The reliability and forensic soundness of the equine shin circumference measurement in living animals versus post-mortem examination

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Summary
Catastrophic injuries in racehorses mostly involve the metacarpal region. Although many studies describe fractures of equine limbs, few examine the relationship between bone morphometrics and musculoskeletal problems in racing horses. And yet, according to the regulation of some Italian traditional races, the shin circumference represents a qualifying prerequisite for horses to be admitted to races. This study aims to evaluate the conformity of the shin circumference measurement in living animals and in post-mortem examinations, in order to evaluate the forensic reliability of these measurements. The right and left distal forelimbs from 11 horses of 5 different breeds were examined. The shin circumference was measured at 3 time points: in the living animal before slaughter/euthanasia, 5 hours post-mortem, and after 14-days of cold storage. The isolated limbs were also weighed in both of the post-mortem examinations. In the examined sample, the mean shin circumference was 24.0 ± 2.4 cm in living animals, 22.9 ± 2.5 cm 5 hours post-mortem, and 22.4 ± 2.3 cm after 14-days of cold storage, with a highly significant difference between these measurements ($P < 0.001$). There was also a significant decrease in the limbs' weight between the 2 post-mortem examinations ($P < 0.001$). According to our findings, the post-mortem measurement significantly underestimates the *in vivo* dimensions of the shin circumference, even when performed a few hours after death; the forensic soundness of this parameter is therefore limited.

Misurazione della circonferenza dello stinco nei cavalli in vita e nell'esame post mortem: attendibilità in ambito forense

Parole chiave
Benessere,
Cavallo da corsa,
Circonferenza dello stinco,
Lesione muscoloscheletrica,
Scienza forense,
Morfometria.

Riassunto
Nel cavallo sportivo le lesioni interessano con maggiore frequenza la regione del metacarpo. Numerosi studi si sono occupati delle fratture a carico degli arti del cavallo ma pochi hanno indagato le possibili relazioni tra l'insorgenza di fratture e la morfometria dei segmenti ossei interessati. Tuttavia, nei regolamenti di alcune corse tradizionali italiane, come il Palio di Siena, la misurazione della circonferenza dello stinco rappresenta un requisito imprescindibile affinché il cavallo possa essere ammesso alla corsa. Scopo dello studio è stato verificare quanto la misurazione della circonferenza dello stinco eseguita nell'ambito dell'esame post-mortem possa differire da quella rilevata sull'animale in vita, per valutare la validità del suo impiego in ambito forense. A tal fine sono stati esaminati gli arti anteriori di undici cavalli appartenenti a cinque differenti razze. La circonferenza dello stinco è stata misurata in tre momenti: nell'animale in vita subito prima della macellazione o dell'eutanasia, cinque ore dopo la morte e, infine, dopo un periodo di conservazione a -20°C per 14 giorni. Gli arti sezionati nel corso delle due misurazioni post-mortem sono stati inoltre pesati. La circonferenza media degli stinchi degli animali in vita è risultata di 24,0 ± 2,4 cm, di 22,9 ± 2,5 cm cinque ore dopo la morte e di 22,4 ± 2,3 cm dopo conservazione a -20°C per 14 giorni. La differenza tra queste misure si è rivelata statisticamente significativa ($P < 0,001$). Tra la misurazione effettuata nell'immediato post-mortem e quella successiva allo scongelamento è stato inoltre registrato un significativo calo del peso medio degli arti sezionati, pari al 9,3% ($P < 0,001$). Secondo questo studio, la validità della misurazione della circonferenza dello stinco in ambito forense risulta essere limitata dato che la rilevazione post-mortem, anche a distanza di poche ore dal decesso dell'animale, sottostima la circonferenza misurata nell'animale in vita.

Introduction

Catastrophic musculoskeletal injuries (CMIs) of Thoroughbred racehorses have been reported as the main reason for wastage (Jeffcott *et al.* 1982, Rossdale *et al.* 1985, Robinson *et al.* 1988, Lindner and Dingerkus 1993, Bailey *et al.* 1997). These injuries occur either during racing or training and are not only noxious to the welfare of the horses (Evans 2002), but can also adversely affect public perceptions of racing. Minimising and managing risk factors for this type of injury are therefore important considerations for those who are involved in this industry.

In 97% of cases of injury to horses, the limbs are involved, and in particular the forelimbs, with the distal part being more susceptible to injuries such as fractures than other structures (Jeffcott *et al.* 1982, Williams *et al.* 2001, Perkins *et al.* 2005).

In a study carried out in Canada by Cruz and colleagues (Cruz *et al.* 2007) on 76 Thoroughbred horses with catastrophic musculoskeletal injuries, the 3 most affected regions were found to be the metacarpal-metatarsal region (29%), followed by carpus (19.7%), and proximal sesamoid bones (18.4%). In a retrospective cohort study of Thoroughbred racing in the National Hunt in Great Britain from 2000 to 2013, more than 75% of fatalities resulted from catastrophic fracture, with most involving the third metacarpal (McIII) or third metatarsal (MtIII) (Allen *et al.* 2017).

Race injuries in horses are considered to have a multifactorial aetiology, including genetics and age, pre-existing pathology and past traumas, biomechanics (conformation), but also race-related factors such as race surface and training schedules (Kobluk *et al.* 1990, Magnusson and Thafvelin 1990, Mohammed *et al.* 1991, Dolvik and Klemetsdal 1996).

There are very few reports on the relationship of overall body conformation to musculoskeletal problems in racing Thoroughbred (Anderson *et al.* 2004). Morphometrical data of equine limb bones are scant, perhaps because of the difficulty involved in making consistent and meaningful measurements of complex shapes, or because of the lack of standard field-measurement procedures.

In order to prevent CMIs, some Italian traditional races like the Palio of Siena have introduced regulations around the measurement of the 'shin circumference'. Measurements are made with a measuring tape in the thinnest part of the metacarpal region of the racing horse. In order to be admitted to the race, the shin circumference must not be below than a given value. The value is different from race to race, but usually around 18-19 cm.

Although there are many reports describing fractures in the bony elements of equine limbs, very few of them provide information about specific morphological details and morphometrical measures of the affected bones.

Nevertheless, according to current regulations, a designated veterinarian must measure the shin circumference of any horse prior to being admitted to race. If a competing horse sustains a career-ending injury or euthanasia and the veterinarian is sued for malpractice, a second examination of the shin circumference may be demanded during the legal proceeding.

The aim of this study is to evaluate the conformity between the measurement of the shin circumference in the living animal and in post-mortem examination in order to assess its forensic soundness.

Figure 1. *Shin circumference measurement in the living horse.* The measurement was performed right above the fetlock joint. Sample 1b.

Figure 2. *Shin circumference measurement of the isolated limb five hours after death.* Sample 1b.

Materials and methods

In this study we examined the right and left distal forelimbs from 11 horses (10 sent to slaughter and 1 euthanised for tetanus).

The animals were selected randomly and the sample included 5 breeds: 4 Saddlebreds, 3 Italian Trotters, 2 Thoroughbreds, 1 Haflinger, and 1 Arabian Horse.

The shin circumference of each horse was measured at 3 time points: In the living animal before slaughter/euthanasia (T1), 5 hours post-mortem (T2), and after 14 days of storage in sealed plastic bags in a refrigerator set at -20°C (T3). Figure 1 shows the shin circumference measurement of the living animal taken by placing the measuring tape right above the fetlock joint.

In post-mortem examinations, we transected the distal limbs at the level of the radiocarpal joint or at the intercarpal joint. Figure 2 illustrates the measurements taken on the isolated distal limb, 5 hours post-mortem.

The isolated limbs were also weighed in both of the post-mortem examinations. The last post-mortem examination was preceded by 24 hours of defrosting. For some limbs, immersion in water was necessary to hasten this process.

Statistical analysis was performed using the repeated measures ANOVA in order to investigate changes in mean scores over the 3 time points. The Bonferroni correction was used for post-hoc analysis. A paired t-test was used to compare the limbs' weight at the 2 post-mortem time points. A P-value < 0.05 was regarded as statistically significant.

Results

Table I lists the subjects included in the study and their respective shin circumference measurements and distal limb weights.

In the examined sample, the mean shin circumference was 24.0 ± 2.4 cm in the living animals, 22.9 ± 2.5 cm 5 hours post-mortem, and 22.4 ± 2.3 cm after 14 days of storage in the refrigerator. The mean shin circumference measured 5 hours after death was therefore 1.1 cm shorter than in the living animal, whereas the mean circumference after 14 days of refrigeration was 1.6 cm shorter. This

Table I. *Shin circumference measurements in the living animal (T1), 5 hours after death (T2) and after 14-days cold storage (T3).* Distal limb weight at T2 and T3.

Sample id	Breed	Right/left forelimb	Shin circumference (cm)			Distal limb weight (kg)	
			T1	T2	T3	T2	T3
1a	IT	Right	23.0	23.0	21.5	2.0	1.5
1b	IT	Left	23.0	21.0	21.0	2.0	2.0
2a	SB	Right	26.0	25.5	23.0	3.0	2.0
2b	SB	Left	27.0	24.0	24.0	3.0	2.5
3a	SB	Right	26.0	25.5	25.0	3.0	3.0
3b	SB	Left	25.5	25.5	24.5	3.0	3.0
4a	TH	Right	21.3	19.5	18.5	1.5	1.0
4b	TH	Left	21.3	20.0	20.0	1.5	1.5
5a	TH	Right	23.0	21.0	21.0	2.0	2.0
5b	TH	Left	22.5	21.0	21.0	2.0	2.0
6a	IT	Right	24.5	24.5	23.5	2.3	2.0
6b	IT	Left	24.0	23.0	22.5	2.3	2.0
7a	IT	Right	22.0	21.5	20.5	2.0	2.0
7b	IT	Left	25.0*	23.5	22.5	2.0	2.0
8a	SB	Right	29.0	28.0	28.0	4.0	3.0
8b	SB	Left	29.0	28.0	26.0	4.0	3.0
9a	SB	Right	23.0	23.0	23.0	2.0	2.0
9b	SB	Left	23.0	22.5	22.5	2.0	2.0
10a	HA	Right	24.0	23.0	23.0	3.0	3.0
10b	HA	Left	24.0	23.0	23.0	3.0	3.0
11a	AR	Right	20.0	19.5	19.5	2.5	2.5
11b	AR	Left	21.0	19.0	19.0	2.5	2.5

The horse breeds are abbreviated as follows: IT = Italian Trotter; SB = Saddlebred; TH = Thoroughbred; HA = Haflinger; AR = Arabian Horse.
* the limb was swollen.

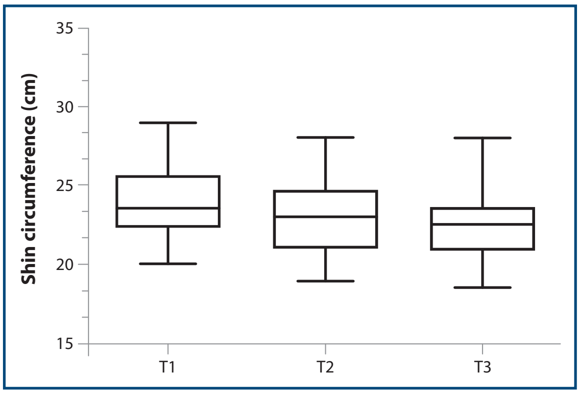

Figure 3. *Box and whiskers plot of the shin circumference measurements at the three time points.*

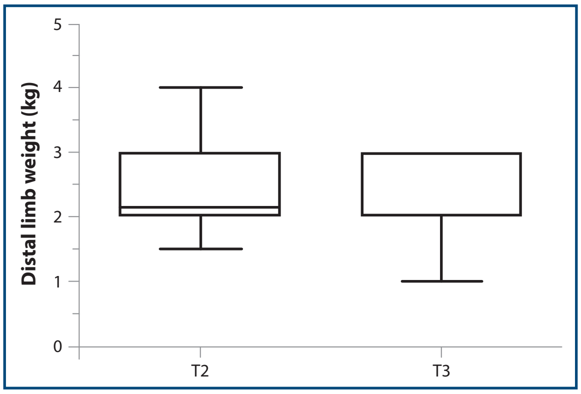

Figure 4. *Box and whiskers plot of the distal limbs weight at the two post-mortem examinations.*

reduction corresponds respectively to the 95.4% and 93.3% of intra-vitam values, and was found to be highly significant (P < 0.001). Figure 3 is a box-and-whisker plot illustrating the distribution of the shin circumference measurements at the 3 different time points. In the living animal (T1) the median circumference value was 23.5 cm, with a minimum circumference of 20.0 cm and a maximum of 29.0 cm. Five hours post-mortem (T1) the median circumference was 23.0 cm, with a minimum value of 19.0 cm and a maximum of 28.0 cm. After 14 days of refrigeration (T3), the median value decreased to 22.5 cm, with a minimum circumference of 18.5 cm and a maximum of 28.0 cm.

The limbs' weight was also found to be significantly different between the 2 post-mortem examinations (P < 0.001). A 9.3% decrease in the mean weight between T2 (2.48 kg) and T3 (2.23 kg) was observed. Figure 4 is a box-and-whisker plot displaying the distribution of the distal limb weights 5 hours post-mortem and after 14 days of cold storage. At T2, the median was 2.3 kg, with a minimum value of 1.4 kg and a maximum of 4.0 kg. At T3, the median was 0.3 kg less, with a minimum value of 1.0 kg and a maximum of 3.0 kg.

Discussion

Competitive activity in horses involves a unique challenge in terms of muscular and athletic abilities, which predispose them to particular types of injury or disease. Concern about the welfare of horses involved in the racing industry together with the popularity of the more well-known races, such as the Palio of Siena in Italy, raises an intense public debate. Regulated examinations should help to ensure that the welfare of racing horses is not compromised, as they prevent horses that are unfit from competing. The shin circumference is considered a formal requirement for any horse to be admitted to various traditional races in Italy. Therewith, if a racing horse sustains a career-ending injury or euthanasia, the designated veterinarian's conduct could be questioned and a second measurement of the shin circumference required during the post-mortem investigation, most likely on a cold-stored carcass or limb after unfreezing.

This study has identified significant morphometric variations between the shin circumference in living horses that are then examined post-mortem, especially after cold storage time.

This difference can be explained by taking into consideration post-mortem phenomena that normally occur after death, including the arrest of blood flow and consequent dehydration, the loss of muscle tone and tissue turgidity, the autolytic processes, and the decrease in volume of the underlying synovial bursa. All of these events critically contribute to the decrease in volume of the studied structure and thence to the reduction of the shin circumference.

Moreover, storage conditions of the carcass such as the temperature and elapsed time prior to refrigeration, the unfreezing process, the beginning of putrefactive phenomena, the potential blood loss that follows sectioning, and the prolonged compression caused by the riding bandage or tendon boots left in place even during storage can contribute to an underestimation of the actual shin circumference in the living animal.

Given the results of this study, we recommend that forensic pathologists consider all factors, including normal post-mortem phenomena, which are likely to cause a reduction of the shin circumference. They should moreover be aware that any measure acquired during the necropsy is an underestimation of the actual shin circumference in the living animal.

According to our study, this underestimation is quantifiable as 4.6% 5 hours after death and 6.7% after 14-day storage in a refrigerator set at -20°C. The forensic soundness of this dimensional parameter is limited.

The correlation between shin circumference and the incidence of catastrophic musculoskeletal injuries has not yet been established.

In order to objectively evaluate the relationship between conformation and the horse soundness, 2 requirements must be met: conformation has to be quantified in an accurate and repeatable way and reliable epidemiological data relating to type and incidence of injury should be available.

However, only a small amount of data concerning the morphometrics of the McIII is available. A 2006 cohort study carried out on 108 National Hunt racehorses, aimed to provide a set of baseline standard conformational traits within the Thoroughbred population. The study took into account 98 conformational parameters consisting of segment lengths, joint angles, inclinations, deviations, and circumference measurements, including the mid-metacarpus circumference. The mean circumference was 20.15 cm, with a minimum size of 18.00 cm and a maximum of 22.00 cm. Significantly different circumference measurements were found between left and right limbs (Weller *et al.* 2006).

A more recent study aimed at identifying morphometrical variations of equine metacarpal, proximal phalangeal, and proximal sesamoid bones recorded the proximodistal length and mid-shaft width and depth of the McIII after boiling, cleaning, and drying the bone. In Thoroughbred horses, the mean mid-shaft widths of the right and left McIII were respectively 4.09 ± 0.04 cm and 4.02 ± 0.04 cm, whereas the mean depths were 3.23 ± 0.07 cm for the right McIII and 3.26 ± 0.05 cm for the left McIII (Alrtib *et al.* 2013). The purpose of Arltib's study was to address the lack of information on the normal range in size and shape of these bones, and to identify reliable techniques for measuring them that are not yet applicable in the field.

There is growing interest in equine epidemiology and the number of retrospective and prospective studies that try to identify risk factors for certain injuries has recently proliferated (Cogger *et al.* 2006, Murray *et al.* 2006, Verheyen *et al.* 2006). In a study investigating the role of conformation in musculoskeletal problems in the racing Thoroughbred, Anderson and colleagues (Anderson *et al.* 2004), only included the length of the McIII in the conformation variables, which was found not to affect musculoskeletal disease, while conformation variables associated with metacarpophalangeal joint problems were long pasterns, offset ratio, carpal angle, and radio-metacarpal angle. Contrary to this, according to Davies and Watson (Davies & Watson 2005), longer McIII bones are associated with ticker dorsal cortices at the mid-shaft in racehorses that were exercising at racing speed, suggesting that the longer bones do bend more and therefore might be expected to fracture more easily.

In light of these considerations, further studies are needed to assess the effects of bone morphology on fracture incidences. Such data will enable veterinarians to better estimate the relative importance of conformational variables, such as the shin circumference, for future soundness in racehorses.

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