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Improving the Foot Health of the Domestic Horse

— The relevance of the feral horse foot model —

RIRDC Publication No. 11/140

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The relevance of the feral horse foot model

by B. A. Hampson and C. C. Pollitt

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Foreword

It has been proposed that the feral horse foot is a benchmark model for foot health in horses and can be used as a guide to optimise care of domestic horse feet. The adoption of this model by some has shifted the focus of hoof trimming away from the traditional farriery model to a tendency towards excessive removal of the bearing border of the distal hoof wall and sculpturing the foot in the shape of the popular ‘natural’ hoof model. However, the foot morphology and foot health of feral horses has not been formally investigated in detail.

The aim of this project was to determine how studies of feral horses may improve management practices for domestic horses, with particular reference to foot care. This study found a profound effect of environment on feral horse feet. The gross morphology of feet was affected by a combination of substrate (footing) and the distance that horses travelled. Travel distance was determined by the separation between water and food sources in the habitat. Each environment studied produced a unique foot type in terms of general appearance, foot morphology and foot health. There were marked differences in some conformation parameters between the feral horses in this study and domestic horses from previous studies.

Given the moderate evidence of sub-optimal foot health, it may be inappropriate to judge the feral horse foot as a benchmark model for equine foot health. Previous observers and proponents of the “natural” foot model were apparently unaware of this inner pathology but regardless, had made assumptions and recommendations for domestic foot care. This report highlights the importance of using empirical methodology, a large sample size, thorough investigation and independent, blinded observations to obtain data for use in the guidance of hoof care practice. The practice of using the ‘natural’ foot model as the optimal morphometric model on which to base foot trimming practices may need to be reconsidered carefully.

This project highlights the importance of animal husbandry disciplines to adhere to the principals of best practice and develop new treatment techniques and animal management systems according to evidence based practice guidelines.

This report is an addition to RIRDC’s diverse range of over 2000 research publications and it forms part of our established industries Horse R&D program, which aims to assist in developing the Australian horse industry and enhancing its export potential.

Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation

Abbreviations

CE	vertical distance between proximal limit of extensor process and proximal hoof wall
°	degrees
° C	degrees Celsius
DWA	dorsal hoof wall angle
GPS	global positioning system
ha	hectare
HWD	hoof wall depth
HWT	hoof wall thickness
km	kilometres
m	metres
MDC	midline dead centre
mm	millimetres
n	sample size
N	vertical force
PA	palmar angle
PEL	primary epidermal lamellar
%	percent
THWT	total thickness of the hoof wall and lamellar layer

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Executive Summary

What the report is about

This report describes the morphology and health profile of the feral horse foot in detail not previously available. It identifies some important aspects of the form and function of the equine foot which should be considered in every day foot care for the domestic horse. The wild horse foot model is discussed in terms of its relevance and limitations to hoof care.

Who is the report targeted at?

The report is targeted at horse owners, farriers and veterinarians so they can make better informed decisions about foot care for horses. This report will be of particular relevance to those who have an interest in the use of the popular wild horse foot model.

Where are the relevant industries located in Australia?

The horse owning community and farriery associations across all regions of Australia may benefit from this report.

Background

It has been proposed that the feral horse foot is a benchmark model for foot health in horses and can be used as a guide to optimise care of domestic horse feet. The adoption of this model by some has shifted the focus of hoof trimming away from the traditional farriery model to a tendency towards excessive removal of the bearing border of the distal hoof wall and sculpturing the foot in the shape of the popular hoof model. It appears that the paradigm model for the feral horse foot was obtained from limited studies of desert dwelling feral horses and may not represent the general appearance of feral horse feet across a range of habitats. The external appearance of the typical desert dwelling feral horse foot appears aesthetically pleasing with little visible pathology. However, the foot morphology and foot health of feral horses has not been formally investigated in detail.

Aims/objectives

The aims of this project were to investigate the effect of varying environments (from alpine mountain to sandy desert) on foot morphology, foot health and related parameters on Australian and New Zealand feral horses and to investigate important aspects of feral horse ecology that relate to foot morphology and function to improve the understanding of the interaction between ecology and foot variables.

Methods used

Fourteen studies of significant numbers of feral horses (range of 12 to 100 horses throughout studies) were performed to investigate the genetic structure, travel profiles, nutritional parameters, foot morphology and foot health in populations of feral horses from different environments.

Results/key findings

This study found a profound effect of environment on feral horse feet. The gross morphology of feet was affected by a combination of substrate (footing) and the distance that horses travelled. Travel distance was determined by the separation between water and food sources in the habitat. Each environment studied produced a unique foot type in terms of general appearance, foot morphology and foot health. There were marked differences in some conformation parameters between the feral horses in the current study and domestic horses from previous studies.

There were a total of 377 gross foot abnormalities identified in 100 left forefeet. There were no abnormalities detected in three of the feet surveyed. The type and severity of abnormality varied between populations. Of the three populations surveyed by histopathology, the incidence of chronic laminitis ranged between 40% and 93%. There appeared to be a balance between hoof capsule wear and growth rate in the hard substrate environments. Consequently, hoof capsules were short and often worn to the level of the peripheral sole. In the softer footing environments growth rate exceeded wear, allowing the hoof wall to grow long and flared. There were signs of pathology, such as ungual cartilage calcification, and traumatic laminitis, consistent with concussive changes, in the feet of horses living on hard footing. Some feet from high travel populations appeared to have overuse changes such as excessive hoof wall wear. A combination of high travel and hard substrate was associated with the more serious foot pathologies observed.

Implications for relevant stakeholders for:

Given the moderate evidence of sub-optimal foot health, it may be inappropriate to judge the feral horse foot as a benchmark model for equine foot health. Previous observers and proponents of the “natural” foot model were apparently unaware of this inner pathology but regardless, had made assumptions and recommendations for domestic foot care, such as promotion of solar loading and excessive bevelling of the distal hoof wall. This work highlights the importance of using empirical methodology, a large sample size, thorough investigation and independent, blinded observations to obtain data for use in the guidance of hoof care practice. The practice of using the “natural” foot model as the optimal morphometric model on which to base foot trimming practices may need to be reconsidered carefully.

Recommendations

The study identifies the negative long term implications of substrate and movement on foot health. Care needs to be taken in choosing one environment over another because of possible harmful consequences. Although feral horses living and travelling on hard substrate appear to have robust feet, modified by the environment and able to withstand locomotion over hard substrates, the current study suggests that there are some negative consequences associated with this lifestyle.

However, it is possible that the hard substrate foot type, because of its robust nature and biomechanical function, allows the feral horse to withstand significant foot pathology without showing overt lameness, thus assisting the horse to survive in extreme environments. In light of this observation, further research is required to fully understand the impact of various models of hoof care and footings on the health and well being of domestic horses in managed care.

Introduction

It has been suggested that the large range of hoof conformation parameters seen in the modern domestic horse is due to a de-emphasis on foot conformation in selective breeding[1]. Research shows that foot conformation is heritable and related to sports performance and duration of competitive life[2]. Due to the relative confinement and sedentary lifestyle of domestic horses, many do not wear their hooves at the same rate as they grow. The resultant conformation, in over 70% of cases, is a long toe/ low heel appearance, with long flared quarters[3]. This conformation represents a broken-back hoof-pastern axis and may lead to quarter cracks [3,4] (Figure 1A). This type of conformation has been attributed to lameness in athletic horses[4,5]. In wild and feral horses living in challenging environments, due to the importance of locomotion for survival, the emphasis on foot and distal limb conformation is likely to have been retained.

As early as 1899 various models of hoof trimming and correct hoof balance have been debated [6] and there is still no universal agreement on the optimal model of hoof conformation. There are still several wild and feral horse populations living close to natural lifestyles and the study of their hooves may provide some information to assist in identifying an optimal model of hoof conformation. An interest in the “wild horse” or “natural” hoof model has emerged several times in the past few centuries and the recent resurgence of the model has been particularly strong. The wild horse foot has recently been proposed as the ideal model for the equine foot [7-10]. The free-roaming lifestyle of the wild horse is suggested to promote ideal foot health due to the long distances travelled, a varied natural diet, and an absence of the perceived harmful impacts of domestication. Jackson[8] and Ovnicek[9] studied the feet of feral horses in the USA and suggested that the natural model was a solution to the poor foot health issues of the modern domestic horse. The wild horse foot (Figure 1B) is claimed to have a very short hoof wall which is heavily bevelled at the ground surface, a deep cup in the sole, strong upright heels[8], and a squared off toe[11] with the break-over point set back towards the tip of a well developed frog [10]. It is suggested that the sole exhibits medial-lateral symmetry, the frog and sole have a large weight-bearing function[10,12] and the palmar surface of the distal phalanx is ground parallel [7,11].

The study of wild horse hoof patterns in the USA [8,9] and Europe [13] has shown that the horse is able to maintain a healthy hoof in its natural state without farriery intervention. The “natural” state however necessitates the horse ranging over a vast area consisting of a variety of landscapes with footing ranging from sandy loam to rugged rocky slopes. Boyd[13] in studying the habits of wild Przewalski horses, and Berman[14] in a thorough study of Australian brumby ecology, reported that horses spent approximately 17 hours per day grazing and were constantly on the move. In the heat of the afternoon the horses moved to high rocky hills, apparently in an attempt to escape the heat and biting insects. This habit may have a secondary function of wearing away the hoof wall and maintaining a balanced hoof.

Much has been discussed and written on the natural foot model but only a little is backed by thorough, evidenced based research. This report, performed in Australia and New Zealand, details recent studies of feral horses and their feet and focuses on the scientific research relating to past assumptions concerning the natural horse foot. The report gives some background on feral horses in Australia and details their movement patterns in comparison to typical domestic horses. This information is helpful in understanding some of the impacts of horse habitat, in particular the effect that the distance between water and food sources has on movement and therefore the horse foot. It then presents the feral horse foot types seen in Australia and New Zealand and details the main parameters of form and structure which are common and which vary between foot types. This discussion leads into a presentation of foot health of feral horses and the surprisingly high incidence of pathology in several populations. Reasons for suboptimal foot health are discussed, particularly in relation to how high travel distances and hard substrate affect hoof wall thickness and hoof capsule flexibility. Finally, all of these factors are considered in a discussion of the relevance of the wild/feral horse foot model to foot care for domestic horses.

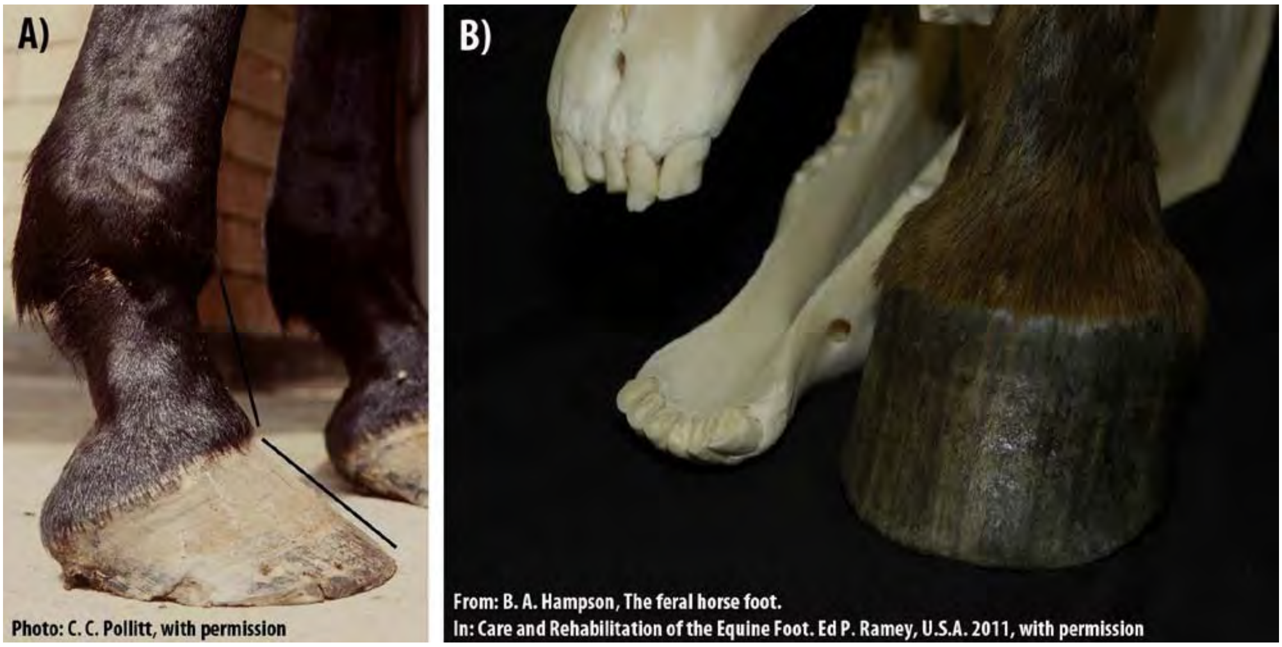

Figure 1 Typical broken-back hoof-pastern axis resulting from a long toe/low heel conformation (A). Aged brumby mare (30-35 years) found dying by a water hole (B). The ever-growing foot remained healthy. Studies of the feral horse foot may offer some solutions to achieving good foot health in domestic horses.

Objectives

The objectives of the project were to:

- gain a better understanding of the natural structure and function of the horse's foot and how this is affected by, and responds to, the environment the horse inhabits;
- describe feral horse feet morphometrically, and determine the foot health profile;
- reduce the injury and disease rate of managed horse feet by applying principles derived from the optimal feral horse foot model;
- identify the errors in modern equine foot care practice and produce guidelines to rectify them;
- present the research findings and disseminate the information to the scientific community, veterinary and farriery professions, industry bodies and to horse owners and horse husbandry providers.

1. The Australian feral horse (brumby)

Background

Horses were introduced to Australia in 1788 by European settlers. Horses have been bred in Australia in large numbers on extensive pastoral holdings since mid 1800 with some individual properties producing as many as 2,000 offspring per annum [15]. Horses were selectively bred to withstand the harsh Australian outback and to function as hard working stockhorses requiring little maintenance. Over the past two centuries horses were released or escaped, forming populations of feral horses commonly known as brumbies (singular: brumby). The largest populations of feral horses colonised the semi-arid and arid areas in the centre and north of the continent not previously inhabited by ungulates. Horses fed upon plant species never before eaten by Equids and they flourished. Australia now has by far the largest population of feral horses in the world. The population was estimated to be between 300,000 to 600,000 horses in 1993 [16] but could be much higher than that now although current data on the subject is inadequate [17]. Large populations of feral horses are widely distributed in parts of the Northern Territory, western and northern Queensland, the arid zone of South Australia, and the northern rangelands of Western Australia. There are smaller isolated populations in NSW, Victoria, the Australian Capital Territory and the coastal fringe of Queensland.

Phenotype

Horse phenotypes in some of the large populations of feral horses in Australia have been described as light Thoroughbred type, with an influence of Arab. They were derived from stock horses and drover's mounts released during the late 1800's through to the 1960's[16]. Nicholas[18] conducted a genetic analysis of Australian feral horses in one of the smaller populations in New South Wales. This population of approximately 1000 feral horses was reported to be most closely related to Arabian-type breeds and saddle and harness light breeds. The genetic composition of four of the larger populations of feral horses in outback Australia determined the brumby to be most closely related to the Australian Stockhorse, with influence from Australian Warmblood, Irish draft, Thoroughbred and Arabian breeds[19]. The Warmblood influence is derived from heavy horse breeds introduced into the Australian outback to pull heavy loads, and were utilised by stockmen to improve the bone and foot size of station stockhorses.

Environment

Most Australian brumby populations have had little to no contact with humans for the past 50 years and live remotely, at least 400 km (250 miles) from the nearest town. They live the true life of wild horses, moving and grazing at will in unfenced wilderness environments. Brumbies must endure regular droughts in many locations (Figure 2), suffer from plant poisoning in times of pasture and browse depletion, and survival is hard. In most locations there is no intervention from humans and many die from thirst and starvation in tough times. These factors produce the right conditions for natural selection and traits that promote soundness are probably strengthened. An example is the internal architecture of the hoof lamellae in the foot of the new born feral horse. They are arranged more effectively than in domestic newborns apparently giving feral foals an early locomotory advantage over their domestic cousins [20].

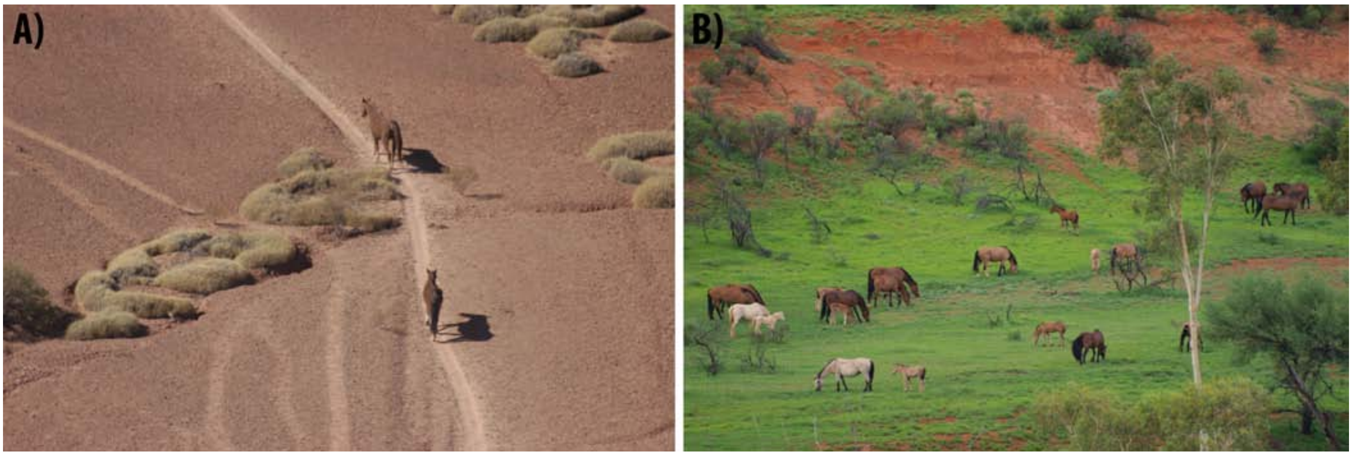

Figure 2 **Feral horses endure environmental extremes. Brumbies in the same location in the desert fringe area of central Australia: during a prolonged drought (A) and following heavy rain (B). (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).**

2. Horse movement

Introduction

Kaczensky et al [21] were the first to report Equid movement and home range size using modern GPS technology. Over a 4 year period in Mongolia, wild Przewalski horses had ranges of 152-826 km^2, significantly larger than reported for feral horses elsewhere. Over this 4 year period Przewalski horses travelled approximately 60 km from one end of their range to the other, but the mean daily distance was only 3.5 ± 0.9 km. On average, Przewalski horses ventured only 9 ± 2.9 km from the nearest water. The same study reported home ranges of between 4,449 and 6,835 km^2 with a mean daily distance of 8.3 ± 0.7 km for Asiatic wild asses. Asses ventured a mean of 13.5 ± 0.9 km away from water. Berman[14] reported finding Australian feral horses 65 km away from the only available water source. Other Equidae studied include the plains zebra which were recorded using GPS trackers walking up to 15 km away from water to feed and returning to water at 3 - 4 day intervals[22].

Movement and the distances travelled by domestic horses may affect general health and hoof quality. It is believed that domestic horses have become more sedentary since the industrial revolution, with many now maintained in small paddocks and stables as land available for horse maintenance has declined. The Thoroughbred racehorse, for example, is an athletic horse that is typically boxed in a stable for 23 hours/day and moved to the training track for a short gallop once daily. The psychological, physiological and musculoskeletal consequences of this relatively sedentary lifestyle are not fully understood, but the low level of mobility from an early age may adversely affect the shape, structure and function of the foot. Domestication of the horse has not only affected mobility but has necessitated an altered diet. Hyperinsulinaemia has recently been associated with laminitis[23] and diets high in non-structural carbohydrates and low activity levels are associated with hyperinsulinaemia in horses[24].

Results and discussion

As part of the Australian brumby foot study, lightweight global positioning system (GPS) data loggers mounted on collars were used to monitor the movement of domestic horses in a range of paddock sizes and internal fence designs for 6.5 day periods [25]. Feral horses were also tracked for up to 4 months in a variety of habitats [25, 26, 27]. For the domestic horses, as paddock size increased so did the mean daily distance that horses travelled (Figure 3). It was not surprising to find that horses kept in small paddocks are quite sedentary in comparison to their feral relatives. Horses kept in a 6x6 m yard moved a mean of only 1.1 km/day. Horses kept in a 16 ha paddock travelled 7.2 km/day in comparison to feral horses in an open rangeland that travelled 17.9 km/day.

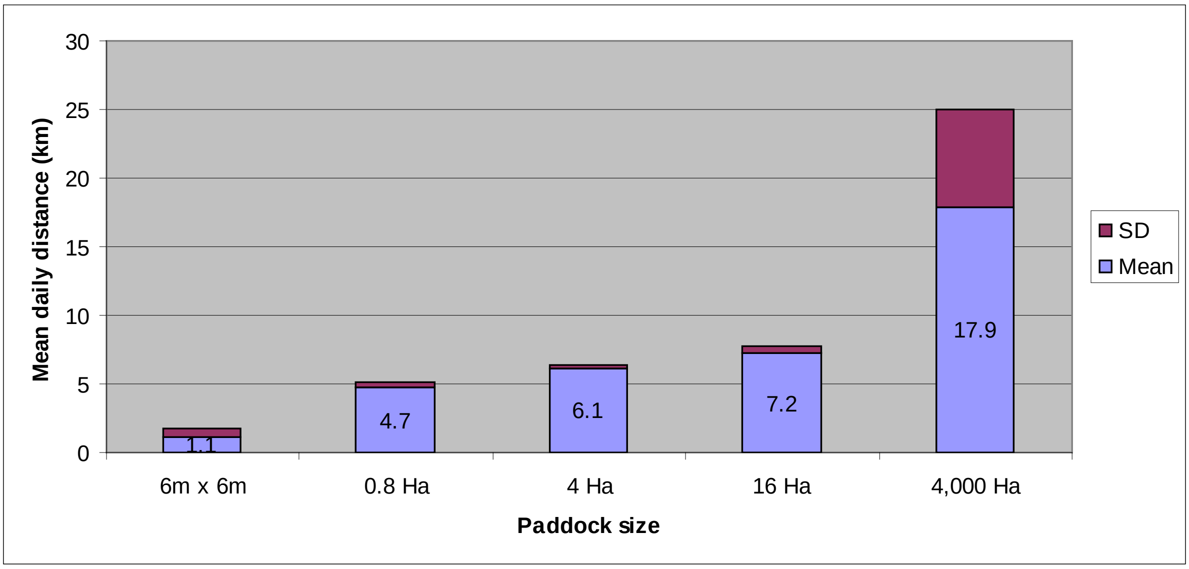

Figure 3 Mean (standard deviation) daily distance travelled by domestic horses (n = 4) in a variety of paddock sizes, ranging from a 6 x 6 m yard to a 16 ha paddock, compared to the mean daily distance travelled by feral horses (n = 3) in an open rangeland (4,000 ha).

The Australian feral horse study found that brumbies travelled larger mean daily distances than reported previously for other equids. Desert fringe horses, in particular, travelled up to 55 km from water and had large inter-watering intervals. In consideration of the long walks the horses made to access water from distant feed grounds it was not surprising that watering frequencies were as low as every fourth day. Scheibe[28] found that Przewalski horses drank less frequently than domestic horses and drank a higher volume of water relative to body size. They suggested that drinking frequency was not as important to wild horses as the amount of water consumed. Horses that drank less frequently also ingested larger volumes of water. These authors, as well as others [29,30] all suggested that desert-dwelling horses are genetically adapted to hot and dry climates as part of the evolutionary strategy of the species. Other equid species have apparently also adapted to arid conditions. Somali donkeys (E. asinus) were subjected to heat stress and dehydration[31]. Donkeys survived water loss equivalent to 30% of their original body weight in temperatures up to 40^0 C and survived up to 12 days without water. Donkeys were able to drink enough water (24-30 litres) in 2 - 5 minutes to restore the deficit. This study concluded that these observations represented a thermal and metabolic adaptation of desert mammals to heat and aridity.

Australian desert fringe brumbies may also be genetically adapted to arid conditions. The ability to travel up to 65 km from water to access feed [14] and survive for at least four days without water [26] may represent a physiological adaptation of the original domestic horse stock which were the founders of the feral horses over 140 years ago. It may therefore be unrealistic to expect that typical domestic horses have the same ability to sustain high travel distances and low watering frequencies as their feral cousins.

The mean distance travelled by 12 brumbies in one study was 15.9 ± 1.9 km/day (range 8.1 - 28.3 km/day).[26] Feral horses in one location, with plentiful pasture (Figure 4), tended to remain close to water (maximum 8 km from water) [26]. In contrast, desert fringe horses were recorded up to 55 km from water and some horses walked for 12 hours to reach water [26] (Figure 5). In the desert fringe habitat feed was scarce within 15 km from the water point due to competitive grazing by large numbers of feral horses, cattle and camels. The watering frequency of these horses was low (3.2 ± 0.8 days; range 2 to 4 days).[26]

Figure 4 **Feral horse travel pattern, determined by GPS, in a habitat where food is abundant close to water. Horses remained close to the water supply and travelled only moderate daily distances. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).**

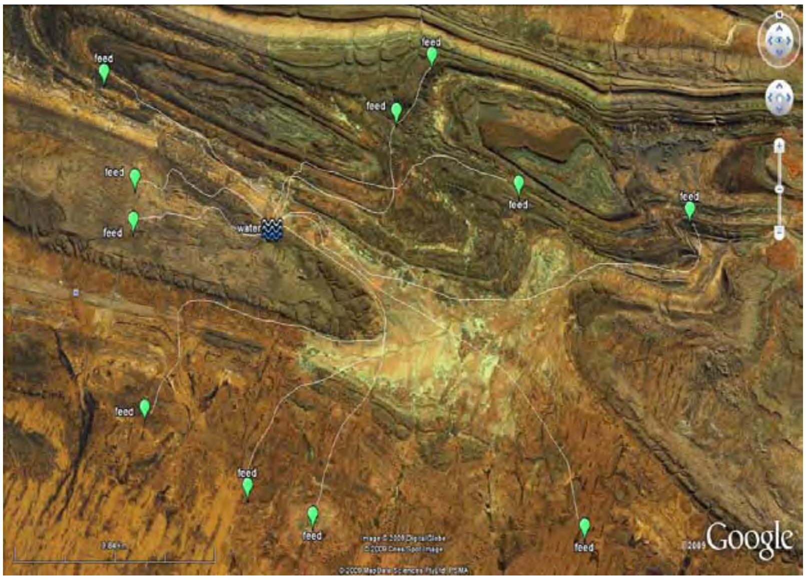

Figure 5 **Google earth image of a desert fringe area in central Australia with typical brumby travel patterns superimposed. When food is scarce close to water, horses must perform mini-migrations, twice weekly, between feeding grounds and the centrally located water source. The distance travelled may be 65km and the return trip is performed within the same 24 hour period. This travel pattern is not typical for wild and feral horses but a necessary survival strategy in marginal conditions. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).**

In a second study four desert fringe horses, accustomed to high travel and low watering frequency, were relocated to an area containing abundant pasture close to water[27] (Figure 6). These horses immediately modified their travel behaviour and were never more than 4.9 km from water over a four-month period.

Figure 6 **When water and food are abundant and feral horses have the choice, they prefer to remain close to the water source. Four desert adapted brumbies accustomed to long treks between from water and feeding grounds were relocated to this area with abundant feed close to 2 water sources. Horses that previously ranged long daily distances in search for food were never more than 4.9km away from water over a 4 month period. All GPS location data points remained within the artificial white perimeter area over a 4 month period. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).**

Conclusions

These studies indicate that wild and feral horse travel is dictated by available food and water resources. Feral horses appear not to want to travel large daily distances but are sometimes forced to, in order to survive. When given the opportunity to reduce travel distances in favourable conditions, desert-adapted horses responded immediately. The Australian brumby studies concluded that desert horse travel was excessive and probably not indicative of “natural” horse movement. By combining the results of the brumby studies with other wild equid studies (Przewalski, zebra and donkeys) it appears that “natural” movement for equids is somewhere within the range of 5 to 10 km/day (3.1 to 6.2 miles/day). Domestic horses housed in paddocks of at least 4 ha achieve this movement.

3. The feral horse foot

Introduction

There have been many studies of wild and feral horse ecology over the past 50 years including Przewalski horses in Mongolia, Konik horses in Poland, Namib horses in Namibia, Kaimanawa horses in New Zealand, Mustangs in the USA and brumbies in Australia. Some studies have concentrated on the horse foot [8-10, 32-34], while others have provided valuable knowledge regarding horse behaviour, nutrition, preferred habitats, genetics and movement. This section describes the findings from recent Australian brumby foot studies (Hampson et al, 2007-2011). These studies investigated various aspects of the foot, including gross form and structure, radiographic anatomy and lamellar and hoof wall histology.

Foot conformation and foot health are influenced by many factors including breed and heritable factors [2], nutrition [35], hoof trimming [36,37], hoof moisture [7] ,housing and environment [13,38]. The Australian project investigated the effect of environment on the feet of Australian and New Zealand feral horses in a variety of habitats from alpine mountain to sandy coastal and rocky desert habitats. This study found a profound effect of environment on feral horse feet. Feet were affected by a combination of substrate (footing) and the distances that horses travelled. The study spanned six wilderness environments and each environment produced a unique foot type in terms of general appearance, foot shape and structure.

Substrate (footing) and travel distance

Footing has been identified as affecting hoof capsule rate of wear in feral horses[13]. The Australian feral horse studies reported that a hard, abrasive surface under foot caused a faster wear rate than a soft, less-abrasive surface. There appeared to be a balance between hoof capsule wear and growth rate in most horses from the hard substrate environments, although there was evidence of excessive hoof wall wear in some horses, in particular young colts pursuing mares in the breeding season. Consequently, hoof capsules were short and often worn to the level of the peripheral sole. There was some evidence of hard substrate substantially accelerating the growth rate of the hoof wall in horses recently introduced to hard footing but the sample numbers were too few (n = 4) for a conclusive statement. In the softer footing environments growth rate exceeded wear, allowing the hoof wall to grow long and flared. Travel distance affected foot shape and form. The distance that horses travelled was determined by the separation between food and water within the habitat [26]. When food was close to water feral horses travelled moderate distances but when food was scarce close to water, horses were forced to travel greater distances to find sufficient food for survival. Some feet from high travel populations appeared to have overuse changes such as excessive hoof wall wear. A combination of high travel and hard substrate was associated with the more extreme foot types observed. The hard substrate foot types most closely resembled the popular “natural” foot type proposed in the past [7-10].

Brumby swap

Part of the Australian project involved swapping brumbies between two contrasting environments. Horses from a hard substrate, high travel area were relocated to a soft substrate, moderate travel area and vice versa. The feet of the horses changed as a consequence of the environment within a very short period. The long flared walls of the soft substrate feet became short, with minimal hoof wall flaring, within 8 weeks of changing to hard substrate (Figures 7 and 8). In contrast, the short straight hoof walls of the hard substrate feet progressively grew long and flared, with white line stretching with the intervention on soft substrate and reduced travel requirements. The initial shape and structure of the hard substrate feet appeared not to enhance protection against the consequences of reduced wear in the new environment.

Figure 7 **Lateral (A), dorsal (B) and solar (C) views of brumby foot from moderate travel, soft sandy country prior to relocation. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).**

Figure 8 **Lateral (A), dorsal (B) and solar (C) views of the same brumby foot following 4 months relocation to a high travel, hard substrate environment. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).**

Foot parameters

Dorsal hoof wall angle

A study measured the foot form and structure in 100 Australian feral horses from five contrasting environments. While the effect of the environment was obvious in 37 of the 40 foot parameters measured, some measurements varied little between populations of horses. The dorsal hoof wall angle (DWA) and palmar angle of the distal phalanx were very similar between populations and varied little between horses. This suggested that these parameters may be important to the biomechanical function of the foot. The range of mean DWA across all feral horse populations was 53° to 57° (Figure 9). The small variation in this important hoof conformation parameter suggests that it may have useful prescriptive value in determining ‘natural’ hoof balance. The mean DWA of 41 sound Thoroughbred racehorses was 48° in the study by Linford[39]. In a study of 95 racing Thoroughbred horses [40], there was a significant effect of DWA on catastrophic musculoskeletal injury. In that study, injured horses had lower DWA than non-injured horses (50.7°). A reduction of only 2° was considered sufficient to have a biomechanical effect on horses and was associated with injury. The DWA of Thoroughbred racehorses in comparative studies is considerably lower than that of the feral horses in the current study. The dorsal hoof wall angle in managed horses is determined by hoof trimming.[36,37] A low DWA is perceived to be advantageous in racing performance [41] and this is partly the reason for the practice of trimming to these parameters. However, there is evidence that there are consequences, such as higher injury rate, with this conformation. The conformation of the feral horse may offer a guide to best practice for overall soundness, but may not necessarily produce the best performance.

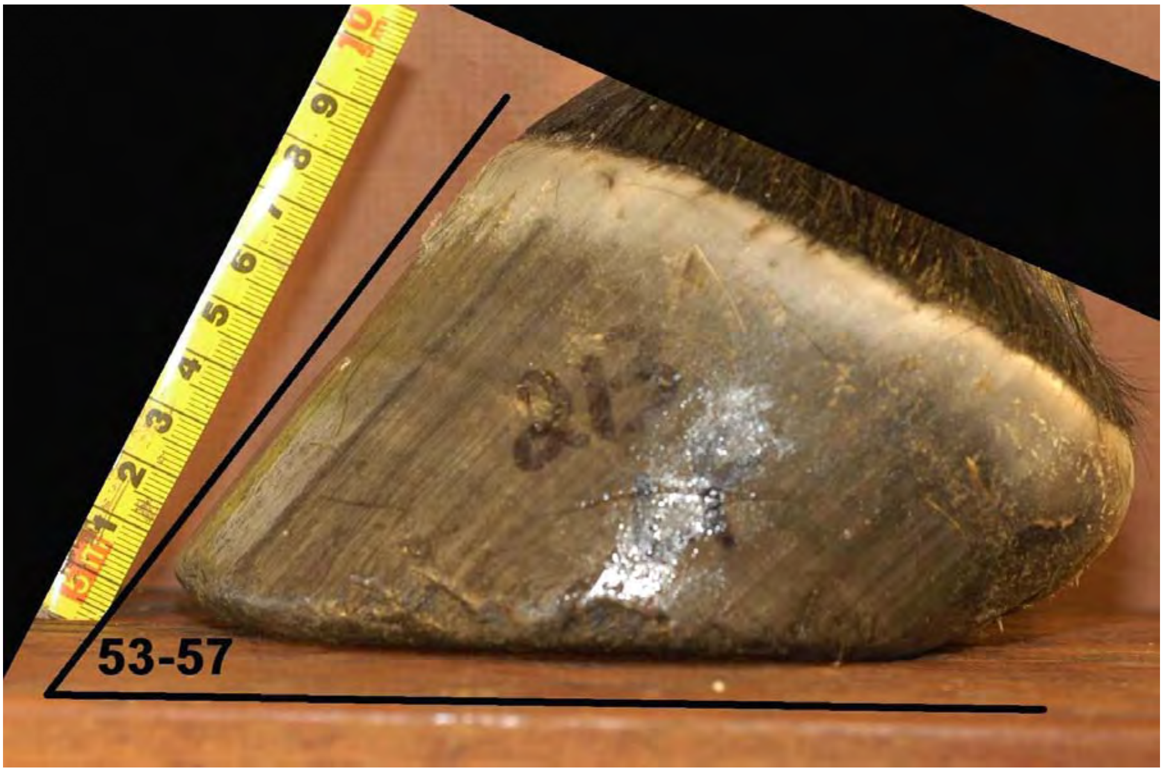

Figure 9 **The range of mean dorsal wall angles (53° to 57°) from 5 Australian brumby populations (n = 100) shown here on a hard substrate, high travel brumby foot. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).**

Palmar angle

The palmar angle (PA) is measured from radiographs and is the angle between the distal border of the distal phalanx palmar processes and the ground. If the PA is zero, the base of the distal phalanx is ground parallel. If the PA is high then the dorsal wall angle will also be high, resulting in an upright foot. In a recent review of the radiographic assessment of the equine foot it was suggested that the normal PA of the forefoot should be 5° to 10°, sloping positively down from the heel to the tip of the distal phalanx[1]. The Australian feral horses fitted into the low range of these dimensions (mean 5.7°; Figure 10). Strasser [7] suggested that the natural orientation of the solar surface of the distal phalanx was ground parallel and claimed observations of wild horses and the lack of foot pain in healthy domestic horses with this PA as evidence supporting this conformation. However, evidence from a Kaimanawa feral horse foot study [42] found that a ground parallel or negative PA was linked to foot pathology in Kaimanawa feral horses. The low range of values in the current study suggested that the PA of horses living in a "natural" environment, with an absence of human intervention, is close to 6°. The small variation between horses from each environment, irrespective of footing type and travel requirements, suggests that the angle of this parameter is important to functional hoof conformation.

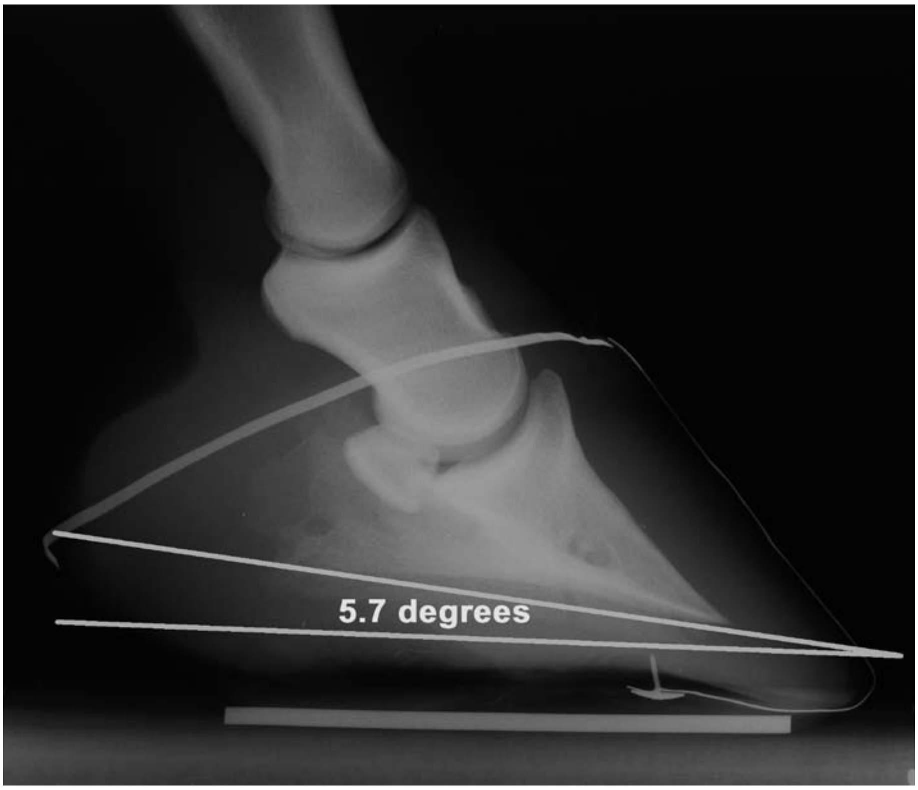

Figure 10 Latero-medial radiograph of a brumby foot loaded under 1/3 of the horse weight showing the mean palmar angle (5.7°) for 100 horses from 5 different populations. The distal phalanx of the brumby is not ground parallel. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).

Solar shape

The shape of the solar surface of Mustang hooves was investigated by Ovnicek [10] who suggested that the natural hoof wall was squared at the toe, promoting early break-over and was beneficial to locomotion. This observation prompted the introduction of a square toe horseshoe (Natural Balance Shoe) based on the wild horse foot model. In the Australian brumby study, the shape of the solar surface of the foot of the high travel, soft sand substrate brumbies was consistently squared at the toe and differed from all other brumby populations. The squared toe was apparently due to excessive wearing from the hoof being dragged through deep sand in the swing phase of the gate. The squared toe also appeared in 20% of the horses living in the hard rocky desert, but this feature appeared to be due to horses digging in the sand to reach sub-surface water. This foot shape was also encountered in horses travelling extremely high distances, typical of young bachelor stallions searching and competing for mares. The Australian study concluded that the typical shape of the feral horse foot was rounded at the toe, as is the case for the domestic horse.

Toe length

Toe length is the distance from the tip of the distal phalanx to the distal end of the hoof wall and is measured from a latero-medial radiograph. It is an important parameter and relates to the forces on the dorsal wall and dorsal lamellae just before the break-over phase of stance. The toe length was predictably highest (33 mm) in the horses living on soft footing and was significantly different to that of horses living on hard footing (toe length 29 mm). Greater wear of the distal hoof wall, by its increased interaction with the harder substrate environment, was thought to cause this difference. The mean depth of the cup in the solar surface of the foot was greatest in the soft substrate populations (5.5 mm) and reduced in the hard and mixed substrate populations (2.9 mm and 3.7 mm respectively). This was considered to be due to a longer hoof wall peripheral to the margins of the distal phalanx from less wear, but may have also been affected by the higher position of the distal phalanx within the hoof capsule (lower CE or sinker distance) in the soft substrate group. The hard substrate feet showed signs of "sinking", as the distal phalanx was positioned lower in the hoof capsule.

Wall flares

In the "perfect" foot, the hoof wall is considered to be straight from the coronary band down to the distal (ground) end of the hoof wall. When the hoof wall is allowed to grow long, the white line may stretch and cause the hoof wall to buckle or flare. The amount of dorsal wall flaring was minimal in the hard substrate brumbies (mean: 0.35^{o} to 0.46^{o}) and this differed significantly to the soft, sand substrate brumbies (mean: 4.89^{o}; Figure 11). In domestic horses the medial wall angle is usually more upright than the lateral wall angle and lateral wall flares are larger. In the brumbies the medial wall angle was more upright than the lateral wall angle in all but one population. The hard rocky desert (hard footing) brumbies had equally upright medial and lateral hoof walls. The combined mean medial and lateral wall flare angles for the soft substrate horses was 20^{o}, and was only 8^{o} for the hard substrate horses. A more upright hoof wall may provide protection against wall flaring, and may be an important factor of foot health in the hard substrate populations, while less important in the soft substrate environment. The high travel, hard substrate environment produced a foot type with symmetrical medial and lateral wall angles and with minimal wall flaring. In contrast the moderate travel, soft substrate environment produced feet that were long and flared with less upright lateral hoof wall angles, similar to domestic horse feet kept untrimmed on soft footing.

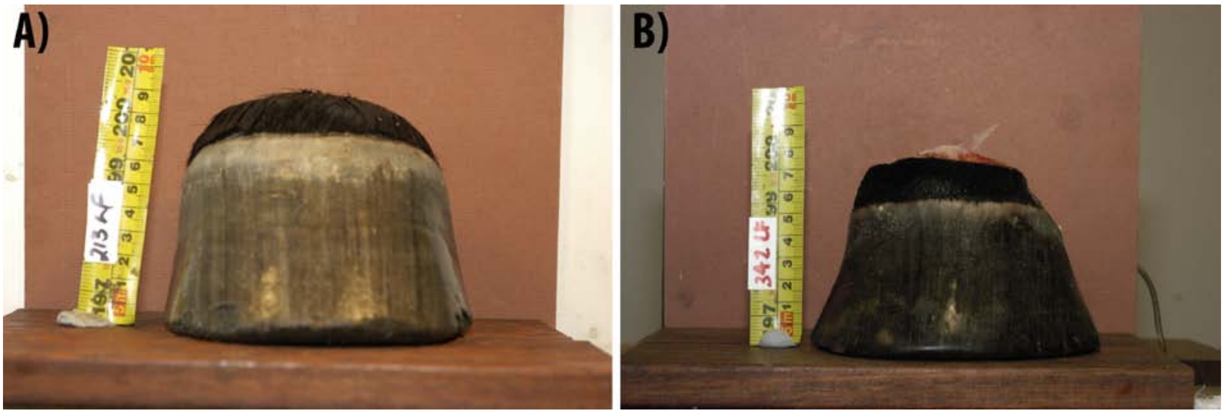

Figure 11 The environment has an affect on the shape of the hoof capsule. In the hard rocky terrain (A) the hoof walls are straight, with minimal flaring and little distinction between the medial and lateral walls angles. In the soft terrain (B) the hoof walls are flared and the medial walls are more upright than the lateral walls. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).

Hoof wall thickness and lamellar density

The thickness of the hoof wall is known to decrease from the dorsal midline (toe) to the heels [43]. This variation in hoof wall thickness (HWT) is believed to be of importance in facilitating hoof function [43,44]. The circumferential variation in HWT is thought to affect the flexibility of the hoof wall at different locations, allowing greater rigidity in areas of high force (toe) and more flexibility in areas requiring greater expansion and contraction (heel quarters). Brumbies, like domestic horses, also have a variation in the HWT from the toe to the heels (Figure 12).

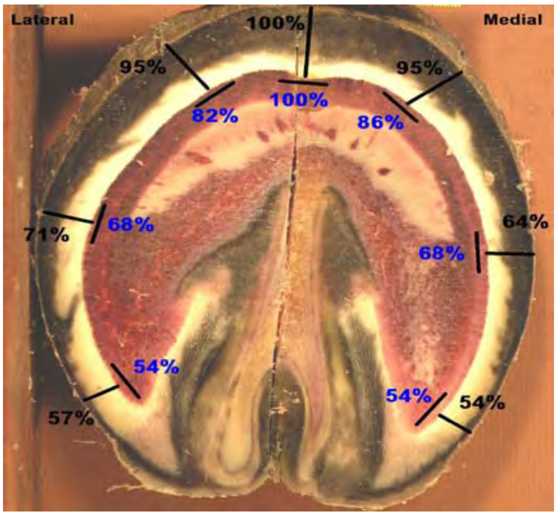

Figure 12 Mean hoof wall depth (HWD) and primary epidermal lamellar (PEL) density distribution around the hoof wall circumference in the left forefeet of 24 adult feral horses. The parameters at each site are represented as a percentage of the mean values at the midline dead centre (MDC). The mean HWD and PEL density values at the MDC are given the value of 100% as they are the largest values. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission) Key: hoof wall depth (black figures), lamellar density (blue figures).

Lining the inner hoof wall are the lamellae, which function to support the weight of the horse within the hoof capsule and dampen forces transmitted from the ground towards the skeleton of the horse. The total number of primary epidermal lamellae in the forefeet of adult horses has been determined in several previous studies[39, 44-47] and range from 500 in mixed breed horses to 561 in Standardbred horses. Primary epidermal lamellar numbers in the forefeet of brumbies approximated the mid range of these values (mean: 539). The spacing between groups of lamellae is referred to as lamellar density. The lamellar density varies, like hoof wall thickness, around the circumference of the hoof wall. At the toe, where the greatest forces are experienced, the lamellar density is high. That is, there are a large number of lamellae per unit length of hoof wall. The lamellar density reduces towards the quarters and further towards the heels, where there is a reduced force requirement. The lamellar density in the forefeet of brumbies is very similar to that found in previous studies of athletic domestic horses. So the distribution of the architectural components of the hoof wall in feral horses appears to be laid down according to known weight bearing and force dissipating requirements of the foot. The mean depth of the outer hoof wall and the corresponding lamellar density is greatest at the toe where, during locomotion, the greatest biomechanical and physiological stresses occur. Both parameters reduced gradually from the dorsal foot towards the palmar heel, where both values represent approximately 55% of the maximum value at the toe (Figure 12).

In racing Thoroughbreds, the total thickness of the hoof wall and lamellar layer (THWT) at the centre of the toe was 14.6 mm [39]. The THWT in brumbies was affected by substrate hardness. Means from the brumby study ranged from 16.5 mm in soft substrate feet to 19.0 mm in hard substrate feet. Thus there can be a 30% difference between the means of Linford's[39] Thoroughbred and the Australian feral horse populations. A further derivative of this parameter is the ratio of the hoof wall thickness and the length of the palmar cortex of the distal phalanx. Linford [39] reported the mean ratio in Thoroughbreds to be 24%. The corresponding means from the study of five brumby populations ranged from 29.5 % and 33.0 % (Figure 13). Such thickening has been found to result from thickening of the lamellar layer and has been linked to chronic laminitis. Pollitt [48] suggested this ratio should be close to 25% in sound feet, and Linford [39] determined that a thickness ratio greater than 28 % should be considered abnormal [39]. Using this ratio, all six Australian and New Zealand feral horse populations would have been identified as being abnormal, with a strong suspicion of a high incidence of chronic laminitis in five populations. Although it has been previously thought that the thick hoof wall in the feral horse foot was a positive adaptation to the environment, it is likely that a thicker hoof wall in some brumby populations represents a pathological consequence of high distance travel over hard substrate, similar to changes seen in traumatic laminitis described by Linford[39] in Thoroughbreds. In other brumby populations, the change is most likely due to dietary induced laminitis. The increased hoof wall thickness in brumbies is therefore due to stretching of the lamellae, cap horn production and perhaps a change in the orientation and width of the coronary band due to distal phalanx sinking.

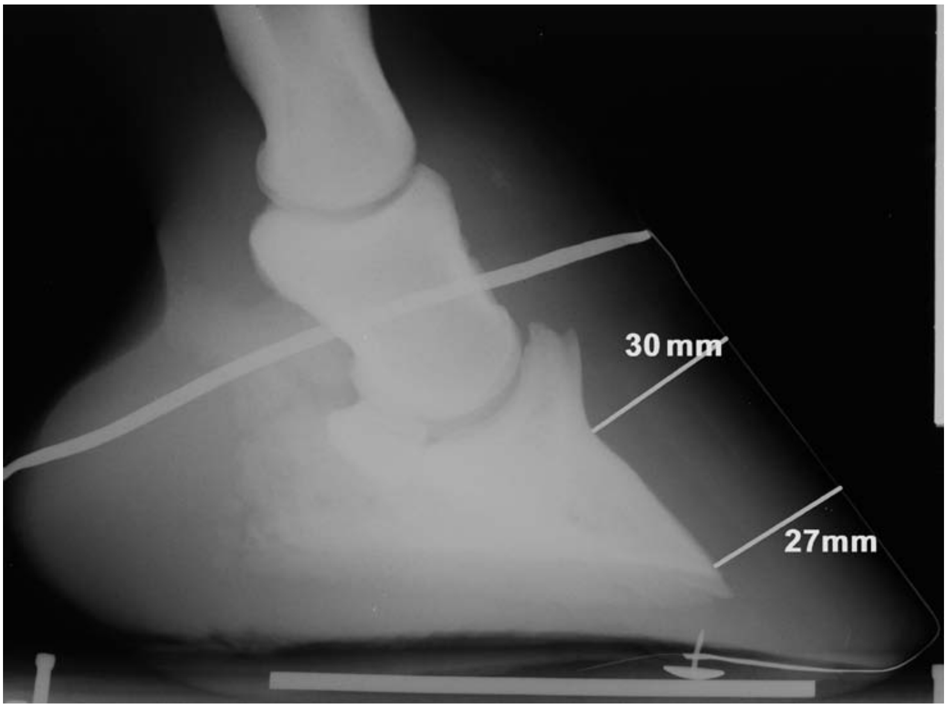

Figure 13 Latero-medial radiograph of a hard substrate/high travel brumby foot showing a large depth (27 mm distally) of the soft tissues and hoof wall dorsal to the border of the distal phalanx. The normal depth for the Thoroughbred is close to 15 mm. The ratio of the depth to the palmar length of the distal phalanx in this horse is 46% in comparison to 25-28% in healthy domestic horses. This high ratio is indicative of chronic laminitis. Note also the calcified ungual cartilage and some bony changes on the dorsal surface of the middle phalanx and the extensor process of the distal phalanx. The hoof wall is thinner distally (closer to the ground) in this foot type as the distal outer hoof wall tubules are worn away by abrasion. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).

Hoof wall and sole plane

The length of the hoof wall distal to the sole plane is of interest to hoof care providers as it is an important guideline in the process of hoof trimming. At the toe midline, the length of distal hoof wall ranged from a mean of 1.47 mm beyond the adjacent sole plane in the soft footing brumbies to 0.75 mm proximal to the adjacent sole plane in the hard footing brumbies (Figure 14). Feral horses, particularly from a hard substrate habitat, bear substantial weight on the peripheral sole as well as the hoof wall and this may be detrimental to foot health. This finding needs to be considered in relation to the high incidence of laminitis in brumbies and is discussed further in this chapter. Copying this wild horse feature by removing the hoof wall distal to the sole plane may do the horse harm.

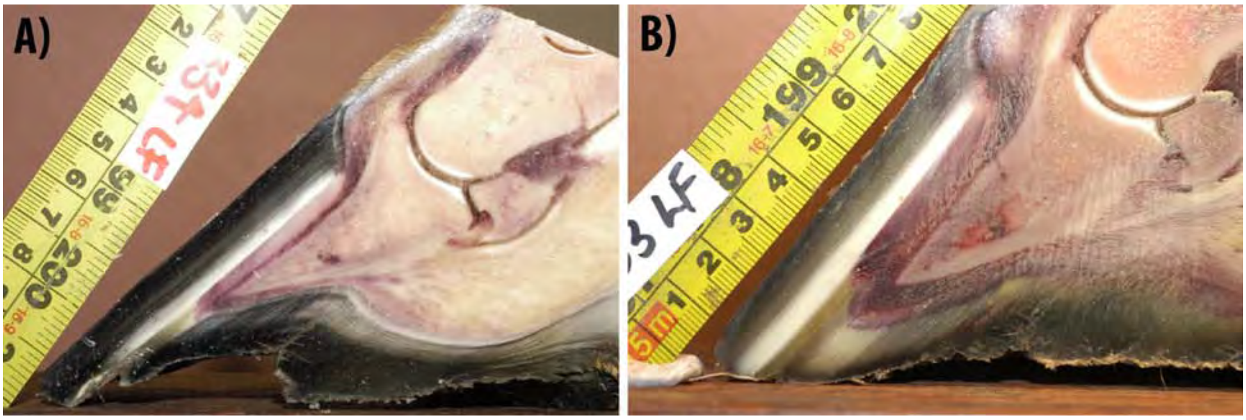

Figure 14 Midline dorsal wall sagittal sections showing the difference in hoof wall length in relation to the peripheral sole in soft substrate (A) and hard substrate (B) brumby feet. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).

Sinker (founder) distance

The vertical distance (CE) between the proximal limit of the extensor process and the proximal hoof wall is an important parameter in foot health, particularly in respect to laminitis. Veterinarians use of figure of 6 mm to represent normal[49]. The brumby study reported a range of means for CE from 6.7 to 11.0. The lower mean value was for the population of feral horses from moderate travel soft, sandy substrate. The higher values are found in the hard substrate populations and are most likely due to stretching of the lamellae due to pathology, such as laminitis, causing the distal phalanx to sink within the hoof capsule (Figure 15). The observation that hoof wall depth was significantly less in the soft substrate horses, in combination with a smaller CE, supports the argument that laminitis was the reason for sinking in the hard substrate populations. The flatter sole cup in the hard substrate horses also supports the possibility of sinking of the distal phalanx in these populations. The feet of the hard substrate brumbies appear perfectly normal externally and they have smooth hoof walls and very thick soles. It was surprising to see the radiographic features of extremely thickened hoof wall and an increased founder (or sinker) distance.

Figure 15 **This series of figures are from the same brumby foot from a high travel/hard substrate environment. The gross appearance (A) is of an aesthetically pleasing, healthy foot. The foot radiograph (B) indicates a nice short toe length (26mm) and thick sole but the sinker distance (11.5mm) raises concern, as does the depth of tissue dorsal to the distal phalanx (19mm). The ratio of this tissue depth to the palmar length of the distal phalanx (32%) is further suggestive of pathology. The histopathology of the lamellar layer (C) is inarguably indicative of chronic laminitis. The primary epidermal lamellae are stretched (lengthened by 40%) and have broken keratinised axes. The secondary lamellae are either absent (stripped away) or deformed. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).**

Sole depth

When in contact with the substrate, a high number of biomechanical events may induce changes in the weight-bearing structures of the equine foot[50]. However, the relationship between biomechanical loading and tissue response is not fully understood. It is widely accepted that a thick sole contributes to good foot health and thin soles have been incriminated as a risk factor for sole bruising, abscesses, corns, laminar tearing, and a lack of confidence in movement [51]. However, it has not been determined how much sole depth is optimal and whether “too much” sole can be detrimental to hoof function.

Australian feral horses have been tracked with global positioning system (GPS) technology, and they can travel up to 28 km/day (17 miles/day) over hard rocky and even mountainous terrain[26]. It is intuitive to expect that the ability of these horses to travel long distances over rough terrain with apparently no foot soreness may be attributable to unique morphology of their hooves. A comparative study of domestic Thoroughbred and brumbies from hard and soft substrate provided conclusive evidence that sole depth is related to substrate hardness. Brumbies from hard substrate footing had significantly greater sole depth than brumbies from soft substrate (Figure 16). Even the soft substrate brumbies had greater sole depth than domestic Thoroughbred horses [61].

The depth of the sole varied among populations of horses, but the shape and distribution of sole material were similar for all horses. The epidermal sole is a dome-shaped structure that follows the contour of the distal phalanx adjacent to it. The mean depth of the sole cup varied from 3.0 to 5.5 mm, depending on the population. The thickest solar epidermal support region was in the peripheral sole near the junction with the white line. The sole epidermis narrowed from the periphery to the centre of the foot (Figure 17). Mean sole epidermal depth increased from the dorsal to the palmar aspect of the foot in each population, again following the contour of the palmar surface of the distal phalanx. The sole dermis depth had a pattern similar to that of the epidermal depth. The mean thickness of the sole dermis for all horses was greatest in the periphery (3.4 mm) and thinner toward the centre of the foot (2.7 mm).

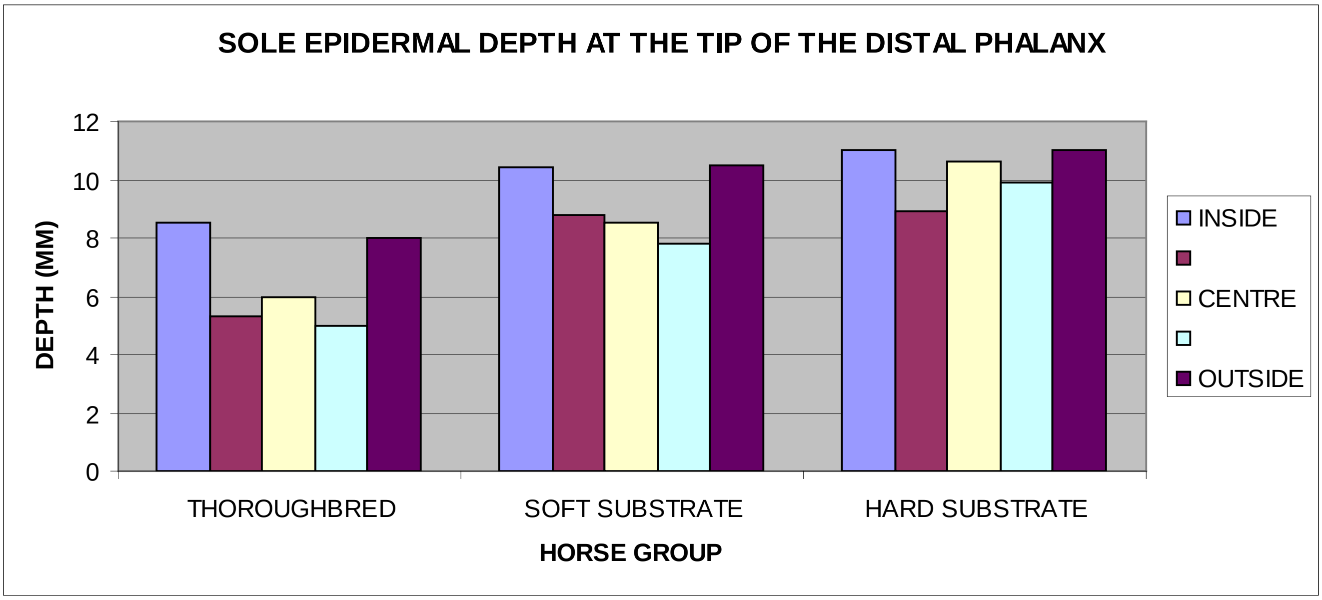

Figure 16 **The mean epidermal sole depth directly beneath the tip of the distal phalanx in 20 horses from each of three populations: Thoroughbred, soft substrate brumbies and hard substrate brumbies. The sole depth is measured at 5 locations from the medial to the lateral perimeter of the hoof wall. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).**

Figure 17 **The dermal and epidermal sole depth followed the same pattern in Thoroughbred and feral horses with the greatest depth at the peripheral wall and reducing to the centre of the foot. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).**

In all three groups of horses the sole depth was greatest peripherally, near the hoof wall. This is consistent with results of a loading study (next section) that indicated that increased sole depth correlated with areas of greatest load bearing and thus greatest rate of wear. Analysis of the data implied that there may be a differential growth rate of sole horn across the solar plane in response to biomechanical feedback mechanisms. The increased sole depth in the horses from the hard substrate habitat may provide greater protection from hard objects (rocks) and force dissipation to cope with the hard environment.

The peripheral aspect of the sole may be underestimated as an important load-bearing and force-dissipating structure. The increased load-bearing surface area generated by the contribution of the peripheral aspect of the sole would reduce force per area, thus reducing stress on individual hoof wall tubules and structures within the foot as well as reducing the rate of wear in that area. The application of a narrow-web horseshoe to the hoof wall may not maximise the load-bearing and force-dissipating properties of the solar structures of the equine foot. However, wide-web horseshoes have characteristics similar to those for the hooves of horses from hard substrate habitats and distribute the load-bearing surface area in a similar manner. However, a relationship between peripheral sole bearing and the presence of internal foot pathology (discussed later) was observed in some brumbies.

Linford [39] found the mean sole depth directly under the central distal phalanx tip of the feet of 103 Thoroughbred racehorses was 11.1mm. In the brumby study, the corresponding mean sole depth was 14.7 mm for feral horses from hard substrate, 12.6 mm for feral horses from soft substrate, and 9.5 mm for domestic Thoroughbreds. Kummer[37] measured the sole depth in 40 large Warmblood horses at 13 mm. It is intuitive to expect that sole depth should increase with size of the horse. In comparison to large horse breeds, the brumbies were smaller in stature, but the sole depth was larger. Comparison of the sole depth of small feral horses to that of larger managed horses further emphasizes the effect of the environment on the morphology of the equine foot. The sole depth of brumbies appeared to respond to travel distance and substrate. The bovine hoof has a similar sole structure to that of the equine hoof. Observations of dairy cows concluded that growth of the sole horn was accelerated by load bearing on hard surfaces[52].

The functional importance of sole depth has not yet been fully established. Further studies are required to determine the correlation between sole depth and foot health in domestic horses. The thin sole of racing Thoroughbreds may be a result of selection to increase speed during the gallop or a direct result of inadequate biomechanical stimulation. However, the resultant lightweight foot may be more vulnerable to injury and lameness. The more robust foot of feral horses inhabiting a hard substrate environment may be a better model for managed domestic horses. However, it is possible that large sole depth may limit hoof capsule flexibility and prevent hoof capsule expansion and contraction. The optimal depth of sole is not known and may be best determined by the individual horse activity.

Load bearing pattern

The load-bearing pattern of the equine foot has been investigated in managed domestic horses. [38,53-56] Ovnicek [9] investigated the load-bearing structures of wild horses using mustang cadaver feet. In contrast to results of studies in domestic horses, the peripheral aspect of the sole of the mustang feet appeared to contribute markedly to the weight-bearing surface, possibly because of the short length of the hoof wall in wild horses.

An Australian study investigated the ground surface load-bearing properties of brumby feet from hard and soft substrate habitats [61]. This study used a loading ram and loaded limbs over an electronic pressure plate using varied surfaces between the feet and the pressure plate. Predictably, different patterns of loading and load-bearing surface area were observed among feet of horses from habitats with differing substrate types. Feet of horses from hard footing had the greatest area of loading on the distal aspect of the hoof wall and peripheral aspect of the sole. Load-bearing surface area increased with incremental increases in load (Figure 18). Surprisingly, the frog and central aspect of the sole did not load until extremely high vertical forces were applied. As expected, the type of substrate covering the loading plate affected the load-bearing surface. Deep sand and gravel resulted in a large load-bearing surface that included the central aspect of the sole and the frog. Feet from soft footing loaded the hoof wall more than feet from hard footing and there was reduced central sole and frog loading even on deep substrate. The mean load-bearing surface area for the hard footing group was 184% greater than that for the soft footing group.

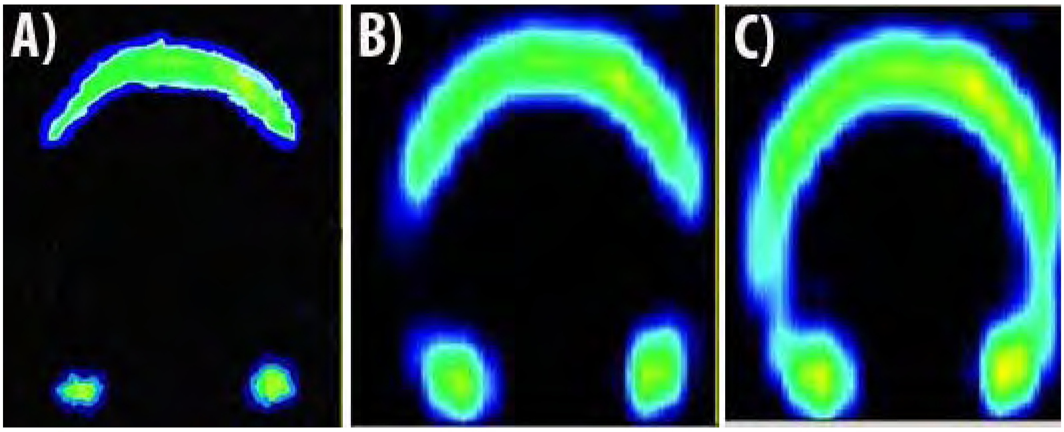

Figure 18 Pressure pattern of a typical high travel, hard substrate brumby when loaded by a hydraulic press over an RS scan pressure plate at a (A) standing load, (B) trotting load, and (C) canter load. This foot type loads the hoof wall and peripheral sole at the toe and heels at low load. At higher loading (faster speed) the load is spread to the quarters and heel quarters and more centrally over the sole. Frog loading on a firm surface did not occur until a much higher load was applied. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).

On a hard flat surface, horses from the hard footing bore weight directly on the perimeter of the sole, the tubules of the inner hoof wall, and the white line. Because of the bevel in the distal aspect of the hoof wall in all feral horses from hard footing habitats, the tubules in the outer hoof wall did not directly bear weight on the hard flat surface. This architecture has been interpreted by some as suggesting that the forces on the sole are transmitted vertically to the solar surface of the distal phalanx and that this mechanism is an important load bearing feature of the feral horse foot. This would be a reasonable assumption if all feral horses shared the same foot form and structure. However, the excessive hoof wall bevel only exists in horses living on hard rough terrain and those travelling high distances for survival. Feral horses living in open grasslands with more moderate travel patterns have a slightly bevelled wall which is maintained longer than the peripheral sole. The question then is: “what is the natural environment and lifestyle for horses”. The previous discussion on GPS tracking of feral horses suggested that moderate travel is normal for horses. High distance travel appears to be excessive and only occurs in horses on the edge of survival. The extremely short hoof wall (exposing the peripheral sole to immediate weight bearing) and large bevel removing the outside hoof wall tubules from immediate weight bearing, may also be considered as excessive and may be to the detriment of the horse. This assumption is supported by the high incidence of pathology, including ungual cartilage calcification and chronic laminitis in feet showing these excessive features. Excessive peripheral sole loading may in fact contribute to the development of these pathologies.

Five of 10 feet from feral horses from a hard footing habitat required a vertical force > 5,000 N to compress the frog over a 3-mm-thick firm surface. This is equivalent to the maximum vertical load produced in a 400 kg horse during a fast trot or slow canter. The palmar surface of the frog in this group of horses was a mean of 5.1 mm above the ground surface. Investigators in another study [57] reported frog-ground contact in Standardbred horses shortly after horseshoe removal at much lower loads (1,800 N). Colles [58] reported frog-ground contact for domestic ponies and horses wearing horseshoes at trotting loads. These comparisons prompt discussion concerning the relative flexibility of hard substrate feral horses versus domesticated horse feet from those studies. The presence of a high mean sole depth and excessively thick hoof wall in hard substrate feral horses compared with that in soft substrate feral horses and domestic horses indicated that the entire hoof capsule of these brumbies may lack flexibility. Although substantial sole depth and hoof wall thickness are usually seen as desirable attributes in the hoof, the consequences of excessive biomechanical loading driving excessive tissue responses may change the ultimate function of the hoof, reducing flexibility. An excessively thick hoof capsule could be viewed as a consequence of overuse. The form and structure of feet associated with this foot type with the typical short hoof wall (exposing the peripheral sole to direct weight bearing) and large bevelled wall (removing the outside hoof wall tubules from direct weight bearing) perhaps should not be viewed as an optimal model for the foot.

Adaptation or consequence?

The brumby foot is a reflection of the environment in which the horses live. The brumby swap case study, previously described, showed that by changing the environment the foot can be significantly altered from one foot type to another in a short period of time. This does not necessarily mean that the foot is a smart structure capable of adapting to suit the environment. The foot change may be merely a consequence of environmental factors. An adaptation suggests that changes that occur to the foot must be beneficial. The foot type of the soft substrate horse with the typical long, flared walls is not an adaptation as it does not give the horse an advantage in that environment. The slow rate of wear in soft substrate under moderate travel conditions is incapable of matching the growth rate of the hoof wall so a long, flared foot type results. The long flared walls put the foot at a potentially vulnerable position as it may severely crack, break away, and expose the white line and lamellar tissues to injury from the environment.

Another example of the consequential, rather than adaptive effect of environment is evidenced in the high travel, hard substrate foot type which has short, straight walls rolled (bevelled) at the bearing border (“mustang roll”). The brumby study determined that the distal wall roll only occurred in the hard substrate foot type, and was excessive in those horses travelling over rough, uneven and mountainous terrain, and in horses required to dig for food or water (Figure 19). This feature is not necessarily a functional feature of the feral horse foot. It occurs excessively in brumby feet which have poor foot health, such as calcified ungual cartilages and chronic laminitis pathology. In contrast, it does not occur in soft substrate brumby feet which have good foot health. Because it is not a consistent feature in all feral horse feet, and is not correlated with good foot health, it may be inappropriate to apply distal wall bevelling to domestic horse feet. This point is discussed further later.

The thickened sole and hoof wall observed in the hard substrate, high travel brumby foot may reduce the overall flexibility of the hoof capsule, resulting in an altered hoof mechanism. This is another example of a consequential, rather than adaptive effect of the environment.

Figure 19 **Desert fringe horses were observed digging for water at this dried waterhole (A). This is one of the reasons for the excessive bevel (B) in the distal hoof wall. (Photos: Marg Richardson) (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).**

4. Not the perfect foot?

Introduction

If the “natural” horse foot is to be used as a guide to model the morphology of the domestic horse foot, first the appropriate model should be identified. The study of feral horses from six environments in Australia and New Zealand identified six different foot models. It appears that the form and structure of feral horse feet is primarily determined by the interaction of the foot with the environment. However, there appear to be some morphometric parameters that are consistent between feral horse populations and these parameters may be important when considering the natural form of the equine foot. The health of the feral horse foot should also be considered when making assumptions on the appropriateness of the feral horse foot model in domestic horse foot care. This section reviews three studies of foot health of 100 Australian brumbies and 76 New Zealand Kaimanawa horses and presents some surprising results (Figure 20).

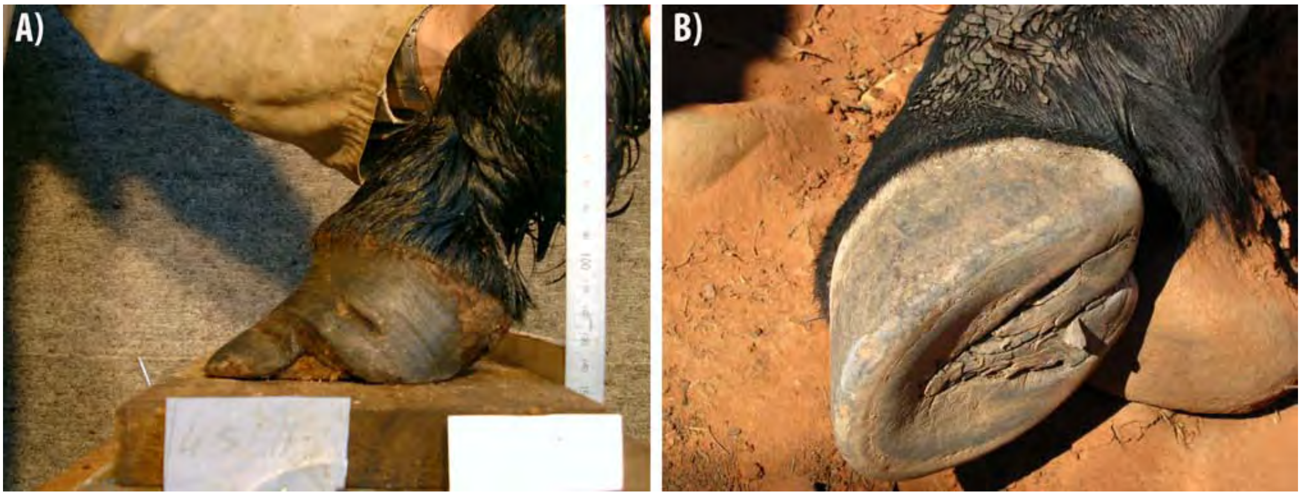

Figure 20 The natural foot shows extreme variations depending on the environment in which the horse lives. These include (A) Kaimanawa feral horses (NZ) and (B) Australian desert brumbies. Which foot is the “natural foot?” (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).

Methodology and results

Foot health assessment (Australian brumbies)

There were 377 abnormalities identified in a health survey of the left forefeet of 100 Australian brumbies from five different populations. Each feral horse population (20 in each) shared a significant incidence of abnormality in the overall survey, with the contribution of each population ranging from 16 - 22%. The abnormalities were separated between those considered to have a minimal and those with a more significant impact on foot function (Figure 21). In this comparison a clear trend emerged in the foot health of horses between hard and soft substrate habitats. While the hard substrate horses had the lowest incidence of less significant abnormalities, they also had the highest incidence of more significant abnormalities. The situation was the reverse for the soft substrate horses with the highest incidence of less significant abnormalities and the lowest incidence of more significant abnormalities. There were only three feet in which no abnormality was detected. These were from horses from the hard rocky desert population. However, this population also had the highest incidence of the more severe pathologies (Figure 21). The less severe abnormalities included capsule deviation, medio-lateral imbalance, hoof wall cracks, hoof wall rings, wall flaring, narrow and uneven heels, white line defects and long hoof wall. The more serious abnormalities included altered distal phalanx/hoof wall alignment (e.g. rotated distal phalanx), distal phalanx bone abnormalities, excessive soft tissue (lamellae) and hoof wall thickness in the hoof capsule and severe ungual cartilage calcification.

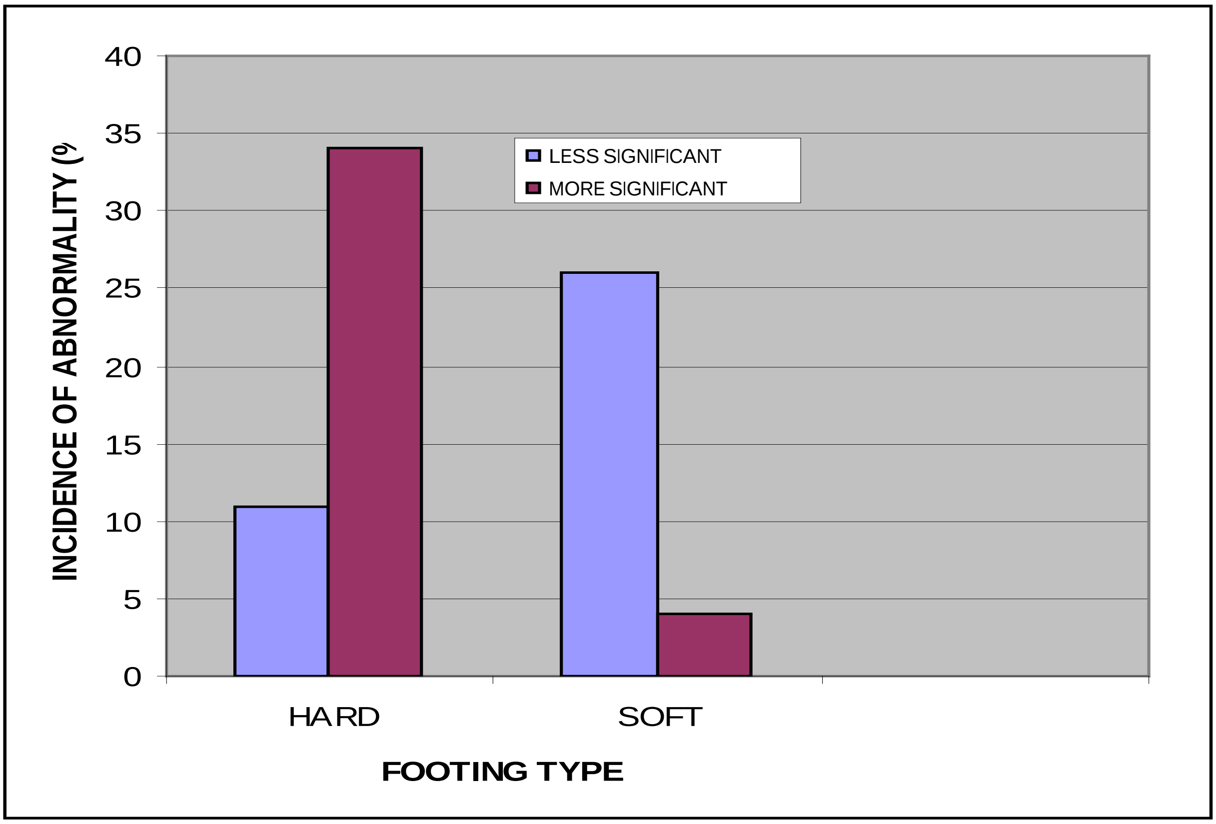

Figure 21 Graphical representation of the effect of substrate (footing) type on the distribution of more and less significant foot abnormalities observed in Australian feral horses from soft (20) and hard (20) substrate environments. Each population shared a comparable incidence of abnormality in the overall survey, however, the incidence of less and more significant abnormalities, in terms of pathogenicity, varied between populations. (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).

A study of the lamellar histology of 15 brumbies from each of three Australian brumby populations reported an incidence of chronic laminitis ranging between 40% and 93%. Once again, foot health appeared to be affected by the environment inhabited by the horses. The most surprising finding was a 67% incidence of chronic laminitis in the feet of rocky desert horses. The external appearance of these feet was not indicative of laminitis and appeared typical of the hard substrate feet, with short, rolled walls, minimal hoof wall flaring and very few hoof wall rings. The chronic laminitis may be attributable to either nutritional or traumatic causes. The nutritional causes are less likely as lush feed had been scarce in the habitat for the previous 6 years prior to the study.

Foot health assessment (Kaimanawa horses)

In a histopathology survey of 56 Kaimanawa feral horses captured on the same day 45% were diagnosed with chronic laminitis[59]. Kaimanawa horses live a feral lifestyle in open range country in New Zealand. The land was formerly sheep grazing country and has been invaded by exotic pasture species. The most likely reason for the high incidence of laminitis in the Kaimanawa population is selective grazing for highly palatable exotic pasture grasses high in non-structural carbohydrates. Another potential explanation for the high incidence of chronic laminitis in this population is the possibility that the Kaimanawa feral horses are insulin-resistant and hyperinsulinaemic.

In another study of all four feet from 20 Kaimanawa horses[42], there was a large variation in morphometric dimensions between horses, indicating poor foot conformation and an inconsistent foot type. Thirty-five percent of all feet had a long toe conformation and 15 % of feet had medio-lateral hoof imbalance. The incidence of pathology 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) and a suspicion of chronic laminitis in a large percentage of horses.

Discussion on foot health

There is evidence to support the possibility that feral horses from hard substrate environments may suffer from foot pathology similar to the traumatic laminitis model induced in domestic horses[39]. Linford[39] induced traumatic laminitis by trimming the hoof wall bearing border to the level of the sole and housing the horses on hard footing for four months. The intervention caused disruption of the lamellar architecture, haemorrhage in the solar corium, solar margin fractures and distal phalanx remodelling. The necessity of some feral horses to travel long distances over hard substrate may also lead to overuse or concussive injuries to the distal phalanx and lamellar suspensory apparatus of the distal phalanx. The high incidence of calcified ungual cartilages in the hard substrate environments supports an hypothesis of concussive injury aetiology. The majority of feral horse travel is performed at a slow walking pace yet significant foot abnormalities develop under this regimen. Thus repeated low-load, concussive conditions, such as unavoidable mini-migrations over hard terrain, predispose horses to foot abnormities.

However, horses living in the hard substrate environment did not appear overtly lame. These feet had a shorter toe length (29.1) than horses from soft substrate (34.6) and domestic horses from previous studies (Kummer[37] : 40 Warmbloods: 36 mm and Linford[39] : 41 sound Thoroughbreds: 31.4 mm). A reduction in toe length has been shown to reduce substantially the peak moment at the onset of break-over. It may be that the robust foot structure and the unique foot morphology of these horses is protective against mechanical trauma and the pain associated with chronic laminitis.

The soft substrate horses did not have abnormal radiographic features and there were no radiographic signs of laminitis. Hoof wall flaring and splitting, were common in feet from soft substrate environments but were absent in feet from hard substrates. The hard substrate may have induced significant internal abnormalities but the high rate of hoof wear may have protected against less significant foot abnormalities. A straight, short walled hoof capsule is a feature of horses surviving in the hard substrate environment and appears to withstand the pathological consequences of this lifestyle. This point is worth noting when considering trimming models for the management of foot diseases such as laminitis. The form of the hard substrate feral horse foot may be a good model to consider in these situations.

Substrate hardness may not be solely responsible for the more significant abnormalities observed in the feral horses. The presence of laminitis in some of these populations may be explained by nutritional factors. Laminitis in some feral horse populations may be due to carbohydrate overload from opportunistic feeding, similar to laminitis caused by grain and pasture overload. Thus the importance of controlled nutrition for laminitis prevention is highlighted.

5. The relevance of the feral horse foot to foot care

Introduction

The traditional farriery model assumes that the hoof wall is the principle weight-bearing component of the hoof capsule [60]. It is responsible for achieving smooth and painless force cycling between the ground and the appendicular skeleton during loading. Leaf-like primary epidermal lamellae project from the inner aspect of the hoof wall and interdigitate with their dermal counterparts attached to the distal phalanx. This complex anatomical arrangement forms an integral part of the suspensory apparatus of the distal phalanx which serves to suspend the appendicular skeleton within the hoof capsule. To achieve this optimal weight-bearing function, the hoof wall must be allowed to grow past the sole plane (at least 3-5 mm length according to Pollitt[60]) so that the sole is relieved of direct pressure on a flat hard surface. When the foot is placed in soft or deep footing, the most distal structure of the hoof capsule (the hoof wall) will continue to bear greater weight than the less prominent structures (the peripheral sole)[61].

Veterinarians and farriers insist that the correct conformation of the equine foot is critical and many recommend a dorsal hoof wall angle of approximately 54 degrees (range 48-55) with a distal phalanx palmar angle of 3-7 degrees for the forefoot of the horse[51]. It has previously been assumed by some authors that the feral horse foot represents an ideal model on which to base foot care practices. The adoption of this model by some groups has shifted the focus of hoof trimming away from the traditional farriery model with a tendency towards excessive removal of the bearing border of the distal hoof wall. The external appearance of the typical hard substrate brumby foot, which is often used as the benchmark model, appears aesthetically pleasing, with little visible pathology. However, this superficial impression was misleading as a more thorough investigation of internal foot structures using radiographic and lamellar histological assessment, revealed significant pathology. Previous observers and proponents of the "natural" foot model were apparently unaware of this inner pathology but made assumptions and recommendations for domestic foot care, such as promotion of solar loading and excessive bevelling of the distal hoof wall. The practice of using the "natural" foot model as the optimal morphometric model on which to base foot trimming practices may need to be reconsidered carefully.

If the "natural" horse foot is to be used as a guide to model the morphology of the domestic horse foot, first the appropriate model should be identified. The current study of feral horses from six environments identified six different foot models. It appears that the hard substrate foot type was selected as the original paradigm for the bare foot horse with aesthetic appearance as the main selection criterion. The current study identified extreme activity levels in feral horses over harsh terrain. These horses were able to survive partly due to the robust hoof structure they had developed since birth. However, this same robust structure had apparently suffered injury and pathology as a consequence of the extreme activity and is not necessarily recommended for the domestic horse functioning within less extreme requirements.

Results and discussion

There was significant pathology identified in the foot types most closely resembling the popular "mustang" foot. Only three feet from the 100 left forefeet assessed were free of abnormality. The most surprising finding in the hard substrate, high travel population was a 67% incidence of chronic laminitis, likely of traumatic aetiology. A 70% incidence of ungual cartilage calcification in the hard substrate, moderate travel population further indicated the possibility of concussive changes as a consequence of overuse on hard substrate. Some of the characteristics of the popular natural foot have proposed advantages, for example a thick hoof wall, thick hard sole and heavily worn distal wall promoting increased sole bearing. However, these characteristics may in fact be associated with pathology, thus making this model inappropriate if applied to domestic horse feet. There is currently no clear evidence to support the use of the extreme feral horse foot as a model for foot care. However, there appear to be some morphometric parameters (dorsal hoof wall angle, palmar angle of the distal phalanx) that were consistent between all feral horses in the brumby studies and these parameters may be important when considering the natural form of the equine foot.

An example of the questionable use of the extreme natural foot model is the application of the squared toe and the over-exaggeration of distal wall roll, often referred to as the "mustang roll". The square (or rockered) toe is a feature thought to be a strategic hoof structure aiding early break-over[10]. The more conservative (and more commonly used) definition of the mustang roll is a soft radius or bevel applied around the entire circumference of the hoof wall. The function is to prevent distal hoof wall cracking, chipping and wall flares. Because these features occur in the "model" feral horse foot they are often applied with the rasp during trimming. The detailed study of feral horse feet showed that the squared toe occurred in extreme cases and was excessive in horses travelling long distances over rough, uneven and mountainous terrain, and in horses required to dig for food or water. The roll is a consequence of constant chipping and abrasion as the hoof makes contact with rocks and abrasive footing from all directions as the horse moves across the terrain. As the foot hits a rock and a fragment of hoof wall is dislodged energy is dissipated, rather than propagated through the hoof to the underlying soft tissues and skeleton. The wearing process that creates the roll may be a protective feature of the hoof wall but the actual architectural feature of the roll itself may have no protective function in the horse's foot. Therefore the practice of creating the squared toe and excessive roll artificially with the rasp may be of no benefit to the horse with a "normal" foot. The application of the exaggerated form of this feature to the managed domestic horse living in a paddock environment should be reconsidered. In specific situations, such as when a lamellar wedge is present, a more extreme trim may be applied to reduce the dorsal wall forces at break-over. However, in healthy, bare-foot horses, a small bevel of the distal hoof wall appears to be effective in preventing hoof wall cracking and chipping and at the same time does not affect the break-over location, and allows the outer most hoof wall tubules to bear weight as they are meant to.

At the trot the peak force through the hoof wall is up to 1.5 times the horses' bodyweight. The back half of the horse foot is designed to deform and absorb shock so it has elastic structures such as the frog, heel bulbs, ungual cartilages and digital cushion. The front half of the foot is designed to be rigid to allow it to perform its major weight bearing function. The outer hoof wall tubules, like the front half of the foot, are rigid, also designed to bear weight [50, 62-64]. The variable water content, and thus elasticity, of the hoof wall tubules (wet on the inside and almost dry on the outside of the hoof wall) provide a natural dampening mechanism to reduce the impact of the forces transmitted to the skeleton. Removing the rigid outside hoof wall tubules from immediate ground contact by excessively bevelling the hoof wall will place the inner moist hoof wall tubules in a position of more direct weight bearing, a function which they are not bioengineered to perform on their own.

Another example of the questionable use of the natural foot model is the practice of attempting to create the same hoof wall thickness around the circumference of the hoof wall. Clearly, the feral horse hoof wall is thickest at the midline dorsal wall (toe) and gradually thins towards the quarters and heels. The selective removal of "thick" sections of hoof wall may be counterproductive as it is likely to remove outside wall hoof tubules, particularly at the toe and break-over locations, from immediate weight bearing. The outside wall tubules are designed to bear weight and the hoof wall must be robust in these areas to support the hoof capsule as it deforms with load bearing.

One challenge currently facing horse owners is the creation of an environment most conducive for horse health. This may include the provision of a surface under foot that balances hoof growth and wear and promotes musculo-skeletal preparedness for the environment in which the horse is used. Horse owners have a choice of substrates for housing horses and there are active feeding systems available that modify the daily distance travelled. The feral horse studies identified some negative long term implications of substrate and movement on foot health. Care needs to be taken in choosing one environment over another because of the possible harmful consequences. Although feral horses living and travelling on hard substrate appear to have robust feet, modified by the environment and able to withstand locomotion over hard substrates, the current study suggests that there are some negative consequences associated with this lifestyle. In light of this observation, further research is required to fully understand the impact of high travel distances and various footings on the health and well being of domestic horses in managed care.

Conclusions

Feral horses in Australia, like many places throughout the world, survive in conditions not entirely natural for horses. These environments at times provide abundant food sources which may be inappropriate for horses. At other times feral horses experience sustained droughts and food and water shortages. The separation between food and water affects travel distance and the choice of terrain over which horses travel. This in turn affects the form and structure of horse feet. Feral horse feet often appear aesthetically beautiful, robust and pathology free, and appear at first glance to be an ideal model for horse feet. While some features of feral horse feet appear to give guidance for trimming practices, others have been misinterpreted and over-emphasised. In light of recent more detailed study of feral horse feet there is sufficient argument for the model to be reconsidered.

While the veterinarian and hoof care provider is often blamed for the demise of the horse [65], it has been the industrial revolution and the changing role of the horse from a beast of burden to a recreational and companion animal, coupled with the shortage of available rural land for horse husbandry in many locations throughout the world, that is the major contributor to the perceived problems of the modern horse. The detailed study of feral horse feet has shown that the feral cousins of the modern domestic horse are also vulnerable to foot pathology despite being free from the confines and influence of human intervention. Best practice in hoof care should evolve from passed on knowledge, new research, clinical practice and practice review. Knowledge of wild horse and feral horse feet provides useful supportive information but a feral horse foot model should not form the basis for the footcare of the domestic horse.

Figure 22 Knowledge of wild horse and feral horse feet provides useful supportive information but should not form the basis of the foot model for the care of the domestic horse. (Photo: Australian brumbies; Tuomas Kauko) (From B A Hampson. The feral horse foot. In: Care and Rehabilitation of the Equine Foot. Ed. Pete Ramey, Lakemont, USA, 2011; with permission).

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Improving the Foot Health of the Domestic Horse

by B. A. Hampson and C. C. Pollitt

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It has been proposed that the feral horse foot is a benchmark model for foot health in horses and can be used as a guide to optimise care of domestic horse feet. This report describes the morphology and health profile of the feral horse foot in detail not previously available. It identifies some important aspects of the form and function of the equine foot which should be considered in every day foot care for the domestic horse. The wild horse foot model is discussed in terms of its relevance and limitations to hoof care.

The report is targeted at horse owners, farriers and veterinarians so they can make better informed decisions about foot care for horses. This report will be of particular relevance to those who have an interest in the use of the popular wild horse foot model.

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