Femoral asymmetry in the Thoroughbred racehorse

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Objective To investigate the occurrence of geometrical asymmetries in the macro-architecture of left and right femurs from Thoroughbred racehorses previously used in competitive training and racing in New South Wales, Australia.

Methods Detailed postmortem measurements were made of 37 characteristics of left and right femurs from eleven Thoroughbred racehorses euthanased for reasons unrelated to the study. Measurements focused on articulating surfaces and sites of attachment of muscles and ligaments known to be associated with hindlimb locomotion.

Results Five measurements were significantly larger in left compared to right femurs ($P < 0.05$). The regions showing significant differences between left and right limbs were proximal cranial and overhead medio-lateral widths, greater trochanter depth, depth of the fovea in the femoral head and distal inter-epicondylar width.

Conclusion The left–right differences in femoral morphology were associated with sites of muscle and ligament attachment known to be involved with hindlimb function in negotiating turns. These differences may be the result of selection pressure for racing performance on curved race tracks and /or adaptations related to asymmetrical loading of the outside hindlimb associated with repeated negotiation of turns on such tracks.
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Preference for using one side of the body over the other has long been recognised in human and non-human primates[1] and is thought to relate to lateralisation of brain function.[2] Such 'handedness', laterality or sidedness has also been noted in quadrupedal animals such as cats and mice[3] and is thought to result from an interaction of a genetically controlled innate motor preference as well as learning.[4] Horses of various breeds previously trained for dressage and show jumping have been reported to exhibit a strong and stable preference for working to the left.[5] Furthermore, racing horses utilising the asymmetrical gait of the gallop, have been shown to exhibit a marked laterality with a strong inherent preference for galloping with the left foreleg leading even when trained in straight lines.[6]

Forelimb skeletal asymmetry has recently been reported in Thoroughbred racehorses and has been suggested to be related to performance and soundness in racing around turns.[7] Hindlimb injuries including damage to the sacro-iliac, pelvic and hip regions have become increasingly recognised recently as important causes of poor performance in competition horses[8,9] and asymmetry of hindquarters associated with problems in these anatomical regions has long been recognised as a cause of poor performance in racing trotters.[10] However, the symmetry of the hindlimb skeleton in the race horse has not to our knowledge been investigated to date.

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The aim of the present study was to establish whether skeletal asymmetry exists in the hindlimb of Thoroughbred horses previously used in competitive training and racing in Australia.

Materials and methods

Eleven Thoroughbred horses were used in this study. All horses had been trained and raced exclusively on clockwise tracks in New South Wales for between 1 and 3 years before they were euthanased for reasons unrelated to the present study. Skeletons from ten of the horses were collected using natural and artificial maceration to reveal the femurs. One specimen was buried at 1.5 metres in depth and recovered 2 years and 3 months later. All bone measurements were carried out by one of the authors (SM-D) using Mitutoyo Digimatic Calipers capable of measuring to 0.1 mm. Thirty-seven measurements were taken from each femur including length and mid-circumference and specific measurements from both proximal and distal ends focusing on articulating surfaces and points relating to attachment of muscle and ligaments known to be associated with hindlimb locomotion. Details of the specific measurements are shown in Table 1.

Statistical analysis

Differences between measurements for left and right femurs from the 11 horses were assessed by one-way analysis of variance with side as treatment and horse as randomised block using Genstat version 6 software and adopting $P < 0.05$ as the significance level.

Results

Mean values for each of the 37 femoral measurements are shown in Table 2. Five measurements were found to be significantly larger on the left femur compared to the right femur (at least $P < 0.05$) and the anatomical position of these measurements is illustrated in Figure 1.

Discussion

Asymmetrical differences in bone mass between the left and right femurs have been reported in humans[11] and dogs[12] with right handedness being associated with greater bone mineral density in the left femur of men.[13] Radiographic studies in horses have demonstrated left to right variations in the width of limb bones particularly in areas of sites of muscular and tendinous attachments.[14] The results of the present study support these findings and extend them to indicate more precise regions of the femur which show left-right asymmetry in this species.

The underlying reasons for how and why this femoral asymmetry exists remain unclear. Recent studies have reported that 76% of racing Thoroughbreds have longer third metacarpal bones in the right leg than the left leg.[7] These authors suggested that this may confer biomechanical advantage to horses when racing on tracks curved in a counter-clockwise direction and result in selection of horses with this asymmetry. Similar biomechanical principles may underlie the differences in femoral dimensions demonstrated in the present study in which horses had been raced exclusively in a clockwise direction but confirmation of this will require future work examining horses raced in both directions.

Table 1. Details of femoral measurements taken form each horse.

Name and abbreviation of measurement	Description of measurement
Length	From the proximal summit of the greater trochanter to the distal lateral trochlear ridge
Circumference	The diameter of the mid shaft region of the femur
Proximal Femur – Overhead: a (P Ov a)	Depth of the femoral head from the cranial to caudal aspect at its deepest point
Proximal Femur – Overhead: b (P Ov b)	Width of the femoral head from the medial to the lateral aspect of the articulating surface at its widest point cranial to the fovea
Proximal Femur – Overhead: c (P Ov c)	Depth of the femoral neck from a cranial to a caudal aspect at its narrowest point
Proximal Femur – Overhead: d (P Ov d)	Entire width of the proximal femur from a medial to lateral aspect at its widest point cranial to the fovea
Proximal Femur – Caudal: a (P Ca a)	Length of the articulating surface of the femoral head from a dorsal to ventral aspect at its longest point
Proximal Femur – Caudal: b (P Ca b)	Width of the femoral head from the medial to the lateral aspect of the articulating surface at its widest point caudal to the fovea
Proximal Femur – Caudal: c (P Ca c)	Entire width of the proximal femur from a medial to lateral aspect at its widest point caudal to the fovea
Proximal Femur – Cranial: a (P Cr a)	Length of the articulating surface of the femoral head from a dorsal to ventral aspect at its longest point
Proximal Femur – Cranial: b (P Cr b)	Width of the femoral head from the medial to the lateral aspect of the articulating surface at its widest point cranial to the fovea
Proximal Femur – Cranial: c (P Cr c)	Height of the greater trochanter (summit) from a dorsal to ventral aspect utilising the neck of the femur as the reference point
Proximal Femur – Cranial: d (P Cr d)	Entire width of the proximal femur from a medial to lateral aspect at its widest point cranial to the fovea
Proximal Femur – Medial: a (P Me a)	Length of the articulating surface of the femoral head from a dorsal to ventral aspect at its longest point
Proximal Femur – Medial: b (P Me b)	Depth of the femoral head from a cranial to caudal aspect of the articulating surface at its deepest point
Proximal Femur – Medial: c (P Me c)	Depth of the fovea at its base from a cranial to caudal aspect
Proximal Femur – Medial: d (P Me d)	Length of the fovea from its apex to the mid base region
Proximal Femur – Lateral: a (P La a)	Depth of the greater trochanter from a cranial to caudal aspect at its deepest point
Proximal Femur – Lateral: b (P La b)	Depth of the notch between the summit and convexity of the greater trochanter from a cranial to caudal aspect at its narrowest point
Proximal Femur – Lateral: c (P La c)	Depth of the summit from a cranial to caudal aspect at its deepest point
Proximal Femur – Lateral: d (P La d)	Depth of the convexity from a cranial to caudal aspect at its deepest point
Distal Femur – Overhead: a (D Ov a)	Depth of the intercondyloid fossa from a cranial to caudal aspect
Distal Femur – Overhead: b (D Ov b)	Width of the femoral condyles from a medial to lateral aspect at the widest point
Distal Femur – Overhead: c (D Ov c)	Width of the trochlear ridges from a medial to lateral aspect at the widest point
Distal Femur – Overhead: d (D Ov d)	Depth of the trochlear groove from a cranial to caudal aspect at its deepest point
Distal Femur – Overhead: e (D Ov e)	Width at its narrowest point where the articulating surface of the trochlear ridges merge into the condyles
Distal Femur – Caudal: a (D Ca a)	Length of the trochlear groove from a dorsal to ventral aspect at its longest point as it merges into the inter-condyloid fossa
Distal Femur – Caudal: b (D Ca b)	Width of the femoral condyles from a medial to lateral aspect at the point where they articulate into the meniscus cartilage whilst the horse is stationary
Distal Femur – Caudal: c (D Ca c)	Width from the medial epicondyle to the widest point of the lateral condyle
Distal Femur – Caudal: d (D Ca d)	Width of the intercondyloid fossa from a medial to lateral aspect at its widest point
Distal Femur – Cranial: a (D Cr a)	Length of the trochlear groove from a dorsal to ventral aspect at its longest point as it merges into the inter-condyloid fossa
Distal Femur – Cranial: b (D Cr b)	Width of the trochlear ridges at the point where the medial trochlear ridge is at its widest
Distal Femur – Cranial: c (D Cr c)	Width of the epicondyles from a medial to lateral aspect at the widest point
Distal Femur – Medial: a (D Me a)	Combined depth of the trochlear ridge and condyle from a cranial to caudal aspect at its deepest point
Distal Femur – Medial: b (D Me b)	Length of the medial trochlear ridge at an oblique angle from its most dorsal articulating surface to its junction with the medial condyle
Distal Femur – Lateral: a (D La a)	Depth of the distal femur from a lateral perspective and incorporates the trochlear ridge and condyle at their deepest point
Distal Femur – Lateral: b (D La b)	Length of the lateral condyle at an oblique angle from its most dorsal articulating surface to its junction with the trochlear ridge

The structure of bone will respond to mechanical stresses placed upon it by altering its macro and micro architecture in an attempt to minimise these stresses.[15] Such adaptation through bone modelling and remodelling has been shown to result in significant changes in the geometric properties of the metacarpal bones in racing horses[16] and greyhounds.[17] In the racing greyhound, the repeated asymmetrical cyclic loading of limb bones occurring as a result of racing around curved tracks has been reported to cause differential remodelling of bones in the left and right limbs with increased bone density and thickness occurring in the outside limb.[17] The asymmetrical differences in bone mass between the left and right femurs of the horses in this study may also be a consequence of asymmetrical stresses associated with repeated exercise on curved tracks inducing significant bone adaptation. Horses in the present study which had been trained and raced exclusively in a clockwise direction on curved tracks, showed

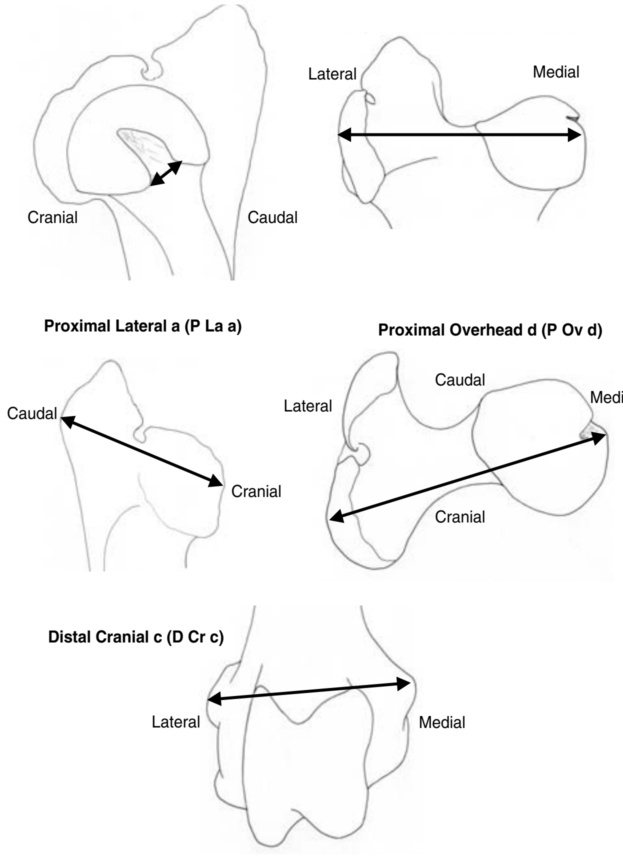

Figure 1. Anatomical position of significant femoral asymmetries.

Table 2. Mean values of measurements on left and right femurs from the 11 horses.

Femoral measurement	Mean value Left femur (mm)	Mean value Right femur (mm)	Least significant difference	P value[a]
Length	47.4	47.5	0.204	0.700
Circumference	145.2	143.7	2.16	0.156
P Ov a	69.5	70.1	1.83	0.501
P Ov b	68.0	65.4	3.76	0.147
P Ov c	44.5	44.8	1.41	0.597
P Ov d	**142.0**	**139.45**	**0.73**	**0.006**
P Ca a	41.3	40.4	4.25	0.648
P Ca b	60.1	61.4	4.52	0.536
P Ca c	138.7	135.4	3.45	0.058
P Cr a	55.6	52.8	3.68	0.119
P Cr b	62.1	59.9	4.84	0.337
P Cr c	55.2	59.6	4.50	0.055
P Cr d	**141.1**	**139.4**	**1.69**	**0.049**
P Me a	52.1	53.7	3.07	0.253
P Me b	69.4	68.2	1.74	0.152
P Me c	**22.7**	**19.8**	**2.46**	**0.029**
P Me d	35.8	35.6	1.97	0.764
P La a	**115.7**	**112.9**	**2.66**	**0.040**
P La b	7.9	7.1	2.22	0.402
P La c	62.3	62.5	2.02	0.822
P La d	69.9	71.7	2.89	0.211
D Ov a	31.3	29.9	3.90	0.429
D Ov b	109.0	107.0	2.63	0.129
D Ov c	80.7	79.2	2.92	0.274
D Ov d	14.5	13.7	1.95	0.381
D Ov e	46.7	45.3	1.05	0.216
D Ca a	17.9	17.2	2.70	0.586
D Ca b	110.6	110.0	2.65	0.620
D Ca c	111.6	111.3	2.49	0.776
D Ca d	21.6	21.1	1.15	0.398
D Cr a	9.7	11.3	2.00	0.137
D Cr b	78.5	76.4	2.23	0.068
D Cr c	**113.9**	**111.1**	**1.85**	**0.007**
D Me a	149.8	149.3	1.58	0.447
D Me b	97.7	95.0	2.79	0.058
D La a	113.9	112.8	2.30	0.308
D La b	75.2	74.3	5.22	0.690

[a]Assessed by one way ANOVA
Rows in bold are significantly different ($P < 0.05$)

several measurements of the left (outside) femur to be significantly larger than the right (inside) femur. Galloping racehorses generally lead with the inside limb in both fore and hindlimbs (the right limbs on a clockwise track).[18] Kinematic studies of galloping horses have demonstrated significant laterality with greater contact duration occurring on the non-lead limb than on the lead limb.[19] The leading hindlimb (inside) has been shown to be the sole weight bearing leg for only 6.5% of the stride duration whereas the non-leading hindlimb (outside) has been shown to bear weight on its own for 16.5% of the stride.[20] Kinetic studies have demonstrated that greater peak stresses occur in bones of the non-lead (outside) leg than the lead (inside) leg during asymmetric gaits such as the canter and gallop[21] and that the increased strain placed on the outside limb is particularly high during negotiation of turns.[22] Theories of bone adaptation would thus predict active hypertrophy and accretion of mass in bones of the outside limbs in horses exercising on curved tracks in response to greater stresses on the outside limb associated with repeated asymmetrical loading during negotiation of turns.[23] This may explain why several femoral measures were significantly larger in the left (outside) limb in the racing horses in the present study.

Hindlimb injuries have been associated with poor performance in post-race examinations with gluteal muscle and sacro-iliac problems most commonly seen.[24] Recent scintigraphical studies of horses with hindlimb lameness have reported greater sacro-iliac asymmetry in racing horses than horses in other disciplines, and this has been suggested to be due to the increased asymmetrical biomechanical stresses being exerted on the hindlimbs while racing.[8] The range of significant left-right differences in femoral measurements identified in the present study support this suggestion and indicate some of the specific biomechanical forces which may contribute to the aetiology of these hindlimb conditions in racehorses. The P Me c measurement represents the size of the fovea where the round and accessory ligaments attach to the femoral head. The round ligament serves to limit adduction of the limb and the accessory ligament serves to restrict abduction of the limb.[25] Increased size of this fovea in the left limb may indicate hypertrophy of these ligaments in association with a requirement for increased sagittal movement in the outside limb of horses racing on circular tracks to accommodate increased stresses in the outside limb when negotiating turns on curved race tracks.[26] The P Ov d and P Cr d measurements represent the width of the proximal end of the femur, from the fovea of the femoral head medially to the greater trochanter laterally. The P La a measurement is related to these as it represents the depth of the greater trochanter from a cranial to caudal aspect at its deepest point. The greater trochanter is the insertion point of the accessory gluteal muscle which acts to abduct the limb, such as is required in swinging the horses' hindlimbs outwards in negotiating turns.[26] The greater degree of abduction of the outside (left) limb suggested to be required in horses negotiating turns whilst racing on curved tracks[26] may lead to the preferential adaptation and enlargement of this area of the femur as seen in this study. The D Cr c measurement represents the width of the distal femur between the medial and lateral epicondyles where the collateral ligaments attach. Broadening of this area in the left femur may be an adaptive response associated with attempts to increase the stabilisation of the outside stifle through hypertrophied collateral ligaments and enlarged areas of attachment in response to increased torsional stress known to occur in this region in horses racing on curved tracks.[10]

In conclusion the present study has identified several areas of significant asymmetry in the femur of racing Thoroughbreds which may be associated with performance whilst racing on curved tracks. However, confirmation of the underlying causes of this asymmetry will require further research comparing femur geometry in horses raced in counter-clockwise and clockwise directions.

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