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Equine Navicular Syndrome in the Fossil Record

by Mary E. Thompson, Greg McDonald and L. C. Østblom

THE EVOLUTION AND DIVERSIFICATION OF THE HORSE LINEAGE IS PERHAPS ONE of the better-documented stories provided by the fossil record. While this story has often been portrayed in the popular literature as a straight line spanning 55 million years from the earliest recognized horse, *Hyracotherium*, to its living descendent, *Equus*, we now know that the true story is much more complicated.

In reality, the history of horses resembles a bush with many branches more closely than a straight line. Each branch on the bush represents an evolutionary experiment, as family members adapted--or tried to adapt--to changing environmental conditions.

Unfortunately the result of most of these experiments was extinction, so that today we have only one successful surviving branch represented by one genus and (depending on your expert) six species.

Because of the abundance of horse fossils, paleontologists have been able to document many trends and changes in horses throughout their evolutionary history. Changes in the teeth and the skull reflect changes in diet as some members of the family shifted from forest-living browsers to open-grassland grazers.

Related to this shift from closed to open country were modifications of the limbs and the animal's locomotion, as they became better runners. This has included either a reduction (fibula) or fusion (radius and ulna) of some bones of the legs and a decrease in the number toes, from the original five in the pre-horse ancestor to ultimately the monodactyl, or "single digit" horse, of today. *(See Figure 4.)*

Another trend has been a general increase in body size, although in reality some family branches stayed small; others decreased in size after becoming larger; and some fossil horses are larger than any of the living species.

All of these trends have been discussed at length in the literature and it is recommended that the interested individual read Bruce MacFadden's *Fossil Horses: Systematics, Paleobiology, and Evolution of the Family Equidae*, which provides excellent coverage of the fossil history of horses.

For the purposes of providing an historical perspective of ENS from the fossil record, two significant trends should be discussed in more detail: that of the increase in size and that of the reduction of the number of digits to one.

Whether we refer to size as overall dimensions, body weight or body mass, biomechanically, the result is the same: an overall increase in weight creates more stress on the feet when they come into contact with the ground, especially during times of extreme activity such as running or jumping.

In animals with multiple digits, this stress is distributed so that no single digit receives the full impact of the activity.

However, with a decrease in the number of digits, the force becomes more focused into a smaller area, so that the bones, ligaments, tendons and muscles need to be more effective in absorbing and transmitting these forces without becoming damaged.

INTRODUCTION

Equine navicular syndrome (ENS) is a chronic and incurable lameness of the horse's foot resulting in the deterioration of navicular bone (distal sesamoid) tissue. Horses predisposed to the syndrome are those used for strenuous work or athletic competitions (barrel racing, jumping, cutting, etc.). ENS occurs more frequently in quarter horses, thoroughbreds, and European warmbloods than other breeds (Rooney, 1998). *(See Figures 1 and 2.)*

The pathology of this condition is poorly understood but appears to be the result of mechanical stress reducing the blood flow to the navicular bone. Typically, this reduction in blood flow increases the rate of bone absorption and decreases the rate of bone replacement, producing a distinctive internal lesion visible in radiographs. *(See Figure 3.)*

In domestic breeds, the increased mechanical stress is often believed to be caused by man's intervention, either by increased usage or by improper breeding practices (i.e. larger body size and relatively smaller feet). Interestingly, ENS appears to be absent in wild horse species (Ramey, 1997).

In order to examine the relationship between man's increased usage of domestic breeds in strenuous work and the incidence of ENS, we examined the navicular bones of large samples of fossil species of *Equus*.

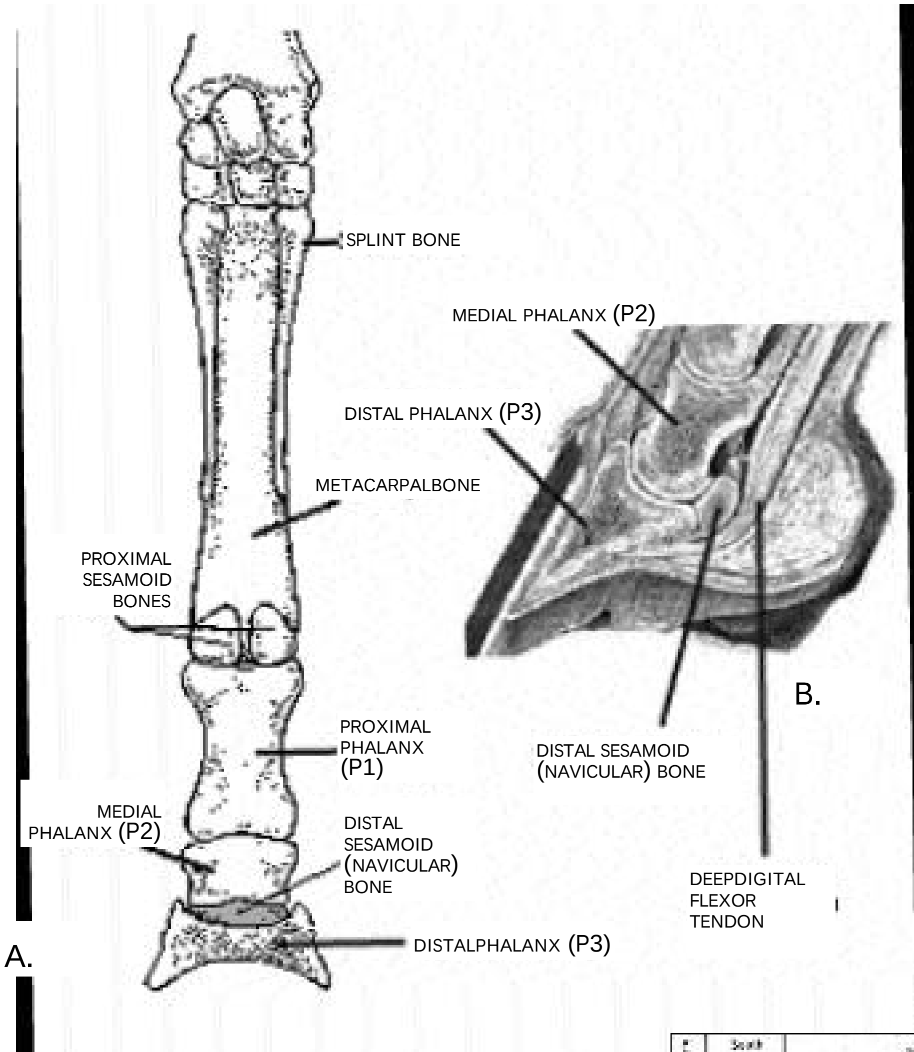
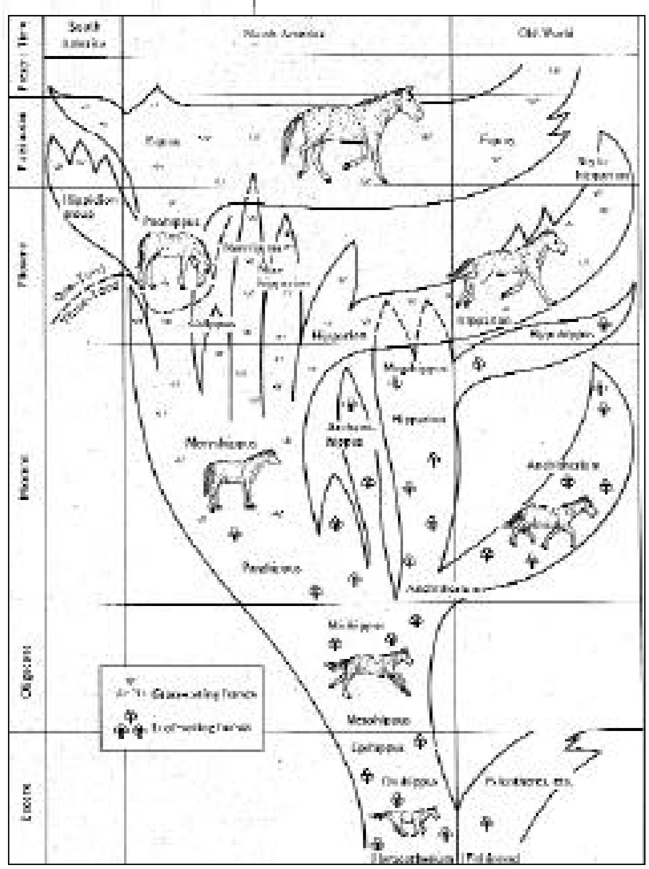


Figure 1. A. posterior-anterior view of lower leg and foot; and B. lateral view of an equine foot showing the position of the navicular bone between tendon and joint.

Figure 1c (BELOW) Radiation of the horse family. Early ancestors had three toes and ate leaves from trees; later forms grazed off the ground. Horse foot anatomical changes are key to understanding horse



The inherent properties of bone and soft tissues cannot be changed, so these properties become limiting factors to the animal's capabilities.

Many of the evolutionary adaptations we see in horses and other animals are compromises between what is required of the animal for survival and what its body will permit.

Fortunately for paleontologists, the shape, proportions and structure of bones reflect these compromises. Bones can even provide clues to some soft tissue such as tendons, ligaments and muscles, since where they attached to the bone often produces a roughened area or scar at the point of attachment.

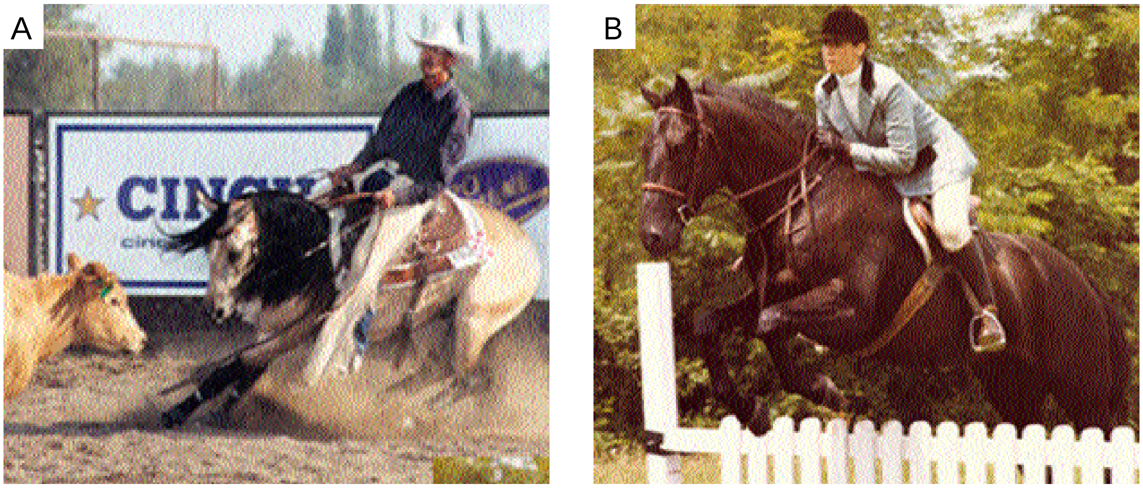
This combined information can tell us much about the habits of extinct species and allow some reasonable inferences about the lifestyles of the dead and buried.

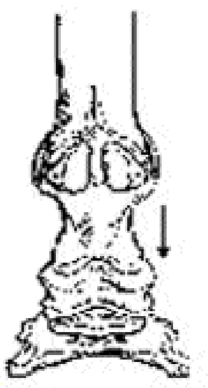
While it is a simple matter to put a living animal on the scale and determine its body weight, our limited source of information in the fossil record—usually only the bones and teeth—presents paleontologists with a challenge to come up with the same information for extinct species.

The body mass of an animal is closely correlated with many other body functions such as metabolism and physiology, ecological characteristics such as diet, population density, and home-range size, to provide a few examples.

It has been said that body size is the single most useful predictor of a species' adaptations. Because of this close connection, determination of body mass in extinct animals is an area of great interest to paleontologists. It provides an

Figure 2. Examples of breeds of horses that are predisposed to equine navicular syndrome and types of activities that increase navicular stress.
A. American quarter horse, cutting;
B. Thoroughbred, jumping;
C. Caudal-cranial view of horse front legindicating increased navicular stress.





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opportunity to make reasonable inferences about numerous aspects of the ecology and habits of extinct species.

Calculation of the body mass also permits a more reasonable extrapolation of the forces generated during locomotion and the amount of stress the bones must withstand.

The prediction of body size is simple in principle. Take measurements of bones or teeth or living animals of known body weight and then calculate a mathematical relationship between that dimension and the body weight.

Once this mathematical relationship is known, you can take the same measurement from a fossil bone, plug it into the formula and calculate the fossil animal's weight. In practice it is not so simple, since not all measurements one might take on a fossil bone are closely related to the weight of the animal.

In any study, a large sample of modern animals of known body weight is needed, and numerous measurements must be taken, before the right ones are found. However, once the best and most accurate technique for predicting the body weight has been found, and tested on living species, one can proceed with some degree of certainty that the calculated body weight for the fossil animal is reasonably accurate.

Just as in modern animals where each individual will vary within the range of the species, this is true for fossil animals as well, so often an average or general weight for the extinct species is produced based on measurements of a number of fossil specimens. While this is a generalization, it at least allows us to compare the relative weight of different species of animals through times, as in Figure 5.

The basic pattern of the mammalian hand and foot is to have five digits, but the number of digits has been reduced in many groups, usually by the loss of the thumb and big toe.

While it is often thought that the earliest horse, *Hyracotherium*, (better known as *Eohippus*) still had five digits in the front and hind feet, this is not the case:they were already reduced to four digits in the front and three in the hind.

An important component of the arrangement of the bones of the hand and foot is that the axis of the foot passes through the middle of the third digit so that it provides the primary support for the weight of the animal. This is also true for relatives of the horse, (i.e., tapirs and rhinos) which still have three digits.

In all these animals it is the middle or third digit that is the largest, thus reflecting its primary role in supporting the animal.

Hyracotherium had already lost the "thumb" of the hand (or foot) but in later forms the fifth toe was lost as well,producing the well-known "three toed horses".

Most fossil horses are three-toed and, in most species, all of the toes were functional, as demonstrated by many fossil horse tracks in which all three toes left impressions.Eventually in some—but certainly not all—horses, digits two and four became reduced (resulting in the splint bones hidden in the skin next to the cannon bone) so that the entire weight of the animal was eventually borne by the single middle third digit (known as "P3", or third phalanx.

We suspect that it was only after horses achieved fully functional monodactyly that we should start seeing evidence of ENS in the fossil record. However the other factor that we are looking at, body size, may also have played a major role.

There may be a critical threshold in size at which the forces generated by the animal exceed the inherent properties of strength and resilience in bones, ligaments and tendons seen in the mechanical arrangement in modern horses.

Our project is to examine the navicular bone in these earlier horse species to try and determine the earliest appearance of ENS. Our preliminary studies have provided us with a basis of what to look for in order to test this model.

To date we have examined extinct species of *Equus* from the Pliocene (Hagerman, Idaho) and Pleistocene (Rancho La Brea,California; American Falls,Idaho;

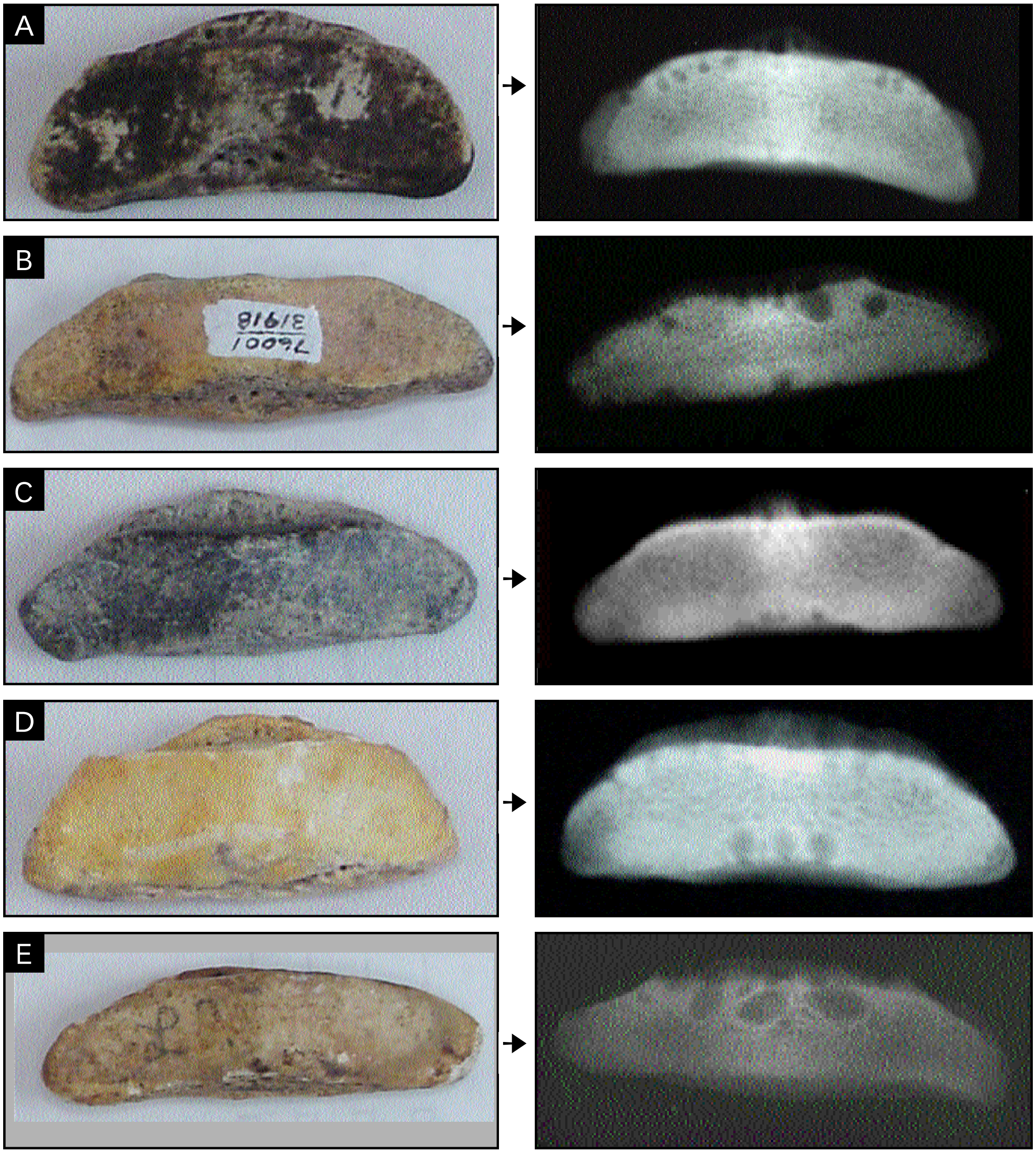


Figure 3. The navicular bone and radiograph in modern and fossil species of Equus.
A. Equus occidentalis, La Brea Tar Pits;
B. Equus scotti, American Falls;
C. Equus simplicidens, Hagerman;
D. Equus conversidens, San Josecito Cave;
E. Equus caballus, modern horse.

and San Josecito Cave, Nuevo Leon, Mexico) eras by radiography.

Lollipop lesions, characteristic of the syndrome, were identified on the radiographs of the large Pleistocene species, *Equus occidentalis*, from the tar pits at Rancho La Brea (21 percent) and to a lesser degree on the smaller Pliocene species, *Equus simplicidens* (6 percent) (Flint et al., 2001a).

This suggests that increased usage by man may not be the sole cause of the syndrome and that body size and the resulting forces placed on the navicular bone may be a critical factor.

As part of our study, we examined the effect of body weight as a possible factor that causes the syndrome. To test this idea we examined different sized species of fossil *Equus* ranging from a small species of Pleistocene horse, *Equus conversidens*, from Mexico with an estimated body weight of 318 kg (700 pounds) to the largest fossil species, *E. occidentalis*, estimated at 519 kg (1142 pounds).

The earliest known species of *Equus* is *E.simplicidens* with an estimated body weight of 425 kg (935 pounds). Another common Pleistocene species is *Equus scotti* with an estimated body weight of 442 kg (972 pounds).

Materials and Methods

All of the fossil samples so far examined are from sites that have produced large numbers of individuals of horses. This has not only increased our chances of locating specimen that might show the disease but also allows us to look at the incidence and frequency of ENS in a population rather than documenting only isolated cases of the disease.

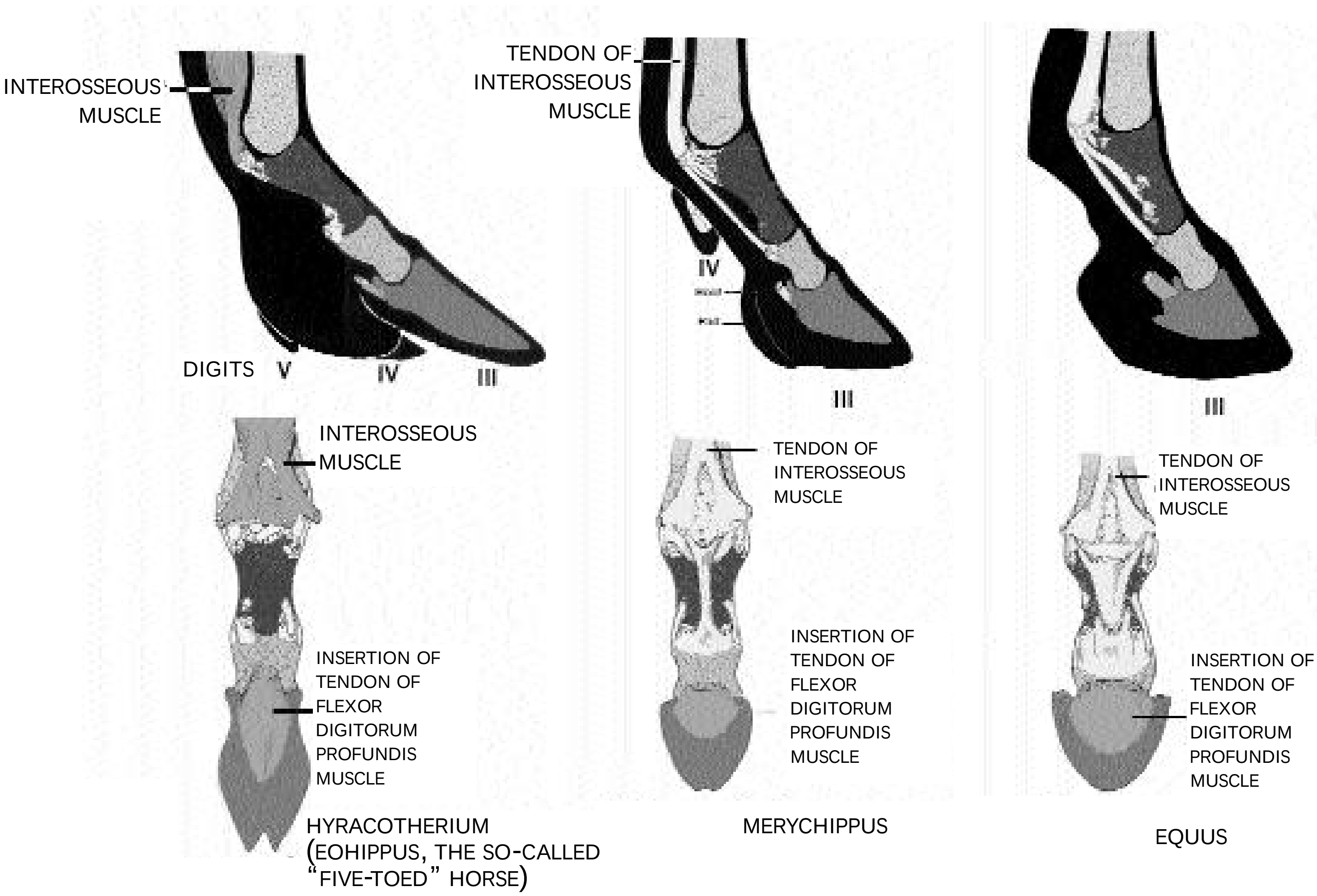


Figure 4. Changes in the front hand of horses through time. Modified from Camp and Smith (1942).

All samples of navicular bones were radiographed using a Picker Single Phase x-ray machine and Kodak Rare Earth screens and film (high speed, high detail). *(See Figure 6.)* Multiple specimen can be placed on a sheet of film and this approach produced images with excellent detail. The radiographs were evaluated for appearance of lollipop lesions and for any other osteolytic changes (i.e. spurs).

This project has taken place in two phases and results from the latest study--our examination of *Equus conversidens*, a small-bodied horse with estimated weight of 318 kg from the San Josecito Cave (Pleistocene, Mexico)--were compared to radiographs from the previous study (Flint et. al.,2001).

Conclusions

Radiographic changes (lollipop lesions) of the navicular associated with equine navicular syndrome in extant horses are demonstrated in both Pliocene and Pleistocene species of *Equus*. There is no significant difference in incidence of lesions among the Pleistocene horses (large vs.small bodied) but the lesions present in the San Josecito Cave material are relatively smaller than in the other species.

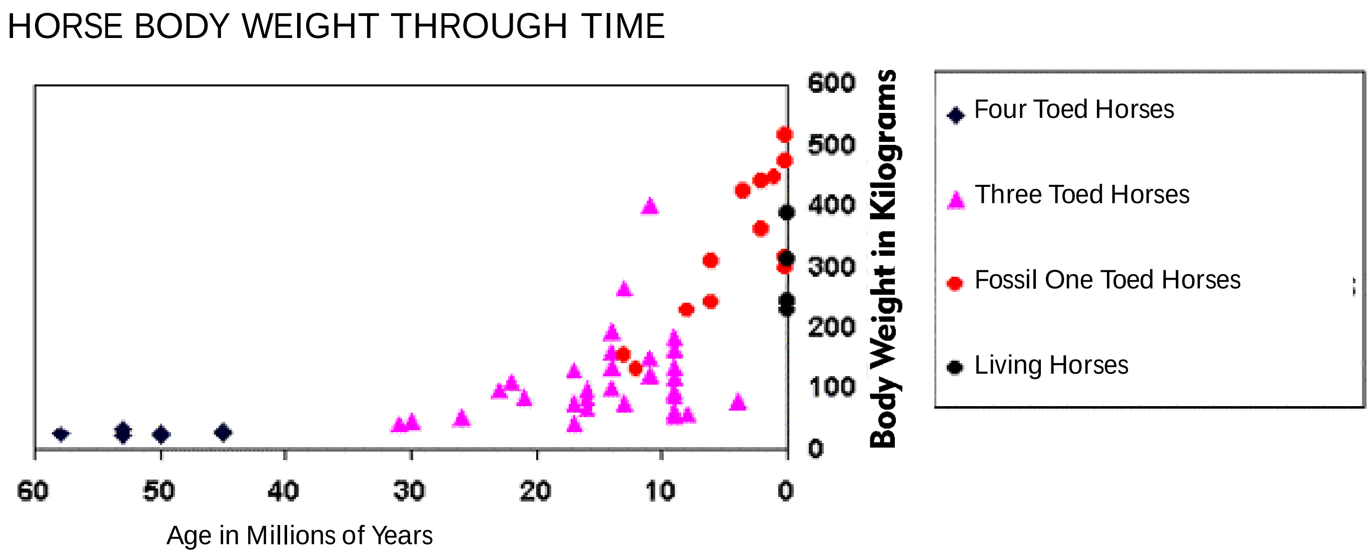
Lesion size of the San Josecito Cave material are comparable to the Hagerman material, (also a relatively small-bodied form) which may indicate the degree of the syndrome. If so, these horses may have displayed fewer symptoms and had less pain than the larger La Brea and American Falls horses indicating that the relative incidence of the disease is related to body size.

The results of this study strongly suggest that man's intervention (whether by increased usage or improper breeding practices) may not be the sole cause of the syndrome.

Our results are preliminary and more work needs to be done. At present we have focused on only a few extinct species of *Equus*, and we would like to expand the sample to more species of different sizes that lived in different environments.

Equus is not the only one-toed horse; earlier smaller genera such as *Pliohippus* and *Dinohippus* had already become one-toed and it would be instructive to look at samples of these animals to see if ENS was already present. This would permit us to check our hypothesis regarding the relationship of body weight and monodactyly as factors.

In addition to dispersing into the Old World, horses also entered South America and are represented by an extinct genus known as *Hippidion*, which is also one-toed. The build and proportions of *Hippidion* is



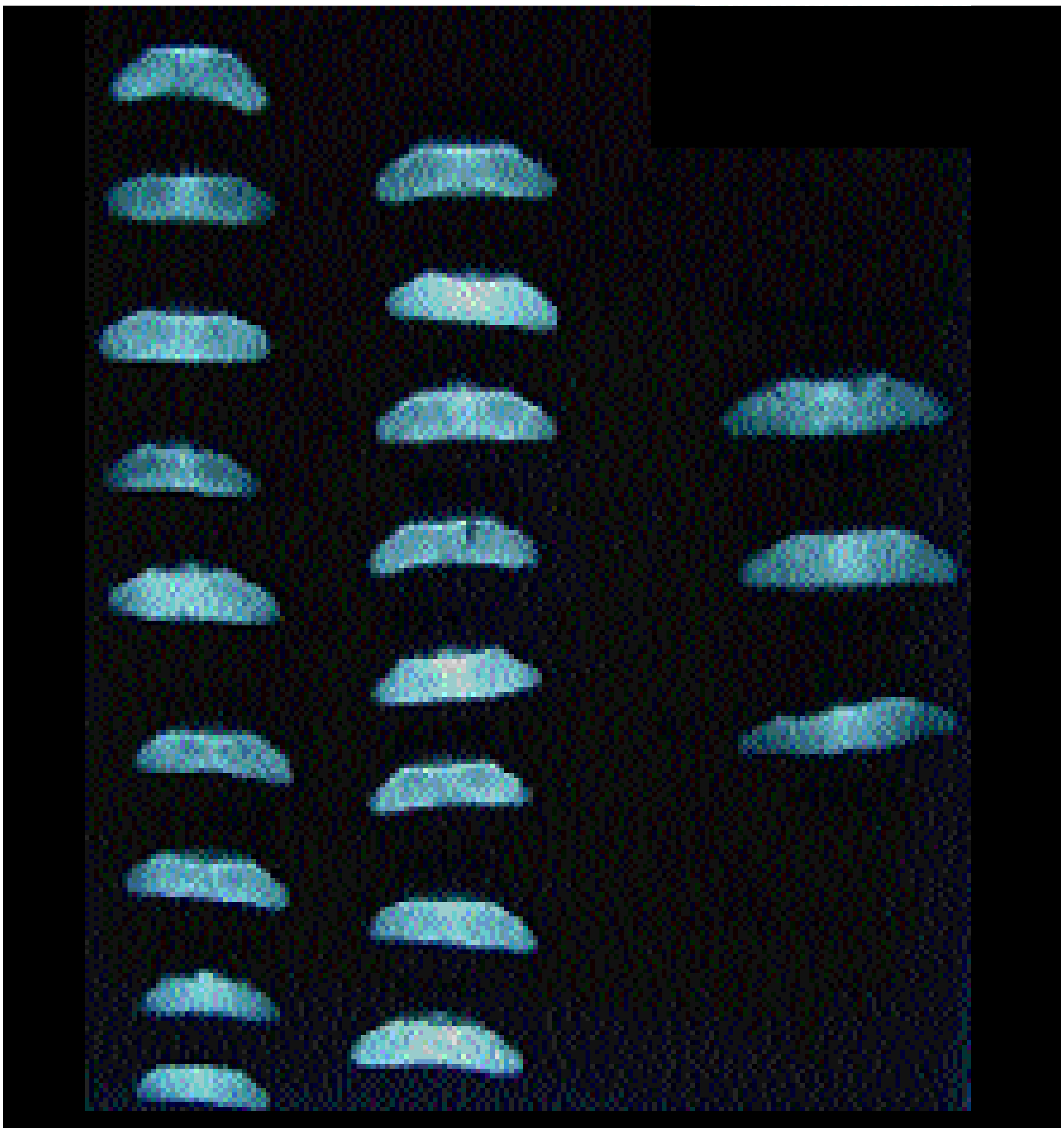


Figure 5. Chart showing the distribution of calculated body weight of different species of fossil horse through time. They have been divided into horses with four, three or one digit in the hand in order to show the size distribution in each of these groups. Modified from MacFadden (1986) with added data from MacFadden and Hulbert (1990) and modern species added.

Figure 6. Radiographs of the navicular bones of extinct horses using high-speed, high-detail screens and film.

shorter and stockier than *Equus*, especially in the cannon bone. It would be most informative to see if ENS was also present in this lineage of horses.

Our preliminary results have been most informative but more work is needed to document the origin and distribution of ENS throughout the course of horse evolution.

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