Bone Mineral Density Changes in Growing and Training Thoroughbreds

E. C. Firth, BVSc, MS, PhD, DipACVS; C. W. Rogers, PhD; A. E. Goodship, BVSc, PhD

Bone mineral density contributes to bone strength, and can be measured accurately in the distal limb of growing or training young horses. In training horses, changes occur within less than 3 months, and consist of trabecular thickening in the subchondral area and specific areas of the body of the epiphysis of longbones and the cuboidal bones. In the growing horse, variation in mineral density between foals becomes much less in the first months of life. The current most practical method for accurate non-invasive quantification of bone changes in the distal limb is peripheral quantitative computed tomography, using a portable axial CT scanner. Authors’ address: Equine Research New Zealand, Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Palmerston North, New Zealand. © 2000 AAEP.

Introduction

Some 70% of the strength of the skeleton is due to its mineral content. It is important to optimize bone mineral in growing and training horses, but to date there has been little sustained scientific investigation of the increase in bone with age or the response of bone to training in young horses, especially of cancellous bone. Therefore, we are not sure of what “optimal” bone actually is, or the optimal stimulus to produce it.

To determine mineral content in bone, some method of imaging is required. For use in the equine industries, any chosen method must be accurate, practical, and cost effective. Also, the changes expected between horses, or within horses over time, must be large in relation to the capability of the technique. The purpose of this paper is twofold: to describe studies which investigated the extent of change in bone mineral density in Thoroughbred horses, and to outline the advantages and disadvantages of dual x-ray absorptiometry (DXA), computerized tomography (CT), and peripheral quantitative CT (pQCT) in detecting these changes in horses.

Materials and Methods

Five studies in young thoroughbred horses have been conducted on:

- Bone mineral density (BMD) in third carpal bones (C3) of random source young Thoroughbreds (DXA), to determine left-right differences in pastured growing animals
- The carpus of 2-year-old Thoroughbred fillies which had been treadmill trained for 18 months (DXA) and
- The carpus of 2-year-old Thoroughbred fillies treadmill trained for 4.5 months (DXA), to determine responses to galloping
- BMD in carpus and distal third metacarpal bone (Mc3) of training track-trained Thoroughbred fillies (CT), to determine if track and treadmill training produce similar responses
- The distal limb of growing Thoroughbreds from 4 days of age using pQCT to non-invasively determine changes in growing foals at pasture.

Random Source Young Thoroughbreds at Pasture

Animals

Tissue was available from 34 animals aged 1–3 years: 18 were from a pasture nutrition study and the other 20 were presented at Massey University for necropsy, the indication for which did not involve the locomotor system.

Exercise Regimen

All animals were at pasture, either constantly, or if in training, for part of the day.

Bone Harvest and Scanning

At necropsy, the C3s were collected; from 24 animals both the left and right, and from the other 10 either the right or left bones were collected. A medial and lateral plane parallel sagittal slab was sawn from
each bone. The site of the slabs was defined by measuring the distance from the most dorsal aspect of the junction of C3/C2 to that of C3/C4; the medial border of a 6 mm thick medial and lateral slab was respectively 34% and 64% of this distance, measured from medial. For each slab, the thickness was measured in at least 4 sites with a sliding caliper, and the slab was scanned with a DXA scanner (Norland XR-26). The volumetric MD was calculated by dividing the surface BMD by the measured thickness of each slab.

Statistics
The difference between BMD in left and right limbs and between lateral and medial slabs was tested using a Student's t test, with the level of significance set at $p < 0.05$.

Treadmill Training for 18 Months

Animals
Six Thoroughbred fillies aged 21.3 ± 1.1 months (exercise group) were paired with six other fillies aged 20.7 ± 1.1 months (control group) on the basis of height, weight, and age. The experiment has been described in detail.

Exercise Regimen
The training protocol for the exercised group consisted of galloping on a high speed treadmill (Sato) three times weekly. This was combined with 10 min trotting on a mechanical horse walker three times weekly and walking exercise on a horse walker (40 min) for six days per week. The control animals were exercised at the walk only for 40 min daily for 6 days per week. The animals were euthanized 18 months after the study began.

Bone Harvest and Scanning
A sagittal slab was sawn from a constant site in the radial and lateral facets of C3 and in the radial carpal bone (Cr), directly opposite the C3 radial facet slab. The BMD scan of each slab was bisected in a proximo-distal direction to produce a dorsal and palmar region of interest (ROI).

Statistics
Analysis of variance was used to test the significance of differences in BMD between exercised and non-exercised horses. The paired t test was used to test differences between the C3 radial facet and Cr of each horse, and between ROI's within each bone. The level of significance was set at $p < 0.05$.

Track Training for 3 Months

Animals
Seven rising two-year-old Thoroughbred fillies were broken to saddle by a licensed trainer over a period of six weeks. Seven other fillies were confined in pasture pens 25 × 8 m, two to a pen (one animal was alone). The seven exercised horses were housed in stalls overnight, and in small dirt yards during the day.

Exercise Regimen
The trained horses were exercised six days a week, in the early morning. The distance and time worked every day were recorded. The exercise regimen consisted of 4 weeks slow cantering, 4 weeks fast cantering, followed by 4 weeks fast cantering with fast gallops superimposed twice weekly.

Tissue Harvest and Scanning
The left and right Mc3 and left Mt3 bones were scanned in a Siemens Somatom AR scanner. A 3 mm sagittal “slice” was taken from the lateral and medial condyles, the axial border being at the junction of the median sagittal ridge and the horizontal surface of the condyle. The carpus was scanned sagittally, 10 mm medial to a line passing through the junction of the radial and intermediate carpal bones. In Mc3 and Mt3 one ROI included most of the distal epiphysis, and another was a crescent 3–4 mm deep on the disto-palmar surface of the epiphysis. In the carpus, the ROIs were in cranio-distal radius, caudo-distal radius, dorsal Cr, C3, and Mc3. The average density values were recorded, and side, site, and exercise effects were analyzed by...
analysis of variance or Student’s t tests with significance set at p < 0.05.

Growing Thoroughbreds at Pasture

Animals
14 thoroughbred foals (6 colts, 8 fillies) raised on a research farm for digestibility trial work were weighed and condition scored at 2 weekly intervals.

Bone Scanning
Under injectable anesthesia, the foals were placed in lateral recumbency on several occasions between 4 and 133 days of age. The left forelimb was placed in the gantry of an axial pQCT scanner (XCT2000, Stratec, Pforzheim, Germany). Sites of scanning were diaphysis of proximal phalanx (P1), diaphysis of third metacarpal bone (Mc3), and epiphysis of Mc3.

Statistics
Preliminary data have been analyzed after grouping the observations into those with mean ages of 15, 45, 75, and 135 days of age. Each foal was scanned at least twice, but the spread of foal ages at the date of scanning meant that there were unequal age group sizes. To correct for this, foal identification was treated as a co-variant within the General Linear Model. Differences between effects (age group and sex) were examined using Tamhane’s Post Hoc test. The level of significance was set at p < 0.05.

Results
Random Source Young Thoroughbreds at Pasture
There was no significant difference between right and left C3 BMD. Across ages, the medial mean BMD was greater than that in the lateral facet (p = 0.019).

Treadmill Training for 18 Months
In non-exercised C3 radial facet slabs, BMD in the dorsal half of the bone was not significantly greater (p = 0.1) than in the palmar half, in exercised horses the difference becoming highly significant (p = 0.006), and the difference in Cr became even more significant (p = 0.003). Exercise resulted in a mean BMD increase of 22.1% in the dorsal half of the C3 slab (p = 0.006).

Treadmill Training for 4.5 Months
The BMD of exercised horses was significantly greater in dorsal regions of radius, Cr, C3 and Mc3, by up to 31%, and was evident in both slab radiographs and DXA scans (Fig. 1 shows radiographs since DXA scans do not reproduce satisfactorily).
Track Training for 3 Months

Most changes were of increased density, which in the Mc3 and Mt3 epiphysis of exercised horses extended from the palmaro-distal to the dorso-proximal surface, leaving an area of lesser density at the most dorso-distal aspect. In the bones of the carpus, the increased density after exercise was in the dorsal aspect. The density of the Mc3 epiphysis of the exercised group was 36.8% greater than that of the non-exercised group (p < 0.001). The subchondral bone density was significantly different between medial and lateral slices (p = 0.0038) in the right but not the left Mc3. For both the epiphysis and subchondral bone ROIs, there was a highly significant (p = 0.0001) effect of exercise on density. In the carpus there were clear differences between the exercise and control group tissue densities in the cranio-distal aspect of the radius (p < 0.01), dorsal aspect of Cr and C3 bones (p < 0.01 and p < 0.001, respectively), but not in the caudo-distal aspect, or in proximal Mc3.

Growing Thoroughbreds at Pasture

In P1 and Mc3 diaphyses, pairwise comparison showed that there was significant difference (p < 0.05) between the 15-day group and all other observations, but not between further successive measurements. In Mc3 epiphysis, increase in values was more linear, with significant increase between almost all age categories. The increase in palmar ROIs was more rapid than in the center of the epiphysis. Mean increases in BMD were up to approximately 52% between the 15 and 135 day age groups.

Discussion

The different number of bones used reveals technique development beginning with pilot studies in C3 of random source animals, and subsequent refinement of ROIs in the 18-month exercise study. Those findings produced the hypothesis for the 4.5-month study, in which radius and Mc3 were available, to determine if regional osteoinduction would be greater in the dorsal than in the palmar aspects of these bones too. In all cases, bone sites with a large proportion of cancellous bone were studied. This was because of the likelihood of greater responses being detected in cancellous than in cortical bone, the predisposition of the areas examined to chondro-osseous abnormality in equine athletes, and also as preparation for study of the relationship between changes in subchondral bone and articular cartilage.

In these first three studies, DXA was used to determine BMD, and relied on the preparation of plane parallel slabs of bone of known thickness, allowing volumetric mineral density to be determined. This was considered necessary in these initial studies of the use of DXA in horses, because effects of age and exercise on the mineral density could be studied without the confounding effect of change in bone size and shape.

The difference between individual random source New Zealand thoroughbreds was considerable (range 0.241–0.955 g/cm³). In the 18-month exercise study, exercise resulted in an increase of almost 30% in one site of C3. In the 4.5-month exercise study, increases of up to 31% were detected. Thus in all 3 studies, these differences between horses or treatments could easily be detected by the scanning technique, and indicate the potential for measurement and management of these changes. There seems little reason why the technique could not be applied to follow BMD changes in a given horse with time, although these would be changes in surface (area) BMD. This requires standardization of views to be taken, recognition of the shape features of the bone(s) chosen, and knowledge of age-related size increase (in the bone dimension parallel to the radiographic beam). Therefore it may be difficult to routinely use DXA in growing animals. In any case, it is difficult to take other than lateral views, because of the difficulty of placing the horse in any other stance except lateral to the x-ray beam.

In the fourth study, a conventional CT scanner was used. Although this study could explore this technology using only excised tissue, such CT scanning of the distal limb is perfectly possible in vivo. However, capital and maintenance costs are still high, the patient requires general anesthesia, and the machines are not portable, requiring transport of animals to the machine itself. These are all disadvantages to routine use.

The results from the fourth study showed that a conventional Australasian training regimen resulted in changes in bone which were similar in extent and site to those found after treadmill training. The similarity of these increases in the same area of C3 show that much of the osteoinductive response occurs within a few months of initiation of exercise. The gait, speed, exercise surface, or amount of exercise (within the total exercise given) which induced the bone response could not be determined from these studies.

In the final study, which is still proceeding, variation in mineral density was greatest in the first age group, which actually had the narrowest age range. Variation was much lower in older age groupings.

The scanner used is portable, and provides accurate measures of bone mineral, cross-sectional shape, and size. The animal must still be anesthetized for safe use. Further study will define the optimal scan sites, exact time and extent of bone response, and the significance of the changes. At that stage it will be possible to better define the site and minimum number of images required for accurate bone mineral quantification in the standing horse. If this leads to short scan times, and if the technology can be altered suitably, the need for anesthesia may be avoided.
References


