence within this higher-risk population.

Authors' declaration of interests

None.

Ethical animal research

The research above has received ethical approval from the Human Subjects Ethics Sub-Committee at the Jockey Club College of Veterinary Medicine and Life Sciences, application number H001734 and the Social Sciences Research Ethical Review Board at the Royal Veterinary College, URN: SR2018-1616. Permission to publish this work has been granted by the Hong Kong Jockey Club research committee and the Royal Veterinary College.

Owner informed consent

Owner consent to use retrospectively collected data was granted by the acceptance of owners of the Rules of Racing of the HKJC, under rule 46.1 and 46.2, when their racing permit was granted.

Data accessibility statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to ethical restrictions.

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Authorship

A. Johnston is the primary author of this study and provided input into the study design, execution, data analysis and interpretation, and preparation of the manuscript. A. Sidhu provided input into the study design and execution, interpretation of findings and preparation of the manuscript. C. Riggs provided input into the study design, execution, and interpretation, and preparation of the manuscript. K. Verheyen provided input into the data analysis and interpretation, and preparation of the manuscript. S. Rosanowski provided input into the study design, execution, data analysis and interpretation, and preparation of the manuscript. All authors gave their approval of the final version.

Manufacturer's address

[a]MiE GmbH©, Seth, Germany.

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Tables

Table 1: Location of stress fractures occurring in racehorses within one year of import into Hong Kong, described by limb and bone.

Limb	**Number**	**Percentage, % (95% confidence interval)**
Left fore	26	29.9 (20.5-40.6)
Right fore	25	28.7 (19.5-39.4)
Left hind	19	21.8 (13.7-32.0)
Right hind	11	12.6 (6.5-21.5)
Both hinds	4	4.6 (1.3-11.4)
Unspecified hind	1	1.1 (0.0-6.2)
Other	1	1.1 (0.0-6.2)
Bone[1]		
Humerus	39	41.9 (31.8-52.6)
Tibia	25	26.9 (18.2-37.1)
Radius	7	7.5 (3.1-14.9)
Pelvis	7	7.5 (3.1-14.9)
Third Metacarpal	7	7.5 (3.1-14.9)
Scapular	5	5.9

		(1.8-12.1)
Femur	3	3.2 (0.7-9.1)

[1]N=93, 7 horses sustained multiple fractures.

Each bone involved in the stress fracture event was included.

Table 2: The number and percentage of race starts, placing percentages and race earnings for each quarter (quarter=three-month period) after date of stress fracture diagnosis for cases and controls.

Race starts					
Percentage of horses that raced % (n)	***Controls***	***Cases***	Number of races (out of those that raced) (Median, IQR[1])	***Controls***	***Cases***
Q1	60.9 (106)	2.3 (2)	**Q1**	2 1-3	2.5 1-4
Q2	66.7 (116)	34.5 (30)	**Q2**	3 2-3	2 1-3
Q3	67.2 (117)	62.1 (54)	**Q3**	2 2-3	2 1-3
Q4	64.9 (113)	58.6 (51)	**Q4**	2 2-3	2 1-3
Race Placings					
Percentage of horses with top three placings (out of those that raced) % (n)	***Controls***	***Cases***	**Top three placing percentage (out of those that raced and had top three placings) (Median, IQR[1])**	***Controls***	***Cases***
Q1	16.1 (28)	0.0 (0)	**Q1**	50 50-100	0
Q2	25.9 (45)	11.5 (10)	**Q2**	50 40-100	66.7 50-100
Q3	34.5 (60)	24.1 (21)	**Q3**	50 36.7-75	50 33.3-100
Q4	32.8 (57)	25.3 (22)	**Q4**	66.7 50-100	50 33.3-66.7
Race earnings					
Percentage of	***Controls***	***Cases***	Race earnings[2]	***Controls***	***Cases***

horses with race earnings (out of those that raced) % (n)			(out of those that gained race earnings) (Median, IQR[1])		
Q1	27.6 (48)	1.2 (1)	**Q1**	158 45.0-476	438
Q2	41.4 (72)	17.2 (15)	**Q2**	167 60.6-505	125 69.0-413
Q3	43.7 (76)	31.0 (27)	**Q3**	277 106-674	262 83.4-638
Q4	42.0 (73)	31.0 (27)	**Q4**	288 127-588	246 80.5-548

[1]Interquartile range

[2]Valued in thousands of Hong Kong Dollars ($), rounded to three significant figures.

Table 3: Race starts and race earnings for cases and controls by quarter (three-month period) and for the total 12 months after date of stress fracture diagnosis.

	Quarter	Cases (Median, IQR[1], Range)	Controls (Median, IQR[1], Range)	Median fewer race starts	P-value
Race starts	1	0 0-0 0-4	1 0-2 0-5		**<0.001**
	2	0 0-1 0-4	2 0-3 0-6		**<0.001**
	3	1 0-3 0-6	2 0-3 0-7		0.509
	4	1 0-3 0-6	2 0-3 0-6		0.096
	Total 12 months	3 1-6 0-11	7 3-10 0-16	**4**	**<0.001**
Race earnings[2]				**Median lost race earnings**	
	1	0 0-0 0-438	0 0-29.4 0-1,285		**<0.001**
	2	0 0-0 0-2,170	0 0-109 0-15,800		**<0.001**
	3	0 0-50.4 0-2,409	0 0-217 0-5,700		**0.049**
	4	0	0		0.087

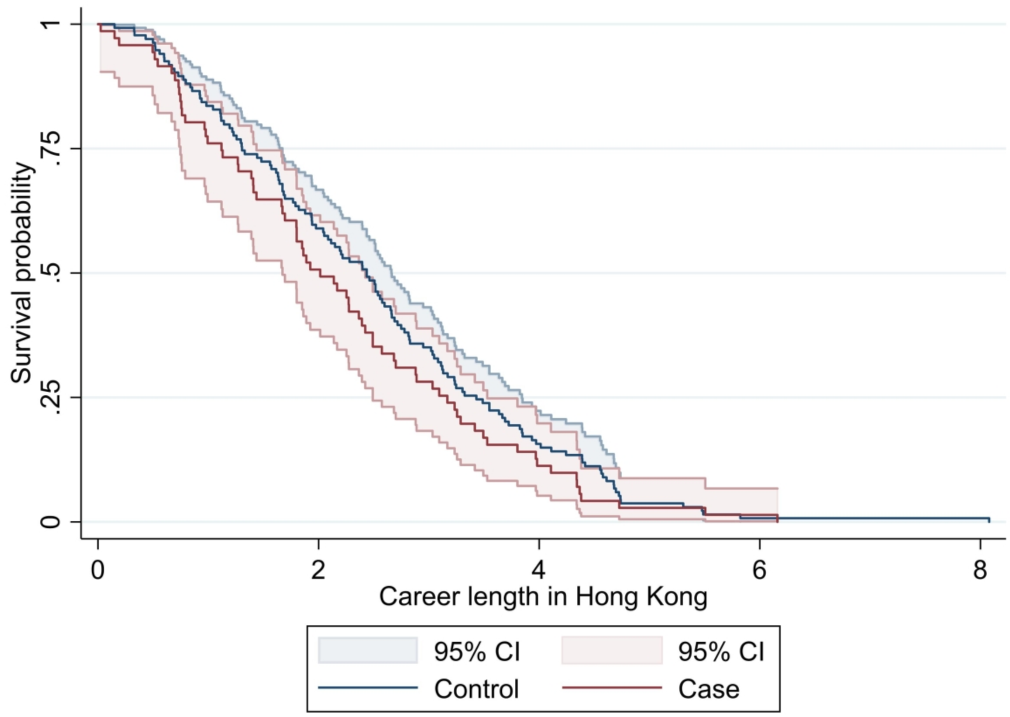
		0-72.8	0-202		
		0-2,260	0-7,500		
	Total 12 months	0 0-409 0-4,859	206 0-846 0-21,800	**206**	**0.014**

[1]*Interquartile range*

[2]*Valued in thousands of Hong Kong Dollars ($), rounded to three significant figures.*

Figure legend

Figure 1: Kaplan-Meier survival curve depicting the career length (from date of import to date of ceasing racing) in Hong Kong between cases of Thoroughbred racehorses sustaining a stress fracture to the apical skeleton within one year of import into Hong Kong and Thoroughbred racehorses that had not sustained a fracture to the apical skeleton within one year of import.



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