Large range of morphometric variables and high incidence of abnormality in the feet of Kaimanawa feral horses.

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Abstract

Objective The objective of the study was to investigate the foot health of the Kaimanawa feral horse population and to test 2 hypotheses:

1. The Kaimanawa feral horse population will possess a large range of foot morphology.
2. The incidence of foot abnormality in the Kaimanawa feral horse population will be significantly high.

Procedures Fifteen morphometric variables were measured from four calibrated photographic views in all four feet of 20 adult Kaimanawa feral horses. Four morphometric variables were measured from a lateromedial radiographs of the left forefoot from each horse. In addition, the study identified the incidence of foot gross abnormality observed from photographs and radiographs of all 80 feet from 20 horses.

Results There was a large variation in morphometric dimensions between horses indicating an inconsistent foot type. Mean hoof variables were outside the normal range recommended for horses by veterinarians and hoof care providers. Thirty-five percent of all feet had a long toe conformation and 15 % of feet possessed a medio-lateral imbalance. The incidence of abnormailty included lateral (85 % of horses) and dorsal (90 % of horses) wall flares, presence of laminar rings (80 % of horses) and bull nose tip of the distal phalanx (75 % of horses). Both hypotheses were therefore accepted.

Conclusions The results of this study demonstrated a broad range of foot abnormaility in the Kaimanawa feral horse population. We propose that one reason for questionable foot health and conformation in this horse population is lack of abrasive wearing by the environment. In comparison to other feral horse populations in Australia and America there may be less pressure on the natural selection of the foot of the Kaimanawa horses by the forgiving environment of the Kaimanawa Ranges. Contrary to popular belief, the feral horse foot type should not ideally be used as a model for the domestic horse foot.

Key words: **Equine, equine lameness, horses, radiology, nutrition**

Definitions: Abnormailty- for the purpose of this paper the term "foot abnormality" refers to a variation from what the two veterinarian assessors considered as optimal morphology, and was considered to impact negatively on the structure and/or function of the foot.

The wild horse foot model has been proposed as the ideal equine foot [1 2 3] despite lack of detailed empirical investigation. The assumption is that the free roaming lifestyle of the wild horse promotes ideal foot health due to long distances travelled, a varied natural diet, and an absence of some harmful impacts of domestication. It has been well documented [4] that some traditional equine husbandry practices, such as incorrect feeding, lack of, or excessive exercise, and poor and infrequent podiatric care, can have deleterious consequences on horse foot health. However, it has not been established whether wild, or feral horses, possess better foot health than horses in domestic care. The aim of this study was, for the first time, to empirically investigate the morphometric characteristics and the incidence of foot abnormalities in a group of adult feral horses.

The purpose of the study was to determine the effect of a free roaming feral lifestyle and lack of human intervention on foot morphology and health of a population of feral horses. The Kaimanawa feral horses were chosen for this study due to the wet climate of their habitat and the low density of substrate on which they travel. Based on previous observations of feral horses in 'soft' environments by this research group, it was considered that feral horses would be unlikely to maintain healthy feet in this environment due to the softness of the majority of the substrate and the easy access to feed and water. The distance travelled by horses in this environment would be expected to be low and have little impact on foot wear.

The following two hypotheses were tested:

1. The Kaimanawa feral horse population will possess a large range of foot morphology.
2. The incidence of foot abnormality in the Kaimanawa feral horse population will be significantly high.

Materials and Methods

Subjects- All horses were assessed by dentition to be over 5 years of age and were from the same feral horse population from the Kaimanawa Ranges of the central North Island of New Zealand. Kaimanwa horses are small (adult height at the wither is 133-151cm)[5]. They are descendants of Welsh and Exmoor ponies feral since the late 1800's mixed with local farm and cavalry horses released by the New Zealand army in the 1940's[6]. Genetic analysis[7] suggests that they are now more closely related to domestic Thoroughbred and local station hacks. The population of Kaimanawa horses is

approximately 1500 and occupies 700 square kilometres of land consisting of upland plateaux, steep hill country and river basins and valleys[8].

Foot collection- All four feet from 20 horses were included in the study. Horses were obtained at necropsy following standard controlled feral horse culling operations. All horses were sourced directly from the feral environment and were euthanased within 2 days of capture, after being held in secure dry yards during dry weather. Limbs were disarticulated at the level of the carpus/tarsus and were frozen within 12 hours of euthanasia. Feet were thawed at room temperature and assessed for radiographic and morphometric measurements on the day of thawing.

Radiographic analysis of foot pathology- A latero-medial radiograph was taken with a portable x-ray machine at a set focal length of 780 mm. Limbs were radiographed in an unloaded position with the third metacarpal/metatarsal positioned vertically and the solar surface of the foot flat on the ground surface. All radiographs were used to identify foot abnormality and the left forefoot radiographs were morphometrically analysed.

Radiographic analysis of morphometric features- Following published methodology[12], four angle and three distance measurements were taken from latero-medial radiographs of 20 left forefeet using ImageJ software (National Institutes of Health). This methodology allows for uncalibrated radiographically obtained distances to be expressed as a proportion of the length of the palmar cortex of the distal phalanx. This methodology was necessary as direct radiographic length calibration proved unreliable. The descriptions of radiographic measurements are shown in Table 1 (legend).

Radiographs were performed with the disarticulated limb in a non-weight bearing position with the solar surface ground parallel. It was expected that the hoof alignment would be altered between the weight bearing and non-weight bearing situation. To account for the difference, a pilot study was performed to measure the radiographical morphometric parameters in all 4 limbs of 3 feral horses under loaded and unloaded conditions. Forelimbs and hindlimbs were disarticulated at the radiocarpal and tibiotarsal joints respectively. A latero-medial radiograph was taken with each limb non-weight bearing with the solar surface of the foot ground parallel and the metatarsal/metacarpal vertical. The radiograph was repeated under a vertical load of 160 kg (approximately 30% of typical body weight) applied through a custom made jig with free weights. Radiographic calibration was achieved by placing a 100mm long steel rod under the foot in the sagital centre of the solar surface. The measurement parameters used in the main studied were obtained using ImageJ software (National Institutes of Health).

Photographic analysis of gross morphometric features - All hooves were photographed on a custom designed camera jig so that each photograph was taken from the same position with a Samsung Digimax 210 digital camera. The camera was mounted by a base screw to the jig and feet positioned in the same location for each foot on a cross marked on the jig platform. A 150 mm ruler was placed in the subject plane to calibrate photographs for digital measurement. The distal limbs were photographed from the

dorsal, medial, lateral and solar views. ImageJ software (National Institutes of Health) was used to obtain calibrated digital measurements. The measurements are shown in Table 1(legend) and are identical to those used previously by Kane[9].

Review of foot abnormality- Visual evidence of gross external hoof abnormality was assessed from calibrated digital photographs of the 4 hoof views taken for morphometric analysis. Radiographic evidence of abnormality in the foot was also assessed from a lateromedial radiograph. Two experienced veterinarians [#] performed the assessment separately and were blinded to each others assessment. A single assistant acted as scribe for both assessors and was neutral to the process. The scribe then collated each abnormality criteria for each foot in an excel spreadsheet. When the two independent assessors identified the same abnormality on a single foot, this was recorded as an "observed abnormality". When only a single assessor identified abnormality, without agreement of the other assessor, this abnormality was disregarded. Only the abnormalities observed by both veterinarians were included in the data set. Additionally, only abnormalities present in at least 10 % of feet were included in the study.

[#]Assessor 1: Prof Chris Pollitt is an expert equine foot veterinarian researcher and clinician.
[#]Assessor 2: Dr Alison McIntosh is an expert equine foot veterinarian. She specialises in teaching the methods of hoof trimming and hoof care.

Statistical analysis Mean morphometric measurements between fore and hind feet, left and right sides and between population groups were compared using a Welch *t*-test. Comparison of morphometric measurements within the Kaimanawa group and between different populations was compared using Pearson's correlation co-efficient. Statistical significance was set at $P<0.05$. All results are presented as mean ± standard deviation.

The project was approved by the University of Queensland Animal Ethics Committee (AEC - PCA) monitoring compliance with the Animal Welfare Act (2001) and The Code of Practice for the care and use of animals for scientific purposes (approval number SVS/393/07/AHF).

Results

Foot morphology Foot morphometric values of the Kaimanawa horse are shown in Table 1. The range of values in most dimensions is high, as are standard deviations. The fore foot length, for instance, varies from 102 - 163 mm. Means for fore foot length were greater than hind feet, but this difference was not significant ($P=0.07$). Mean sole width was greater laterally than medially and this corresponded to a larger mean wall flare laterally than medially, with no correlation existing between medial and lateral wall flare angles ($P=0.99$). This was the case for both forefeet and hind feet, with forefeet, on average, being longer and wider. There was no significant difference observed in the foot length ($P=0.89$) and width dimensions either medially ($P=0.67$) or laterally ($P=0.44$),

between left feet and right feet. Medial and lateral sole widths were closely correlated (P<0.01) in all feet.

The mean medial wall angle was steeper than the lateral wall angle in both forefeet and hind feet. There was no difference in wall angles between forefeet and hind feet, either medially (P=0.58) or laterally (P=0.52). Dorsal wall angle also did not differ (P=0.52) between forefeet and hind feet. The dorsal wall flare angle ranged from 0 to 23 ^{o} in forefeet (mean 5.8 ^{o}), with similarly high values for the hind feet (mean 7.6 degrees, range 0 to 30 degrees). These data, along with medial and lateral wall flare angles reported above, suggest that gross hoof capsule deformity is widespread in this population of feral horses.

There was no significant difference in medial (P=0.30) heel angle between fore and hind feet. The lateral heel angle (P=0.01) and lateral sole width (P=0.02) were significantly different between fore and hind feet, with forefeet heels being steeper and lateral sole wider than hind feet . The medial and lateral heel angles were significantly correlated (P<0.01). The range of heel angle measurements was high. Forefeet heel angle measurements varied up to 27^{o} and hind feet heel angle measurements varied to 26 ^{o}.

Figure 1 is a three dimensional visualisation model of key mean values for the Kaimanawa population forefeet. This allows the reader to visualise the morphometric parameters of the “average” Kaimanawa foot and shows medio-lateral asymmetry and wall flaring.

Hoof morphology data from this population of Kaimanawa horses is presented in Table 2 with comparisons to data on other populations derived by similar methodology. The degree of left forefoot wall flaring is significantly higher both laterally (P<0.01) and dorsally (P<0.01) but not medially (P=0.1) in the Kaimanawa population than the Australian feral horse population reported by Hampson [11].

The pilot study performed to assess the effect of unloaded versus loaded radiographic measurements found variations between the two situations which were considered insignificant in terms of the outcomes of this study. Mean angular measurements for the 12 limbs varied between 0.4 ^{0} and 1.0^{0}. The distance measurement (STTD) varied 0.9%. Radiographic morphometric analysis (Table 1) found a mean dorsal hoof wall angle (DFAX) of 53.6 ± 3.8 degrees, compared to 54.3 (± 4.5) by photographic measurement (TA). The mean radiographic measurement of the distal phalanx dorsal wall angle (DPAX) was 51.3 (± 2.5) ^{o}. The distal phalanx rotation angle (ROTA) is the measure of the parallelism of the hoof wall and distal phalanx. It indicates pathological rotation of the hoof capsule about the distal phalanx when the value is positive. The mean ROTA for this population was -2.1(± 3.1), but 4 of the 20 left forefeet measured had a positive rotation value. Mean distal phalanx palmar angle (PA) was 2.45 (± 3.1) degrees with a range of -3 to 9 ^{o}. Seven of the 20 left forefeet measured had a palmar angle of zero or below zero.

The mean soft tissue thickness for the left forefeet of the Kaimanawa horses was 27.3 (± 3.3) percent of the palmar cortex length, with a range of 21.4 to 34.2 %. Fourteen from 20 Kaimanawa left forefeet had a STTD% value higher than 25 %.

Foot abnormality survey Results of the survey of foot abnormality are presented in Table 3. There were 20 types of abnormalities identified by both surveyors and present in at least 10 % of the 80 feet surveyed. The total number of abnormalities recorded was higher in forefeet (242) than hind feet (192). Three of the four types of bony abnormalities identified were more evident in forefeet than hind feet. However, a high incidence of dorsal exostosis (bull nose tip) of the distal phalanx of hind feet (25), accounted for an overall higher incidence of all bony changes seen in hind feet (39) as compared to forefeet (29).

Seventy five percent of Kaimanawa horses had at least 1 foot with a long toe, and 90 % of horses had at least 1 foot with a significant dorsal flare. Lateral flares (85 % of horses) were more common than medial flares (50 % of horses) and 75 % of horses had at least one contracted/under run heel. Frog abnormality (mainly the appearance of thrush) was common (65 % of horses) and an exuberant inflamed periople was present in 60 % of horses.

Hoof wall defects (75 % of horses) were mainly in the form of significantly chipped or broken away distal hoof wall. In 50 % of horses, the hoof wall defect had exposed the sole to the appearance of significant sole weight bearing.

Discussion

This study found a broad range of foot conformation and many undesirable foot morphometric traits in the Kaimanawa feral horse population. Previous studies reported a consistent foot type and good foot health in wild horses in the United States of America[1] [2]. The results of this study provide conclusive evidence that a high incidence of foot abnormalities exist in the Kaimanawa feral horse population. Whereas, it has previously been believed by some that due to the nature of the feral horse environment (free roaming lifestyle and natural feed selection), the foot health of the feral horse was ideal[1], this does not appear to be the case.

The following two hypotheses were tested:

1. The Kaimanawa feral horse population will possess a large range of foot morphology.
2. The incidence of foot abnormality in the Kaimanawa feral horse population will be significantly high

Both hypotheses can be accepted.

Gross morphological features There was a large variation in foot conformation values in the Kaimanawa horse population studied. Variation in length measurements can only be partly explained by a range in the size of the Kaimanawa horses. Although the racing Thoroughbreds in a comparative study [9] were younger, trimmed regularly and presumably much larger horses, the mean foot length of the Kaimanawa horses was greater. However, one group of the Standardbreds studied [10] had a similar mean foot length to the Kaimanawa population. It is generally assumed that angular dimensions should be relatively consistent, irrespective of foot size, in a homogenous population. This was not so for the Kaimanawa population. Angular dimensions varied as broadly as length dimensions and were often outside of the normal ranges quoted by veterinarians and farriers. Feral horses in Northern Australia [11] in contrast, had very little variation in foot conformation. North Australian brumbies inhabit seasonally dry, hard rocky country, where competition for survival can be challenging due to feed and water shortages during regular drought conditions. Studies performed on the American feral horses found a similarly homogenous foot profile, and describe the Mustang habitat as being harsh semi-arid country[1 2]. We postulate that there may be insufficient environmental pressure driving the natural selection of foot type in the Kaimanawa feral horse population to produce a homogenous foot type. Perhaps an environment containing soft substrate under foot and easy access to pasture and water, tolerates a broad range of foot conformation in the Kaimanawa horses. If a more demanding natural selection process was in place, such as in semi-arid habitats, a more homogenous foot type, presumably necessary for survival in a harsh environment, would be expected. Environmental factors may therefore contribute to variations in foot type between the Kaimanawa horses and other feral horse populations.

Comparison to the data from 22 adult feral horses from hard dry country in northern Australia[11] supports the observation of a long toe conformation in the Kaimanawa feral horse. A long toe conformation is in keeping with large dorsal flare angles reported in 90 % of the Kaimanawa horses studied. Lack of abrasive wearing is most likely responsible for this feature. The foot morphology study of feral horses in hard dry country [11] reported a mean dorsal hoof wall flare angle of 1.1 ^{o} in comparison to the present study mean of 10.4 ^{o}. Although breed differences may account for variations between the two populations (North Australian feral horses measure 145-160 cm), we propose that the differences in foot length and the degree of wall flaring is most likely a result of the differences in substrate hardness and distance travelled, and the effect that these two variables has on hoof wall wear. A study of hoof growth and wear in semi-feral ponies [20] described a period of 'self trimming' during the drier months of the year when increased wear, due to dry hard substrate, was greater than the growth rate of the hoof wall. Similarly, Konik horses (the wild horses of Poland) have been observed to have an altered hoof growth pattern according to seasonal shifts and substrate hardness [22]. Distal limb conformation abnormalities and disease may also impact on foot conformation [12]. Lameness, limb deformities and excessive hoof wall growth, may affect both length and angular measurements. One group of researchers [21] observed that wet pasture conditions may also be associated with a reduced hoof angle in free-ranging horses. This is in keeping with our observations in this feral horse population.

The solar margin of the distal phalanx of Kiamanawa horses was ground parallel or negatively sloping in 7 of 20 left forefeet measured. In a recent review of radiographic assessment of the equine foot [4] it was suggested that a normal palmar angle of the forefoot should be 5 to 10 ^{o}, sloping positively down from the heel to the tip of the distal phalanx. Only 6 from 20 Kaimanawa horses fitted within these dimensions. The previous author suggests that a negative palmar angle was commonly associated with lameness and palmar foot pain. Another source [3] suggests that the natural orientation of the solar surface of the distal phalanx is ground parallel. This author claims observations of wild horses and pain-free healthy domestic horses as evidence for this conformation. However, empirical evidence has not yet sufficiently established the range of foot morphology in the wild or feral horse population. Evidence from the present study suggests that a negative palmar angle may be linked to foot pathology in the Kaimanawa feral horse.

Some caution should be exercised in interpreting data taken from frozen and thawed limbs invitro. Although complex studies of foot morphology gave been performed on frozen and thawed equine limbs [18,19], the effects of the freezing and thawing process on the morphology of the foot has not been investigated. It is possible that slight changes in foot morphology may occur due to hoof moisture changes over time. The degree of change, if a change does occur, is not likely to be in the magnitude to affect the gross morphological assessment of hoof archicture described here. However, this issue requires investigation.

Incidence of foot abnormality To our knowledge no previous studies have investigated the foot health of feral horses. The results of this study provide conclusive evidence that a high incidence of foot abnormality exists in the Kaimanawa feral horse population. The most surprising finding is radiographic and visual evidence of chronic laminitis. Other unexpected signs of abnormality occurring in high incidence include gross medio-lateral imbalance, large hoof wall defects, frog abnormality, and contracted and under-run heels. These are problems commonly encountered in domestic horses.

In a study of racing Thoroughbreds [12], of the 41 sound horses studied, five horses were found to have laminitis-related signs on radiographic examination. These signs included curved hoof wall, hoof surface undulant, bone formation along the dorsal surface and tip of the distal phalanx, resorption of bone at the palmar cortex, and a hoof wall rotation angle of greater than 2 ^{o}. The authors add that one or more of these signs are often associated with the ski tip appearance of the distal phalanx often observed in chronic laminitis. Furthermore, the presence of one or more of these signs was significantly negatively related to race earnings. Two horses (10 %) in our study were found to have a hoof wall rotation of more than 2 ^{o} in relation to the distal phalanx orientation in the left forefoot. Six horses (30 %) displayed a ski tip appearance in at least one foot, and the majority (80 %) displayed laminar rings, suggesting the possibility of a high incidence of chronic laminitis in the Kaimanawa population. Radiographic assessment of soft tissue thickening dorsal to the distal phalanx also supports this evidence. Thickening of the soft tissue dorsal to the dorsal surface of the distal phalanx has been found to result from

thickening of the laminar layer [13] and has been linked to the crippling disease of laminitis [12 14]. Pollitt [16] suggested that this figure (STTD%) should be close to 25% in the sound foot, while Linford [12] determined that a thickness (STTD%) greater than 28.1 % exceeded the 95 % confidence limits and should be considered abnormal. Eleven from 20 Kaimanawa left forefeet had a STTD% value higher than 28.1 per cent.

Another study of foot pathology [14] found an 11.5 % incidence of white line disease in 1,781 in racing Thoroughbreds. Our study reported a 50 % incidence of significant white line separation in the Kaimanawa feral horse population.

Evidence of osteoarthritis in the metacarpophalangeal joints of 22 adult Kaimanawa feral horses has been reported [15]. That study did not report morphometric or conformation analysis but it can be assumed, that as the horses were from the same population of feral horses, these factors are likely to be consistent with our own population sample. Our study found gross asymmetries within feet, altered medio-lateral balance, long toes and large wall flares in a significant percentage of the population. These foot conformation abnormalities may contribute to the etiology of osteoarthritis. In contrast, another feral horse study [11] reported minimal asymmetry, absence of long toes and minimal wall flaring in feet from dry stony country in Australia. Preliminary work by the current research team has found little evidence of bone and joint changes in the feet and pasterns of Australian feral horses. Further study will reveal if the assumptions made by the previous authors [15] that osteoarthritic changes may occur in all horses, are correct. The disease observed in the Kaimanawa horses may be unique to this particular feral horse population and poor foot conformation may be an important contributing factor.

At present we can only speculate on reasons why this feral horse population had poor foot conformation, a high incidence of foot abnormality and a significant incidence of fetlock joint osteoarthritis. The Kaimanawa horses inhabit upland plateaux, steep hill country, river basins and valley floors. The micro climate of the Kaimanawa feral horse habitat has been studied in detail [5]. Minimum temperatures range from -10 to 7 degrees Celsius, while maximums range from 12 to 32 degrees Celsius throughout the year. Rainfall ranges from 75 to 180 mm per month and averages 100 mm per month. Kaimanawa feral horses prefer to graze red tussock grasslands in the autumn and winter seasons while exotic grasses are utilised in winter and spring. Flush zones in short open grasslands are utilised in winter and northern facing slopes are preferentially grazed.[5] Long day length in extreme latitudes may allow forage plants the opportunity to create more sugar. The north facing slopes may focus the diffuse, obliquely angled sunlight for better photosynthetic efficiency even during winter months. Coupled with temperatures below freezing, this scenario can conceivably produce significant seasonal increases of carbohydrates, especially in the exotic grasses and clover that have invaded this ecosystem. The diverse habitat that these horses occupy provides a great variety of food choices. Palatability is closely associated with nonstructural carbohydrate content. A more diverse diet will give more opportunity for selective grazing of those forage plants that are highest in nonstructural carbohydrate content in any given season. Pony breeds, having evolved metabolic adaptations to survive in harsh environments, are particularly

prone to laminitis[16]. Pony breeds contribute to the genetic make up of the Kaimanawa population[7]. Horses, however, are not exempt to carbohydrate overload and "grass founder" [16]. Further study of the dietary aspects of horses affected with hoof abnormality would be helpful in unraveling the etiology.

The effect of the environment, in terms of the hardness of the substrate under foot, and the distance travelled by horses, on the wear and conformation of horse's feet, has already been discussed. Excessive hoof wall due to insufficient wear, is capable of causing disruption to the hoof attachment apparatus and bony architecture of the distal phalanx [9 10], due to the increased lever forces placed on the tissues. Overgrown hoof wall also contributes to hoof wall cracks and breakages [17].

The large range of morphometric variables and high incidence of abnormality in the feet of Kaimanawa feral horses may be due to dietary or environmental influences, or a combination of both. Low pressure on natural selection may also play a role in this population. Further study is required to determine the etiology of the foot abnormalities described in this study. The value of the current study has been to describe foot conformation and abnormality, commonly seen in horses kept in domestic environments, in a group of feral horses. Clearly, this group of feral horses should not be used to guide the direction of foot care practice.

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	Photographic measurements
SAX	Sagittal axis, midline reference of the hoof. Line draw bisecting heels and passing through the point of frog.
PF	Point of frog, reference for sole view and lateral view.
FL	Length of ground baring surface of the foot when on a flat surface.
MWF	Medial wall flare measured from dorsal view. The angle between the proximal 1/3 of the hoof wall and any distal angulation.
LWF	Lateral wall flare measured from dorsal view. The angle between the proximal 1/3 of the hoof wall and any distal angulation.
FW/L%	Frog width to length ratio as a percentage
MSW	Medial sole width, from SAX to widest medial point of hoof.
LSW	Lateral sole width, from SAX to widest lateral point of hoof.
DL	Dorsal length, from point of frog to tip of toe.
MWA	Angle of the proximal 1/3 of the medial wall, excluding wall flare.
LWA	Angle of the proximal 1/3 of the lateral wall, excluding wall flare
TL	Toe length, hairline at toe to end of bearing surface.
TA	Angle between the dorsal hoof wall and the ground surface measured from the lateral view.
DFA	Dorsal flare angle. Angle between proximal 1/3 of the dorsal wall and distal wall flare at toe. Measured from the lateral view.
MHA	Medial heel angle (external), between palmar/plantar margin of hoof wall and ground surface.
LHA	Lateral heel angle (external), between palmar/plantar margin of hoof wall and ground surface.
	Radiographic measurements
HFAX	Hoof axis, caudal angle formed between a line along the dorsal surface of the hoof wall and a line along the bearing surface of the hoof wall.
DPAX	Distal phalanx axis, caudal angle formed between a line along the dorsal cortex of the distal phalanx and a line along the bearing surface.
ROTA	Rotation of the distal phalanx, DPAX-HFAX
PA	Palmar angle, cranial angle formed between a line along the solar surface of the palmar process of the distal phalanx and the bearing surface.
PCL	Palmar cortex length, distance from the solar margin of the tip of the distal phalanx to the mid-sagittal articulation between the distal phalanx and the distal sesamoid bone.
STTD%	Total soft tissue thickness, shortest distance between the dorsal surface of the hoof wall and the dorsal cortex of the distal phalanx, assessed adjacent to the distal tip of the distal phalanx. Expressed as a percentage of PCL.

Table 1 (legend)

	ALL FOREFEET (40)				ALL HIND FEET (40)			
	MEAN	STDEVA	RANGE MIN	RANGE MAX	MEAN	STDEVA	RANGE MIN	RANGE MAX
FL	133	17.3	102	163	126.7	14.2	97	152
MWF	5.1	6.6	0	23	5.1	5.8	0	25
LWF	8.5	6.4	0	25	7.8	7.5	0	27
F W/L% *	58.2	9.2	43	85	67.9	7.9	56	90
MSW	51	8.3	32	64	48.6	6.7	36	62
LSW *	56.8	9.4	43	93	52.5	7	38	65
DL *	44.1	7.9	29	64	40.4	6.6	26	55
MWA	81.6	5.5	72	93	81	4.4	74	91
LWA	74.2	4.9	65	85	74.9	5.1	62	85
TL *	74.8	9.5	58	93	71.2	7.9	56	86
TA	54.3	4.5	45	62	53.7	3.6	47	61
DFA	10.4	5.8	0	23	7.6	7.6	0	30
MHA	44.8	6.4	32	57	43.1	7.8	25	55
LHA *	44.7	6	31	58	40.8	8	20	56

	LEFT FOREFEET (20)			
DFAX	53.6 (3.8)	3.8	47	61
DPAX	51.3 (2.5)	2.5	48	58
PA	2.45	3.1	-3	9
ROTA	-2.1(3.1)	3.1	-8	4
STTD%	27.3 (3.3)	3.3	21.4	34.2

	ALL LEFT FEET (40)				ALL RIGHT FEET (40)			
	MEAN	STDEVA	RANGE MIN	RANGE MAX	MEAN	STDEVA	RANGE MIN	RANGE MAX
FL	129.7	16.5	97	163	130.3	15.9	100	161
MWF	4.9	6.4	0	20	5.3	6.1	0	25
LWF	6.7	6.4	0	27	9.6	7.2	0	25
F W/L%	62.6	9.7	43	82	63.6	10	43	90
MSW	49.5	7.7	36	64	50.2	7.6	33	63
LSW	53.9	6.8	41	67	55.4	10	38	93
DL	42.1	6.8	30	56	42.4	8.2	26	64
MWA *	83.2	5.2	74	92	79.3	4	72	93
LWA *	73.1	3.7	66	79	76	5.7	62	85
TL	72.2	8.3	56	89	73.8	9.4	59	93
TA	54.7	3.9	46	61	53.2	4.2	45	62
DFA	8.6	6.6	0	30	9.4	7.2	0	23
MHA	42.4	6.7	26	54	45.5	7.2	26	57
LHA *	44.5	7.4	21	58	41.1	6.9	20	52

Table 1. Mean, standard deviation and range of morphometric measurements of 80 feet from 20 mature age Kaimanawa horses. * indicates a significant difference (*P<0.05*) between data pairs.

PHOTO MEASURES	KAIMAN 40 FF 20 HORSES	LINFORD 1993 41 TB LF	HAMPSON 2008 22 LF FERAL	CRUZ 2006 9 SB RF	KANE 1998 94 TB FF	CUST 2008 LF 636 TB
FL	133 (16.5)		111 (8)	131(5.3)	116 (8.3)	
MWF	5.1 (6.4)		1.9 (3)			
LWF*	8.5 (6.4)	(*P*<0.01)	0.5 (2)			
FW/L%	58.2 (9.7)				50(10)	
MSW	51 (7.7)			60 (4.5)		
LSW	56.8 (6.8)			61 (5.4)		
DL	44.1 (6.8)					
MWA	81.6 (5.2)		83.6 (4)	82 (3)	77 (6.3)	
LWA	74.2 (3.7)		81.6 (3)	78.7 (4.9)	73 (6.8)	
TL	74.8 (8.3)			85 (3.8)	89 (5.5)	
TA	54.3 (3.9)		55	52.6 (3.3)	51 (2.5)	48.1 (2.9)
DFA*	10.4 (6.6)	(*P*<0.01)	1.1 (2)			
MHA	44.8 (6.7)		43	46.5 (3.4)		
LHA	44.7 (7.4)		44	46.7 (6.8)		
RADIOGRAPH MEASURES	**20 LF**					
DFAX	53.6 (3.8)	48.2 (2.6)				
DPAX	51.3 (2.5)	47.8 (3)				
ROTA	-2.1(3.1)	-0.5 (1.3)				
STTD%	27.3 (3.3)	24.1 (2)				

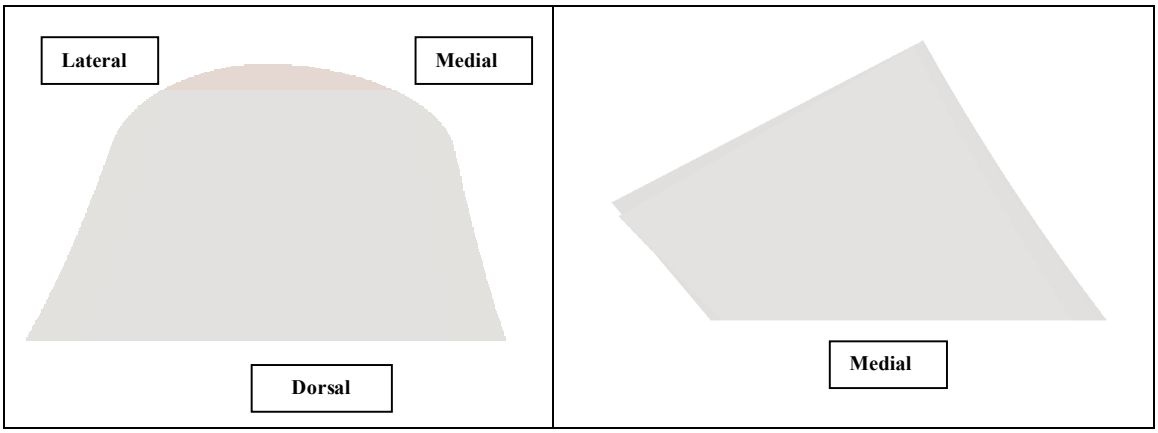
Table 2. Hoof morphology data from Kaimanawa horses with comparisons to data on other populations derived by similar methodology. (See Table 1 (legend) for measurement definitions.) * indicates significant difference between Kaimanawa and Australian feral horse populations. Figures in parenthesis are standard deviations.

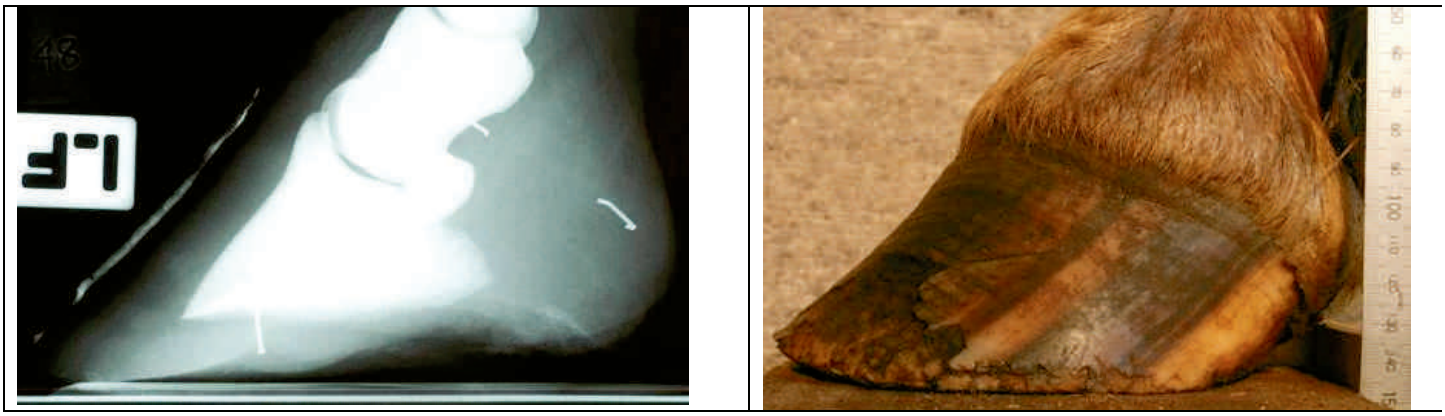
YPE OF PATHOLOGY	SITE OF LESION	ALL FEET		HORSES AFFECTED		FOREFEET		HIND FEET	
		NUMBER	%	NUMBER	%	NUMBER	%	NUMBER	%
ong toe	H	28	35	15	75	13	33	15	
oss of parallel tubules	O	8	10	6	30	5	13	3	
ledial flare	O	20	25	10	50	13	33	7	
ateral flare	F	39	49	17	85	23	58	16	
orsal flare		33	41	18	90	20	50	13	
apsule deviation	C	18	23	11	55	13	33	5	
/all defect	A	25	31	15	75	12	30	14	
resence laminar rings	P	35	44	16	80	24	60	11	
ubule deviation	S	9	11	6	30	5	13	4	
led/lat imbalance	U	12	15	8	40	9	23	4	
ontracted/underun heels	L	27	34	15	75	20	50	8	
ole bearing	E	17	21	10	50	6	15	11	
bnormal periople		26	33	12	60	15	38	11	
eep frog sulcus	EXTERNAL	14	18	9	45	6	15	9	
/hite line separation	TISSUE	23	29	10	50	13	33	10	
rog pathology		27	34	13	65	16	40	12	
ki tip P3		8	10	6	30	7	18	1	
ull nose tip P3	DISTAL	31	39	15	75	6	15	25	
ndevel palmar processes	PHALANX	20	25	9	45	10	25	11	
edal osteitis		8	10	6	30	6	15	2	

YPE OF PATHOLOGY	SITE OF LESION	ALL FEET		HORSES AFFECTED		FOREFEET		HIND FEET	
		NUMBER	%	NUMBER	%	NUMBER	%	NUMBER	%
ong toe	H	28	35	15	75	13	33	15	
oss of parallel tubules	O	8	10	6	30	5	13	3	
ledial flare	O	20	25	10	50	13	33	7	
ateral flare	F	39	49	17	85	23	58	16	
orsal flare		33	41	18	90	20	50	13	
apsule deviation	C	18	23	11	55	13	33	5	
/all defect	A	25	31	15	75	12	30	14	
resence laminar rings	P	35	44	16	80	24	60	11	
ubule deviation	S	9	11	6	30	5	13	4	
led/lat imbalance	U	12	15	8	40	9	23	4	
ontracted/underun heels	L	27	34	15	75	20	50	8	
ole bearing	E	17	21	10	50	6	15	11	
bnormal periople		26	33	12	60	15	38	11	
eep frog sulcus	EXTERNAL	14	18	9	45	6	15	9	
/hite line separation	TISSUE	23	29	10	50	13	33	10	
rog pathology		27	34	13	65	16	40	12	
ki tip P3		8	10	6	30	7	18	1	
ull nose tip P3	DISTAL	31	39	15	75	6	15	25	
ndevel palmar processes	PHALANX	20	25	9	45	10	25	11	
edal osteitis		8	10	6	30	6	15	2	

Table 3.Abnormailities observed in photographs and radiographs of 80 feet from 20 Kaimanawa adult feral horses. Only abnormalities observed by both surveyors with an incidence of at least 10 % of feet are included.

Figure 1. Three dimensional visualisation models representing the mean forefoot dimensions from foot morphology analysis in the sample population. Models are constructed using the dimensions of toe length, coronary band length, dorsal hoof wall and heel angles, medial and lateral hoof wall and wall flare angles.





A. **B.**

Figure 2. Typical left forefoot of a Kaimanawa feral horse from the sample population.

A. Radiograph shows excessive hoof wall growth, loss of parallel alignment between the hoof wall and dorsal border of the distal phalanx, and appearance of dorsal exostosis of the distal phalanx. Underdeveloped distal phalanx palmar processes were a feature of this population.

B. Photograph shows the typical dorsal hoof wall flaring and significant chipping and breakage of the distal hoof wall. Laminar rings are prominent.