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ORIGINAL RESEARCH

Incidence of disease, injury and death in Thoroughbred foals and yearlings on stud farms in the UK and Ireland

Rebecca Mouncey[1] | **Juan Carlos Arango-Sabogal**[1,2] | **Amanda M. de Mestre**[3] | **Kristien L. Verheyen**[1]

[1]Department of Pathobiology and Population Sciences, Royal Veterinary College, Hatfield, UK

[2]Département de Pathologie et Microbiologie, Faculté de Médecine Vétérinaire, Université de Montréal, Saint-Hyacinthe, Quebec, Canada

[3]Department of Comparative Biomedical Sciences, Royal Veterinary College, Hatfield, UK

Correspondence
Rebecca Mouncey, Department of Pathobiology and Population Sciences, Royal Veterinary College, Hatfield, UK.
Email: rmouncey18@rvc.ac.uk

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Abstract

Background: Up-to-date estimates of early-life morbidity and mortality in Thoroughbreds are lacking.

Methods: A birth cohort was established on Thoroughbred stud farms across the UK and Ireland. All veterinary interventions for disease or injury between birth and 18 months of age or leaving the study were recorded. Multilevel Poisson regression models with farm and foal as random effects were fitted to estimate incidence rates.

Results: Data were available for 3328 foal-months at risk for 275 foals on seven farms. The overall rates of disease and injury requiring veterinary intervention and mortality were 11.9 cases/100 foal-months at risk (95% confidence interval [CI] 8.6–16.2) and 0.2 cases/100 foal-months at risk (95% CI 0.1–0.4), respectively. Almost half (n = 133/273, 49%, 95% CI 43–55) of the live-born cohort required veterinary intervention for musculoskeletal disease or injury, equating to 5.8 cases/100 foal-months at risk (95% CI 4.1–8.2), predominantly reported as developmental orthopaedic disease (DOD).

Limitations: Convenience sampling of participants may affect the generalisability of the findings.

Conclusions: Rates of musculoskeletal disease and injury, in particular DOD, on Thoroughbred stud farms were high. Further work to identify modifiable risk factors and further understanding of the economic impact of these conditions and long-term consequences for musculoskeletal health and performance is required.

KEYWORDS
disease, foal, incidence, musculoskeletal, thoroughbred, yearling

INTRODUCTION

Up-to-date estimates of early-life disease and mortality in Thoroughbreds in a UK setting are currently lacking. Such data are needed to inform the recently published industry-led welfare strategy, which called for improved transparency around horses' health prior to entering training and the fate of individuals who do not reach this milestone.[1] With evidence demonstrating the potential of early-life disease to influence later-life health and susceptibility to injury,[2] benchmarking of disease and injury during this period would also allow for future assessments of associations with athletic ability and racing performance.

In young Thoroughbreds, disease and mortality rates have historically been described as being highest in the postnatal period and declining thereafter, with causes of mortality and disease varying with age.[3–5] With advancements in husbandry, management practices and veterinary preventative healthcare, rates of infectious disease, particularly in the neonatal period, appear to have reduced over time.[3,5–7] However, musculoskeletal disease and injury appear to remain important causes of both early-life morbidity and mortality[3,5] and, in a survey of Thoroughbred breeders in Canada, were also reported as the most common reason for yearlings to be deemed unsuitable for racing.[4]

We studied the epidemiology of disease and injury in young Thoroughbreds with the overarching aims of the project being to understand the effects of early-life exposures on later-life health and performance and

identify modifiable risk factors that may potentially reduce rates of injury and disease in this population. The specific objectives of the study reported here were to estimate the incidence of disease, injury and mortality in Thoroughbreds between birth and 18 months of age on stud farms in the UK and Ireland and to describe between-age and between-farm variation in disease/injury incidence. The results will provide much needed transparency and benchmarking of disease and injury in this population. Findings from multivariable risk factor analyses and descriptions of turn-out regimens and other farm management practices will be presented separately in a future paper.

MATERIALS AND METHODS

Study design and period

A prospective cohort study was set up using a convenience sample of Thoroughbred studs across the UK and Ireland. The study period started on 1 January 2019 and ended on 31 December 2020. Studs were recruited to the project prior to the start of the 2018/2019 breeding season through consultation with equine veterinary practices known to have Thoroughbred stud farms under their care and via targeted communications from the Tattersalls sales house, the Thoroughbred Breeders Association and the Newmarket Stud Farmers Association. Recruited farms were a convenience sample of those willing to participate by collecting daily management and health data and consenting to grant the researchers access to veterinary and stud farm records. All foals born in 2019 on the recruited studs entered into the study and were under observation from birth until either exiting the study or entering training/pre-training for racing at around 18 months of age. To increase the sample size, some studs also agreed to enrol all foals born in 2020; these foals were followed until exiting the study or 31 December 2020.

For the purposes of the overarching research project, of which this study forms one part, sample size calculations were carried out using Epi Info (STATCALC version 7.2.5.0, Centres for Disease Control and Prevention, USA). It was estimated that, for a survival analysis approach to investigate risk factors for early-life disease or injury, a total sample size of between 160 and 220 foals was required to be monitored up to entering race training. This assumed a 50%–25% exposure prevalence, study entry over a 6-month period, an average follow-up time of 20 months, median survival in the 'unexposed' of 15–20 months and a hazard ratio of 2. It was estimated that a sample size of between 137 and 316 foals would be required to estimate a disease incidence between 10% and 30% with 95% confidence and 5% precision in a population of 15,000 foals (estimated size of the combined UK and Ireland 2018 Thoroughbred foal crop[8]).

Data collection

Participating farms were given a customised daily recording booklet in which they made a coded entry that identified any day(s) that a foal received veterinary intervention for any reason. Similarly, coded entries were also made to identify days that foals were attended to by a farrier, routine or otherwise. Any periods where foals left the farm for any reason, for example, for the mare to be covered, were also recorded. Periodically, recording booklets were collected, and stud farm and veterinary records were retrospectively accessed to gain details of and reason(s) for the veterinary intervention and farriery booklet entries. Customised electronic data collection forms were designed to ensure consistency of data collected for each coded entry. Data were entered and stored in a database (Access, Microsoft) specifically built for the project.

Data processing

From all recorded veterinary intervention episodes, 'new events' were identified as episodes where a foal received veterinary intervention for the first time for a new condition. Episodes where a foal was attended to again either for ongoing treatment or recurrence of the same condition were therefore not included. New events were then independently verified by two veterinary-qualified reviewers (R. M., J. C. A.) and categorised by body system affected, or syndrome where multiple systems were affected simultaneously, and into infectious (where an infectious pathogen was suspected/identified as the cause) and non-infectious conditions. Further sub-categories were created within body systems where case numbers allowed. A third veterinary-qualified reviewer (K. V.) was available to review data in case of disagreement. Definitions and lists of key descriptive terms were created from available literature[3–5,9–16] to aid with the categorisation process and are given in Table S1. Similarly, farriery events were categorised into either routine (trimming and/or shoeing) or remedial, where corrective trimming, shoeing and/or the application of extensions were undertaken.

Categorised veterinary and remedial farriery data were imported into Stata (Release 16, StataCorp, College Station, TX, USA) alongside foal data, which consisted of date of birth, date of study exit and the dates of any periods where foals were recorded as having left the farm temporarily. Imported data were merged using foal ID as the unique identifier and sorted by observation date (date of veterinary or remedial farriery event or date of leaving the farm). To calculate the total time at risk for each foal, start and end dates were created for each observation. The start date of the first observation for each foal was the date of birth (study entry). The end date was then either the date of study exit for foals with only one observation (i.e., those with no recorded veterinary or remedial farriery events, and which did not leave the farm), or the

date of the next observation (event or off-farm period) minus 1 day for those foals with multiple observations in the dataset. The end date of the last observation for each foal was the date of study exit. Time at risk was calculated for each observation using the start and end dates and added (where required) to provide the total time at risk for each foal. Any periods where foals were recorded as having temporarily left the farm were considered as not under observation, and were therefore subtracted from the total time at risk. The age of the foal, in days, at the time of each event was calculated as date of event minus date of birth.

The study period was also further divided into 6-month periods of foal age by generating entry and exit dates. For example, for the first 6 months of life, the entry date was the date of birth, and the exit date was either the date of birth plus 180 days or the date of study exit, if this was earlier. Similar methods were used to generate entry and exit dates for periods between 6 and 12 months (181–365 days) and 12 and 18 months (366–540 days) of age for all foals remaining in the study at the beginning of each period. Total time at risk for each 6-month period was then calculated from the respective periods' entry date, including all observations occurring within that period, to the periods' exit date or date of study exit if this was earlier.

Data analysis

Analysis was carried out using Stata (Release 16). Data were described at the foal level. To describe available data and descriptive features of the cohort, histograms were plotted for continuous data and visually inspected for normality. The mean and standard deviation (SD) were reported for normally distributed data, the median and interquartile range (IQR) were reported for non-normally distributed data, and the range was reported for all data. Incidence risk was calculated as the total number of cases (new events) divided by the total number of foals at risk at the beginning of the time period of interest. Data were considered potentially clustered by farm; therefore, incidence rates (total number of cases [new events] divided by total time at risk for the period of interest) were calculated by fitting a Poisson null model with farm as a random effect. Rates and 95% confidence intervals (CI) were calculated as cases per 100 foal-months at risk and generated for the study period as a whole and for each 6-month period of foal age. Differences in rates between 6-month periods of foal age and between farms were assessed using Stata's *iri* command within the *epitab* suite,[17] which calculates incidence rate ratios and attributable fractions and reports exact significance tests. Statistical significance was set at *p*-value less than 0.05.

For some categories of disease (developmental orthopaedic disease [DOD], musculoskeletal trauma, wounds and conditions affecting the foot), more than one new event in a foal was identified during the study period; therefore, data were potentially clustered at the foal level. Under such circumstances, rates were calculated by additionally adding foal as a random effect to the Poisson model. Individuals were considered at risk of a second event immediately following the first (i.e., it was assumed, for example, that it was possible for a foal to sustain a second wound while under treatment for the first). The results are presented with number of cases and numbers of foals to indicate where multiple events per foal were considered.

RESULTS

Data were available for 275 foals ($n = 138$ colts and $n = 137$ fillies) born over two seasons ($n = 197$ in 2019 and $n = 78$ in 2020) on seven stud farms serviced by five veterinary practices across the UK and Ireland (three farms supplied data on foals born in 2020, all of which had also supplied data in 2019). Foals were born to 235 mares ($n = 40$ foaled in both seasons), covered by 89 stallions. The average number of foals per farm was 39 (SD 39, range 122). The total time at risk for the cohort was 99,850 foal-days, with a median time at risk/foal of 309 days (IQR 390, range 716). Figure 1 describes losses to follow-up and destinations of individuals leaving the stud farm by foal age for the study period. Table S2 gives a summary of time at risk data stratified by farm.

Incidence of disease and injury requiring veterinary intervention

Over the study period, a total of 437 events that required veterinary intervention for the first time for a new condition were identified. A summary of the types of new conditions requiring veterinary intervention is given in Table 1, with incidences calculated for the study period as a whole and stratified by 6-month periods of foal age. Incidences of the most frequently reported conditions stratified by farm are given in Table S3. Three foals (1.1%, 95% CI 0.4–3.2) were stillborn (reported to have died during parturition) and therefore excluded from disease and injury incidence calculations.

The overall rate of disease and injury requiring veterinary intervention (all new conditions) was 11.9 cases/100 foals-months at risk (95% CI 8.6–16.2), equating to 12 foals requiring veterinary intervention a month on a farm with 100 foals. Rates of disease and injury were over three times higher (25.0 cases/100 foal-months at risk, 95% CI 19.3–32.7) in foals aged between birth and 6 months of age than in those aged 6–12 (8.1 cases/100 foal-months at risk, 95% CI 3.6–18.2) or 12–18 months (5.7 cases/100 foal-months at risk, 95% CI 2.0–16.5) of age (both $p < 0.0001$). Overall, 71% ($n = 195/273$, 95% CI 66–76) of the cohort required veterinary intervention for a new condition during the study period. The distribution of age at veterinary intervention for all new conditions is displayed in Figure 2.

Musculoskeletal disease and injury (DOD, $n = 91$ cases; musculoskeletal trauma, $n = 71$; conditions affecting the foot, $n = 41$; splint, $n = 6$; sesamoiditis,

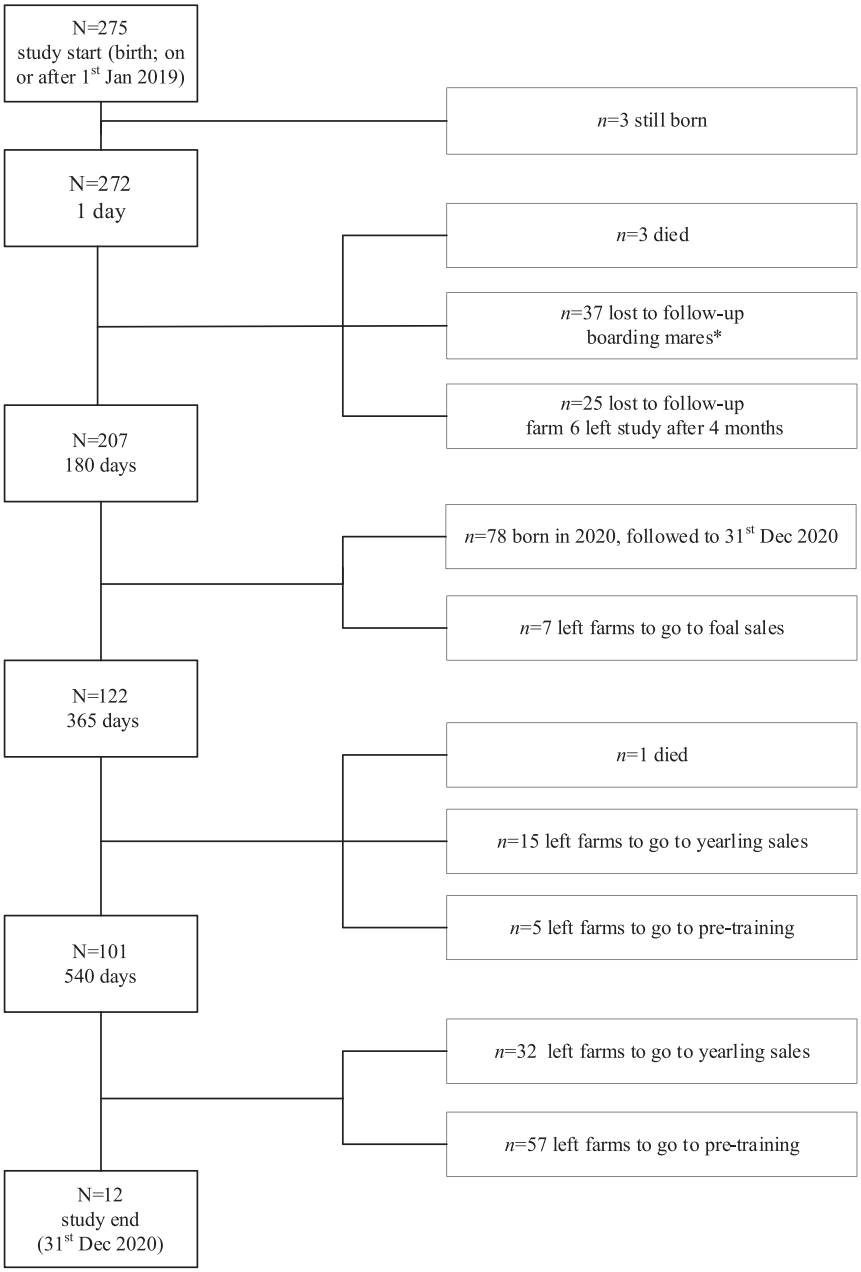

FIGURE 1 Flow chart of relative cohort size (*N*, boxes on the left), losses to follow-up and mortality, and destinations at study exit (*n*, boxes on the right) by foal age (days) for a cohort of 275 foals born on seven stud farms over two seasons ($n = 197$ in 2019 and $n = 78$ in 2020). Study period was from 1 January 2019 to 31 December 2020

$n = 3$; rhabdomyolysis, $n = 1$; osteomyelitis, $n = 1$; septic arthritis, $n = 1$) was the most common category of conditions, accounting for 49% ($n = 215/437$, 95% CI 44–54) of all cases requiring veterinary intervention, affecting 49% ($n = 133/272$, 95% CI 43–55) of foals, with an overall rate of 5.8 cases/100 foal-months at risk (95% CI 4.1–8.2).

DOD was the most common condition requiring veterinary intervention in the cohort, accounting for 21% ($n = 91/437$, 95% CI 17–25) of all new events, with 28% ($n = 76/272$, 95% CI 23–33) of foals affected. Half of all DOD cases required veterinary intervention within the first month of life, and rates were over three times higher in individuals aged between birth and 6 months compared to those aged 6–12 months ($p = 0.006$) and 12–18 months ($p = 0.01$) (Table 1). Rates of DOD also varied significantly ($p = 0.004$) between farms (Table S3). Reported presentations of DOD requiring veterinary intervention are given in Table 2. The majority of cases of contracture (74%, $n = 28/38$, 95% CI 58–85), angular deformities (81%, $n = 13/16$, 95% CI 57–93) and physitis (86%, $n = 6/7$, 95% CI 49–97) were reported to affect the carpi. Cases of laxity mainly affected the fetlocks (88%, $n = 6/7$, 95% CI 49–97), with half described in the forelimb(s) and half in the hindlimb(s). Subchondral bone cysts were mainly reported in the stifle (80%, $n = 8/10$, 95% CI 49–94) and osteochondrosis dissecans (OCD) lesions were mainly reported in the stifle (50%, $n = 5/10$, 95% CI 24–76), tarsus and fetlock (20% each,

TABLE 1 Summary of new conditions requiring veterinary intervention in a cohort of 275 foals born on seven farms over two seasons ($n = 197$ in 2019 and $n = 78$ in 2020), study period between 1 January 2019 and 31 December 2020

			Overall incidence				Incidence stratified by age at veterinary intervention						Age at veterinary intervention (days)		
							0–6 months ($N = 272$)		6–12 months ($N = 207$)		12–18 months ($N = 122$)				
Condition	**Cases, *n***	**Foals, *n***	**Risk[a]**	**95% CI**	**Rate[b]**	**95% CI**	**Rate**	**95% CI**	**Rate**	**95% CI**	**Rate**	**95% CI**	**Median**	**IQR**	**Range**
DOD—all types	91	76	33.5	28.1–39.3	2.8	1.8–4.2	6.2	3.9–9.8	1.8	0.8–4.2	1.1	0.5–2.2	27	206	545
MS trauma	71	60	26.1	21.2–31.6	2.1	1.7–2.7	3.9	3.0–5.1	2.9	1.6–5.3	2.6	1.7–4.1	193	292	625
Wounds	53	42	18.4	14.2–23.4	1.0	0.4–2.2	2.1	1.4–3.0	2.7	1.9–5.7	1.9	0.7–5.8	333	348	572
Foot	41	35	15.1	11.3–19.8	0.3	0.04–2.2	0.7	0.1–4.8	1.0	0.2–5.7	1.5	0.4–5.4	262	325	572
Umbilical hernia	28	28	10.3	7.2–14.5	0.8	0.4–1.6	2.0	1.2–3.5	0.5	0.2–1.2	0	N/A	88	49	189
Omphalitis	21	21	7.7	5.1–11.5	0.4	0.1–1.3	1.5	1.0–2.4	0	N/A	0	N/A	13	14	155
Enteritis/colitis	21	21	7.7	5.1–11.5	0.6	0.4–1.0	1.3	0.8–2.1	0.4	0.1–1.0	0	N/A	58	137	357
Pneumonia	19	19	6.6	4.2–10.2	0.6	0.4–0.9	0.8	0.2–3.4	0	N/A	0	N/A	89	32	128
Colic	16	16	5.9	3.6–9.3	0.4	0.1–1.3	0.8	0.2–2.7	0.4	0.1–1.0	0.4	0.1–1.3	39	225	511
FPT	10	10	3.7	2.0–6.6	0.2	0.04–1.4	0.3	0.1–3.0	0	N/A	0	N/A	2	2	5
MS misc[c]	10	9	3.7	2.0–6.6	0.1	0.01–1.0	0.2	0.02–1.8	0.8	0.4–1.5	0.2	0.01–2.8	379	127	480
Other[d]	56														
Morbidity—all	437	195	71.4	65.8–76.5	11.9	8.6–16.2	25.0	19.3–32.7	8.1	3.6–18.2	5.7	2.0–16.6	115	288	626
Mortality—all[e]	7	7	2.5	1.2–5.2	0.2	0.1–0.4	0.4	0.1–0.9	0	N/A	0.1	0–0.6	0	31	362

Note: All incidence rates are adjusted for the effect of farm (those with n cases > n foals are also adjusted for the effect of foal) and calculated for the study period as a whole and stratified by age of foal at first veterinary intervention, with cohort size (N live foals) at the beginning of each 6-month period.

Abbreviations: CI, confidence interval; DOD, developmental orthopaedic disease; FPT, failure of passive transfer; IQR, interquartile range; MS, musculoskeletal.

[a]Incidence risk calculated as number of cases/total number of live foals excluding stillbirths ($n = 3$).

[b]Incidence rate calculated as cases/100 foal-months at risk with estimates adjusted for the effect of farm.

[c]MS misc: miscellaneous musculoskeletal conditions, including splint ($n = 6$), sesamoiditis ($n = 3$) and rhabdomyolysis ($n = 1$).

[d]Other conditions: upper respiratory tract infection ($n = 9$), abscess ($n = 8$) entropion ($n = 8$), perinatal asphyxia syndrome ($n = 8$), dermatitis ($n = 6$), corneal ulcer ($n = 3$), conjunctivitis ($n = 3$), pyrexia of unknown origin ($n = 2$), ruptured bladder ($n = 1$), choke ($n = 1$), congenital microphthalmia ($n = 1$), neonatal isoerythrolysis ($n = 1$), osteomyelitis ($n = 1$), patent urachus ($n = 1$), septic arthritis ($n = 1$), vasculitis ($n = 1$), and upper respiratory tract noise ($n = 1$).

[e]Mortality risk calculated including all foals ($n = 275$).

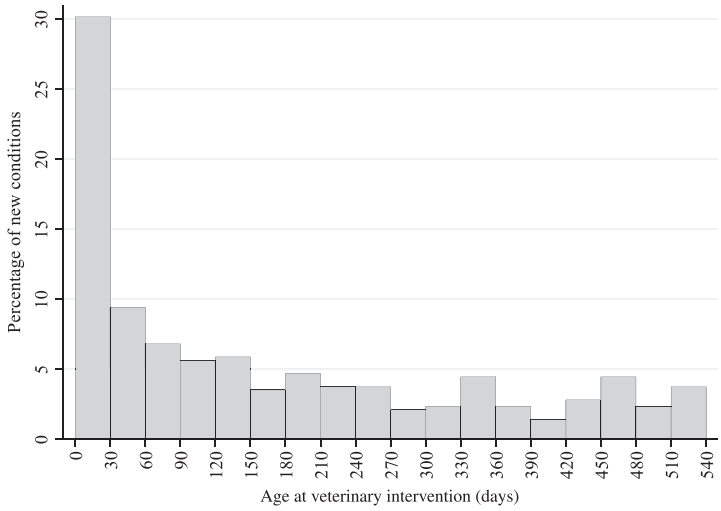

FIGURE 2 Distribution of age at time of veterinary intervention for all new conditions occurring between birth and 18 months of age or leaving the study in a cohort of 275 Thoroughbred foals born on seven farms in the UK and Ireland over two seasons ($n = 197$ in 2019 and $n = 78$ in 2020) within a study period between 1 January 2019 and 31 December 2020

TABLE 2 Summary of presentations reported in 91 cases of developmental orthopaedic disease requiring veterinary intervention in a cohort of 275 foals born on seven farms over two seasons ($n = 197$ in 197 and $n = 78$ in 2020), within a study period between 1 January 2019 and 31 December 2020

				Incidence		Age at veterinary intervention (days)		
Presentation	***n***	**%**	**95% CI**	**Risk[a]**	**95% CI**	**Median**	**IQR**	**Range**
Contracture	38	41.7	32.2–52.0	14.0	10.3–18.6	5	29	132
Angular	16	17.6	11.1–26.7	5.9	3.6–9.3	22	56	418
OCD	10	11.0	6.1–19.1	3.7	2.0–6.6	334	176	361
SBC	10	11.0	6.1–19.1	3.7	2.0–6.6	346	21	151
Laxity	7	7.7	3.8–15.0	2.6	1.2–5.2	4	16	19
Physitis	7	7.7	3.8–15.0	2.6	1.2–5.2	141	355	457
CVM	3	3.3	1.1–9.2	1.1	0.4–3.2	87	79	79

Abbreviations: Angular, angular deformity; CI, confidence interval; CVM, cervical vertebral malformation; IQR, interquartile range; OCD, osteochondrosis dissecans; SBC, subchondral bone cyst.
[a]Incidence risk calculated as number of cases/total number of live foals excluding stillbirths ($n = 3$).

$n = 2/10$, 95% CI 6–51). Overall, 43% ($n = 33/76$, 95% CI 33–55) of individuals requiring veterinary intervention for DOD were also reported as having undergone remedial farriery, predominantly in cases of limb contracture (42%, $n = 14/33$, 95% CI 27–59) and angular deformities (27%, $n = 9/33$, 95% CI 15–44). A further 34 individuals were reported to have undergone remedial farriery but did not receive veterinary intervention for any conditions affecting the musculoskeletal system.

Musculoskeletal trauma accounted for 16% ($n = 71/437$, 95% CI 13–20) of cases requiring veterinary intervention during the study; rates did not vary significantly between age groups or between farms (Tables 1 and S3). In the majority (70%, $n = 50/71$, 95% CI 59–80) of these cases, no specific diagnosis was made, while 16% of cases ($n = 11/71$, 95% CI 9–26) were fractures, and in 14% ($n = 10/71$, 95% CI 8–24) of cases, a diagnosis of haematoma was made. Fracture locations were described as the fetlock (sesamoid, $n = 2$; proximal phalanx, $n = 1$), pedal bone ($n = 2$), head (frontal bone, $n = 1$; maxilla, $n = 1$), pelvis (tuber coxae, $n = 1$), carpus ($n = 1$) and ribs ($n = 1$).

Wounds accounted for 12% ($n = 53/437$, 95% CI 9–15) of all new veterinary events. Rates were significantly higher in individuals aged between 12 and 18 months than in those aged 0–6 months ($p = 0.002$) and 6–12 months ($p = 0.01$) but did not vary significantly between individuals aged 0–6 and 6–12 months ($p = 0.74$) or between farms (Table S3).

Conditions affecting the foot accounted for 9% ($n = 41/437$, 95% CI 7–12) of new cases, and rates were not significantly different between foal age groups or between farms (Table S3). Almost all (95%, $n = 39/41$, 95% CI 84–99) of these records contained 'abscess' in the description, 21% ($n = 9/41$, 95% CI 12–37) mentioned 'hoof crack' and 5% ($n = 2/41$, 95% CI 1–16) mentioned 'white line separation'.

Enteritis/colitis accounted for 4% ($n = 21/437$, 95% CI 3–7) of all new cases requiring veterinary intervention during the study period. Rates were significantly higher in individuals aged between birth and 6 months than in those aged 6–12 months ($p = 0.02$); no cases requiring veterinary intervention were reported in individuals older than 12 months. Rates did not vary significantly between farms (Table S3). Pathogens were only identified in 19% ($n = 4/21$, 95% CI 8–40) of enteritis/colitis cases; however, data to confirm whether samples had been submitted from all cases for pathogen identification were not available. Pathogens reported were *Lawsonia intracellularis* ($n = 3$) and rotavirus ($n = 1$).

Pneumonia also accounted for 4% ($n = 19/437$, 95% CI 3–7) of new cases requiring veterinary intervention during the study period, with all cases presenting in the first 6 months of life. In the majority (84%, $n = 16/19$, 95% CI 62–94) of pneumonia cases, a diagnosis of *Rhodococcus equi* infection was made using ultrasonography, where pathognomonic lesions of the condition were identified. Laboratory testing to identify pathogens was not reported to have been undertaken in any pneumonia cases. Rates of both pneumonia and *R. equi* varied significantly between farms ($p = 0.02$ and 0.005, respectively, Table S3).

Incidence of mortality

In total, seven foals died during the study period, giving an overall rate of 0.2 cases/100 foal-months at risk (95% CI 0.1–0.4). Rates in the first 6 months of life were around four times higher than those observed in other age groups (Table 1), with 86% of cases ($n = 6/7$, 95% CI 48.7–97.4) presenting in the first 31 days of life. These differences were significant when compared to individuals aged 6–12 months ($p = 0.04$) but not when compared to individuals aged 12–18 months ($p = 0.43$). Mortality did not vary significantly between individuals aged 6–12 months and those aged 12–18 months ($p = 0.41$) or between farms (Table S3).

Three foals were considered stillbirths, having died during parturition where dystocia was reported. A further foal was euthanased within the first 24 hours due to congenital microphthalmia. One foal died at 5 days of age while under veterinary treatment for perinatal asphyxia syndrome following premature placental separation. One foal was found dead at 31 days of age in the field, having sustained cranial trauma. A final foal was euthanased at 369 days (31 months) of age following forelimb lameness of several weeks' duration, which was diagnosed as OCD of the fetlock and a large subchondral bone cyst within the coffin joint.

DISCUSSION

This study has provided up-to-date estimates and further description of causes of disease, injury and mortality in Thoroughbreds between birth and 18 months of age on stud farms in the UK and Ireland. Incidence rates of musculoskeletal disease and injury were high, with nearly half of the cohort requiring veterinary intervention for a musculoskeletal condition at least once during the study period. DOD was the most common condition overall, with incidence rates observed to be highest in the first 6 months of life. To date, the majority of previous evidence describing disease and injury in young Thoroughbreds has presented estimates of either prevalence or incidence risk.[3–5,7,18] Methods utilised in the current work, both to estimate incidence rates using time at risk and to adjust estimates for data clustering at the farm and foal level to account for variation between farms and foals within farms, therefore provide novel epidemiological information about disease and injury in this population. By comparing rates between ages, these data also give clues towards the aetiology of certain conditions, for example, where rates were observed to be much higher in the first 6 months of life, in utero and neonatal exposures might be important risk factors for that condition.

Overall rates of disease within the present cohort were over three times higher in the first 6 months of life compared to all other age periods, with around one-third of all new cases receiving veterinary intervention in the first 30 days of life. These findings mirror patterns previously described in non-UK studies where disease incidence risk was highest in the neonatal period and then declined with age.[4,5,7] Similarly, in keeping with findings from other Thoroughbred populations,[19–21] musculoskeletal disease and injury were by far the most common reasons for individuals requiring non-routine veterinary intervention, affecting half of the cohort and around six cases/month/100 foals. High rates of musculoskeletal disease and injury are of particular concern in young Thoroughbreds due to early-life exposures not only having the ability to affect developmental processes but also to alter susceptibility to injury and disease in later life.[2] Thoroughbreds' ability to achieve their maximum athletic potential and financial returns through sale and race earnings are heavily reliant on the health and durability of their musculoskeletal system.[22] Findings from this work therefore highlight the importance of evaluating the effects of these early-life disease and injury exposures both on horses' sales, training and racing outcomes, and stud farms' production costs and profitability.

DOD was the most common condition requiring veterinary intervention overall, and also the most frequently reported musculoskeletal condition in the study population. Previous studies from other countries[18,23–26] have estimated that up to two-thirds of Thoroughbreds could be affected by the condition. It is important to consider in the present study that, due to financial constraints and the expertise of farriers and farm personnel, many milder cases may well have been managed on farms without seeking veterinary advice. To highlight this, if cases that were reported to have received remedial farriery, but not veterinary treatment, were included in the present study, it would be estimated that at least 40% of the cohort may have been affected by the condition. Diagnostic imaging studies have also demonstrated that many presentations of DOD can go undetected, particularly in early life, if routine screening is not performed,[27,28] as was the case in the present study, where radiographs were taken only of a limited number of individuals prior to attending yearling sales. Alongside this, specific diagnoses were not made for the majority of cases of musculoskeletal trauma. Acute onset of clinical signs (lameness, pain, joint distension) is commonly reported in individuals with osteochondral or subchondral cystic lesions, which may be misdiagnosed as traumatic lesions if diagnostic imaging is not carried out.[29] For these

reasons, rate estimates for DOD in the present study are likely to underestimate true rates of the condition in the population.

A recently published study highlighted the importance of congenital DOD lesions as a cause of neonatal mortality in Thoroughbreds.[30] Findings from the present work suggest that congenital DOD lesions are also an important cause of neonatal morbidity, with half of all DOD cases requiring veterinary treatment within the first month of life. Incidence rates of DOD were highest in the first 6 months of life, during which it was likely in some cases that on-farm management and remedial farriery would have been attempted as a first-line treatment. With farriery intervals of several weeks' duration, such practices would lead to considerable delays between the onset of clinical signs and veterinary intervention. It may therefore be reasonable to hypothesise that the majority of DOD lesions observed in the first 6 months of life were likely to be congenital in origin. Rates of DOD varied significantly between farms for the study period as a whole. It is important to acknowledge that while these differences may reflect true differences in rates of these conditions between farms, they may also reflect (as could also be the case in other conditions where significant between-farm differences were reported) differences in elected levels of on-farm veterinary intervention and diagnostics, the relative value of individuals and whether they were to be prepared for sale.

Historically, infectious disease was the most common cause of neonatal morbidity and mortality in Thoroughbreds.[3,7] However, estimates of neonatal infectious conditions in the present work were considerably lower than those from much older studies.[3,7] This suggests that, most likely due to advancements in husbandry and management practices and an increased focus on preventative veterinary medicine and vaccination,[6] non-infectious orthopaedic conditions now represent the most important cause of neonatal and early-life morbidity in Thoroughbreds. Further understanding of the role of in utero exposures in the aetiology of conditions such as DOD are therefore warranted.

In the present study, the majority (87%) of deaths occurred in the first 31 days, mirroring distributions of mortality described in other studies.[5,7] The mortality estimate (2%) compares favourably to figures previously reported in the USA, where 5% of a cohort of 2468 Thoroughbred foals on 167 farms died by 6 months of age,[7] in Ireland, where 6% of 343 Thoroughbred foals on four farms died (including stillbirths) by 12 months of age,[5] and in Canada, where owners reported that 11% of 805 live Thoroughbred foals died in the first year of life.[4] It is important to acknowledge that such differences may be due to true differences in disease and injury between populations but may also be affected by levels of veterinary intervention, elective euthanasia and the value of individuals. The stillbirth estimate in the present work (1%) was similar to those reported in other studies.[3,5,7,31]

The main limitations of this study were the non-random selection of participants and loss to follow-up, which are inherent to the study design. However, these limitations may be balanced by the superior level of evidence generated by prospective longitudinal studies.[32] Participants were self-selected as those willing to collect data over a lengthy period, which could introduce bias as the study population may not be representative of the population as a whole, although farms were a mixture of sizes and owner–breeder and commercial enterprises from a range of geographical locations and veterinary practices. Bias may also have been introduced by the use of veterinary events to identify disease due to differences in levels of on-farm veterinary intervention. Biases were minimised by adjusting for potential farm-level clustering within data when calculating estimates; however, sample size calculations were not adjusted for this and may therefore be conservative. Alongside this, loss of individuals to follow-up, mortality during the study period and foals born in 2020 only being followed for the first year of life (Figure 1) could lead to reduced power in some estimations; however, methods utilising time at risk minimised this.

In conclusion, rates of musculoskeletal disease and injury requiring veterinary intervention in young Thoroughbreds on stud farms in the UK and Ireland are high and now represent the most important cause of early-life morbidity and mortality in this population. Overall, DOD is the most frequently reported condition, particularly in the first 6 months of life. Such conditions may influence affected individuals' ability to achieve their maximum athletic potential, and therefore, further work to identify risk factors, evaluate economic implications and assess longer term consequences, including effects on future racing performance, are clearly warranted.

AUTHOR CONRIBUTIONS

Substantial contributions to conception and design of the study: Kristien L. Verheyen, Rebecca Mouncey and Amanda M. de Mestre. *Acquisition of data*: Rebecca Mouncey. *Analysis of data*: Rebecca Mouncey. *Interpretation of data*: Rebecca Mouncey, Juan Carlos Arango-Sabogal, Amanda M. de Mestre and Kristien L. Verheyen. *Drafting the article*: Rebecca Mouncey. *Revising it critically for important intellectual content*: Rebecca Mouncey, Juan Carlos Arango-Sabogal, Amanda M. de Mestre and Kristien L. Verheyen. *Final approval of the version to be published*: Rebecca Mouncey, Juan Carlos Arango-Sabogal, Amanda M. de Mestre and Kristien L. Verheyen. *Accountable for all aspects of the work*: Rebecca Mouncey, Juan Carlos Arango-Sabogal, Amanda M. de Mestre and Kristien L. Verheyen. The corresponding author confirms that she had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

Ethical approval was granted by the Royal Veterinary College's Clinical Research Ethical Review Board (URN: 2018 1843).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Rebecca Mouncey https://orcid.org/0000-0001-9850-7878
Juan Carlos Arango-Sabogal https://orcid.org/0000-0003-3395-8410
Kristien L. Verheyen https://orcid.org/0000-0002-5077-224X

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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