Chapter 5. Dietary Carbohydrates and Fat Influence Radiographic Bone Mineral Content of Growing Foals

ABSTRACT

Hydrolyzable carbohydrate in horse diets may become excessive when rapidly growing pastures are supplemented with grain-based concentrates. The substitution of fat and fiber for hydrolyzable carbohydrate has certain advantages but may decrease the availabilities of dietary calcium and magnesium. Our objective was to compare bone development in foals fed pasture and concentrates rich in sugar and starch or fat and fiber. Forty foals were examined, twenty each in 1994 and 1995. In each year, ten mares and their foals were fed a corn and molasses supplement (SS) and ten a corn oil and fiber supplement (FF). The concentrates were formulated to be isocaloric and isonitrogenous, with mineral contents balanced to complement the pastures and meet or exceed NRC requirements. Anterioposterior radiographs were taken of the left third metacarpal, and bone mineral content was estimated using imaging software and an 11-step aluminum stepwedge. Bone mineral content was lower in weanlings and yearlings fed the FF supplement than those fed SS. Leg evaluations by standardized examinations indicated differences in physitis, joint effusion, angular and flexural limb deformities in response to age, or possibly season, but not diet. Horses consuming diets containing fat and fiber, which tend to capture cations, may require increased dietary calcium.

Key Words: Radiographic Photometry, Bone, Developmental Orthopedic Disease.

Introduction

Hydrolyzable and rapidly fermentable carbohydrates have been implicated as etiologic factors in colic, laminitis, and developmental orthopedic disease (Sprouse et al., 1987; Clarke et al., 1990; Kronfeld et al., 1990). Hydrolyzable carbohydrate concentrations in horse diets may become excessive when rapidly growing pastures are supplemented with concentrates containing corn and molasses. The substitution of fat and fiber for hydrolyzable carbohydrates has been explored in nutrition for the exercising horse and the growing horse (Potter et al., 1992; Kronfeld, 1996). Fat may decrease availability of dietary calcium and magnesium by the formation of calcium and magnesium soaps (Palmquist et al., 1986). Fiber may bind divalent cations through cation exchange and water holding capacity (Allen et al., 1985). Our objective was to compare growth and bone development, using a radiographic photometry technique (Ott et al., 1987) and standardized leg scores, in foals fed pasture and supplemented with concentrates rich in sugar and starch or in fat and fiber.

Materials and Methods

The research was conducted at the Virginia Tech Middleburg Agricultural Research and Extension (MARE) Center in 1994 to 1996. Twenty mares with foals were kept each year on mixed bluegrass/clover pasture. Twenty mares were used in 1994, but ten of the twenty were replaced for the second year, due to them being aged or reproductively inefficient. In each year, ten mares and their foals were fed a corn grain and molasses supplement (SS) and ten a corn oil and fiber (beet pulp, soybean hulls, oat straw) supplement (FF). The supplements were formulated to be isocaloric and isonitrogenous (Table 5.1), and their mineral contents were balanced with the pastures to meet or exceed 1.4 times requirements (NRC, 1989). Samples of the supplements and pastures were analyzed by the Northeast DHIA Forage Testing Laboratory (Ithaca, NY). The mares and foals were fed in pans on the ground so that both had access to the supplement. The foals were weaned in late October/early November, at 5 to 7 mo of age. Anhelmintic, vaccination and hoof care procedures followed routine protocols of the MARE Center (Ley et al., 1992).

Anterioposterior radiographs of the left third metacarpal of the 1994 and 1995 foals were taken using a high frequency portable x-ray unit (MinXRay HF-80, MinXRay Inc., North Brook, IL). Radiographs of the 1994 foals were taken (80 KV, .6 mas, 66 cm focal distance) every second month, beginning in September 1994, and ending in May 1995. Radiographs of the 1995 foals were taken (80 KV, .4 mas, 66 cm focal distance) every month beginning in May 1995 until August, and then taken (80 KV, .6 mas, 66 cm focal distance) every second month from September until May 1996. An 11-step aluminum stepwedge (Atomic Products Corp., Atom Lab Div. Center, Moriches, NY) was taped to each cassette (Kodak X-Osmotic with lanex screen, Eastman Kodak, Rochester, NY) and exposed simultaneously in each radiograph as a reference standard. Films (Kodak X-Osmotic film, Eastman Kodak, Rochester, NY) were developed using an automatic processor (Kodak RP X-Omat processor, Model M6AW, Eastman Kodak, Rochester, NY).

At the same times, legs were evaluated for physitis, joint effusion, flexural and angular limb deformities using standardized subjective scores (Tables 5.2–5.5) made by an observer unaware of the dietary treatments.

Bone density of the foals was estimated using a digital camera (CCD72, DAGE-MTI, Michigan City, IN) which transferred images of the films to imaging software (Image-Pro Plus for Windows, Ver. 1.2, Media Cybernetics, Silver Spring, MD). For each film, a calibration curve was developed using the 11-step standard. Three sites within a 2 cm section on each metacarpal were evaluated, at the nutrient foramen, one centimeter above and one centimeter below the nutrient foramen. Radiographic bone aluminum equivalents (RBAE) were recorded for the point of greatest density on the medial and lateral aspects of the bone, and the point of least density ("midpoint") in the medullary cavity. The relationship between bone cross section and RBAE is shown in Figure 5.1 (adapted from Meakim et al., 1981). Bone width, medullary width, and bone and medullary areas were also recorded. The data from the three sites within the 2 cm section were averaged, and estimated bone mineral content (BMC) was calculated from RBAE using the following equations derived by Ott et al. (1987):

Medial peak BMC, g/2 cm section = .87 * RBAE – 2.35 r = .92

Midpoint BMC, g/2 cm section = .98 * RBAE – 1.47 r = .93

Lateral peak BMC, g/2 cm section = .93 * RBAE – 2.86 r = .93

Data were summarized as least squares means and standard errors. Analysis of variance was used to evaluate effects of diets, sampling times and their interaction (SAS 1988).

Results

Fiber and fat were 200 and 400% higher, respectively, and NSC was 77% lower in the FF supplement than the SS supplement (Table 5.6). Although the diets were formulated to have equal mineral content (Table 5.1), laboratory analysis indicated some differences between diets (Table 5.6). However, of the minerals which may have influenced lower bone mineral content, calcium and magnesium in particular were higher in concentration in the FF diet.

The BMC data in the 1994 foals are summarized in Figure 5.1, the 1995 foals in Figure 5.2, and the 1994 and 1995 foals combined in Figure 5.3. The foals fed the FF supplement exhibited lower estimated bone mineral content which first became noticeable in November of the foals' first year of life (5 to 7 mo of age), after weaning. The BMC of the foals in the FF group, as compared to the SS foals, were consistently lower through March of their yearling year (9 to 11 mo of age), but then ceased to differ by May. In May 1995, the SS yearlings had a decrease in BMC that was not evident in May 1996.

Standardized subjective evaluations for physitis, joint effusion, angular and flexural limb deformities are summarized for the 1994 foals in Figures 5.4 and 5.5, and for the 1995 foals in Figures 5.6 and 5.7. Over time, physitis increased until January for the carpus and hind fetlocks, and until May in the front fetlocks. Joint effusion peaked largely in January, and to a lesser degree, in March, but was nearly nonexistent in other months. Flexural deformities were more prevalent near the time of birth, around September, and the following March, with low scores in July, January and in yearlings in May. Angular limb deformities were more prevalent near time of birth, decreased from July to November, increased again slightly until January and decreased by the following May. For the 1994 foals, the standardized evaluations indicated more hind fetlock physitis and less angular limb deformities in the SS group, as compared to the FF group, but these differences were not apparent in the foals born in 1995.

Discussion

The lower BMC in weanlings and yearlings fed the FF supplement suggests that the availability of calcium may have been decreased through the formation of calcium soaps with fat (Palmquist et al., 1986), or through cation exchange and the water holding capacity of fiber (Allen et al., 1985). The higher iron concentration in the FF diet also may have interfered with calcium absorption.

Other factors may have also influenced BMC of the FF supplemented weanlings and yearlings. Incidental observation indicated that the FF horses were more quiet and manageable, and they may have been less spontaneously active in the pasture, although activity was not quantified. In another study, horses fed a fat-supplemented diet has less spontaneous activity in the field, measured by pedometers (Holland et al., 1996). If the FF supplemented horses in this study were less active on a daily basis, then decreased load on their bones could have contributed to lower BMC.

Metabolic and hormonal changes associated with the feeding-fasting cycle are noted primarily in meal feeding animals and not so much in the grazing horse. However, the supplementation of starchy grains provided in meals to the horse may initiate the feeding-fasting cycle. During the fed state, glucose and insulin increase, while free fatty acids, growth hormone and IGF-I, and perhaps thyroid hormone, decrease. During fasting, free fatty acids, growth hormone, IGF-I and thyroid hormone increase, while glucose and insulin decrease. The feeding-fasting cycle may have been more marked in the SS supplemented horses, compared to those receiving the FF supplement. Exaggerated changes in the feeding-fasting cycle of the SS supplemented horses may have caused hormone interactions which may have influenced BMC.

The process of bone formation is influenced by a number of hormones and other factors, including growth hormone, insulin-like growth factors (IGF), insulin, thyroid hormone, vitamin D, calcitonin and parathyroid hormone (Reddi and Sullivan, 1980; Spencer, 1989; Caplan and Boyan, 1994). Insulin-like growth factors, produced mainly by osteoblasts, osteocytes and bone marrow stromal cells, mediate the growth-promoting effect of growth hormone on bone in an autocrine or paracrine manner (Rosen et al., 1994). Insulin, thyroxine, parathyroid hormone, vitamin D_3, estrogens and corticosteroids also interact with IGFs.

The decrease in BMC in the SS supplemented yearlings noted in May of 1995 (Figure 5.2) corresponded with a spring slump in the growth rates in the SS but not the FF group, as evidenced by body weight and condition score (Hoffman et al., 1996).

The decrease in BMC in the SS yearlings was not noted in May, 1996 (Figure 5.3), but these yearlings did not exhibit differences in spring growth rates in response to dietary supplement.

Estimated BMC was lower in January for the 1994 foals but only tended to be lower in January for the 1995 foals. This decrease may be due to seasonal differences during which twice daily routine observations indicated decreased activity of the yearlings in the snow and ice covered pastures. The decrease in BMC may have been due to decreased load on the yearlings bones associated with decreased activity during this time.

The differences in BMC as noted in this study, though temporary, should be considered when managing growing horses. Breaking load, the force required to break the bone, was positively correlated with BMC (r^2 = .92; $P < .001$) of horses (Lawrence et al., 1994). Breaking strength, which assesses material strength or bone quality, was correlated with BMC (r^2 = .84; $P < .001$) of horses, and elasticity and BMC was also correlated (r^2 = .79; $P < .001$). The lower BMC in the FF supplemented weanlings and yearlings may have compromised breaking load, breaking strength or elasticity.

The differences in leg evaluations over time corresponded with season and perhaps changes in intake and growth. Physitis in all joints generally increased from birth until weaning, decreased somewhat in November after weaning and then increased again as the yearlings began to consume increased amounts of feed and new pasture growth. Joint effusion peaked in January, during the season in which the ground was the hardest.

An increased incidence of flexural deformities was noted near birth. Flexural limb deformities, commonly known as contracted tendons, may be congenital or acquired. Foals may be born with a flexural deformity as a result of uterine position, viral infection, or a plant toxin consumed by the mare. Acquired flexural limb deformities have been associated with orthopedic pain (Bramlage, 1987). “Contracted tendons” may be due to a shortening of the muscle, not the tendon. Affected foals alter their gait by walking on their toes in effort to alleviate joint pain, and eventually the tendon-muscle unit readjusts and shortens to the new position. Flexural deformities were noted in horses allowed ad libitum access to a pelleted forage diet or a pellet containing 62% concentrate (Cymbaluk , 1989). In this study, the increase in flexural deformities in September may have been due to intakes of the foals which were nursing, grazing and consuming approximately 1 kg of the rations each day. The subsequent decrease in November and January corresponds with weaning and consumption of hay in the winter. The final increase in flexural deformities in the yearlings in March may have been due to increased energy intake associated with rapidly growing pasture.

Implications

Differences in energy source of concentrates fed in supplement to pasture may influence metacarpal BMC in growing horses. Horses consuming diets containing fat, which tends to form calcium soaps, and fiber, which tends to capture cations, may have an increased requirement of calcium and other minerals.

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Table 5.1. Nutrient profile of the supplements and pasture fed to the mares, foals, weanlings and yearlings. Data are summarized as fed[a] for supplements and on a dry matter basis as a 90% confidence interval for pasture.

Nutrient	SS	FF	Pastures (n = 38)
DE, Mcal/kg	3.00	2.98	2.20 – 3.38
CP, %	14.6	15.3	16.5 – 29.5
ADF, %	7.2	22.8	20.3 – 35.6
NDF, %	12.6	34.0	36.5 – 60.0
Fat, %	2.3	12.2	2.7 – 5.6
NSC, %	63	25	6.1 – 23.9
Ca, %	.93	.95	.36 – 1.04
P, %	.57	.56	.26 – .46
Fe, mg/kg	150	150	0 – 1845
Zn, mg/kg	192	192	16.8 – 60.0
Cu, mg/kg	60	60	0 – 63.2
Mn, mg/kg	192	192	51.8 – 124.6
Se, mg/kg	.6	.6	< .08
I, mg/kg	.6	.6	< .08

[a]Calculated using NRC (1989) tables.

Table 5.2. Standardized subjective scores for the evaluation of physitis.

Physitis	Score	Description
None	0	No swelling.
Mild	1	Mild swelling at physis, no lameness.
Moderate	2	Moderate swelling at physis, noted “ridge,” no lameness.
Severe	3	Extreme swelling at physis, lameness attributable to condition.
Symmetrical	+0	Swelling at physis is symmetrical to medial and lateral sides; add 0 to mild, moderate, severe score.
Asymmetrical	+.5	Swelling at physis is asymmetrical to medial and lateral sides, (most commonly more swelling on medial side compared to lateral); add .5 to mild, moderate, severe score.

The score for the carpi is a combined score from both the L and R carpus; likewise, scores were combined for a final front fetlock score and a hind fetlock score.

Table 5.3. Standardized subjective scores for the evaluation of joint effustion.

Joint Effusion	Score	Description
None	0	No joint effusion.
Mild	1	Palpable increase in joint fluid.
Moderate	2	Visible increase in joint fluid, able to easily indent capsule.
Severe	3	Easily visible increase in joint fluid and joint capsule tense.

The scores from all joints (carpi, fetlocks, tibio-tarsals, and stifles) were combined for a final joint effusion score.

Table 5.4. Standardized subjective scores for the evaluation of angular limb deformities.

Angular Limb Deformity	Score	Description
None	0	No angulation.
Mild	1	Mild angulation, less than 8 degrees.
Moderate	2	Moderate angulation, greater than 8 and less than 12 degrees.
Severe	3	Extreme angulation, greater than 12 degrees.

Angular limb deformities were evaluated in the front legs at the forearm-cannon angle and the cannon-fetlock angle. These scores were combined for a final angular limb deformity score.

Table 5.5. Standardized subjective scores for the evaluation of flexural contraction.

Flexural Contraction	Score	Description
Hoof-pastern angle		
None	0	No alteration in angle beyond normal.
Mild	1	Slight alteration in hoof-pastern axis.
Moderate	2	Hoof wall near vertical.
Severe	3	Unable to place heel, walking on toe.
Pastern-Cannon angle		
None	0	No alteration in angle beyond normal.
Mild	1	Pastern-cannon angle decreased.
Moderate	2	Straight joint.
Severe	3	Unable to straighten joint.
Cannon-Forearm angle		
None	0	No alteration in angle beyond normal.
Mild	1	Slightly over at the knee.
Moderate	2	Moderately over at the knee.
Severe	3	Unable to bear weight easily.

Scores were combined from all above angles for a final flexural contraction score.

Table 5.6. Nutrient profile of the supplements and pasture, fed to mares, foals, weanlings and yearlings, as analyzed by the Northeast DHIA Forage Testing Laboratory (Ithaca, NY). Data are summarized on a dry matter basis as means ± SE for supplements and as a 90% confidence interval for pasture.

Nutrient	SS (n = 10)	FF (n = 15)	Pastures (n = 38)
DM, %	90.0 ± 0.36[a]	91.7 ± 0.30[b]	15.7 – 36.5
DE, MJ/kg	14.7 ± 0.2[a]	10.8 ± 0.1[b]	9.2 – 14.1
CP, %	15.0 ± 0.6	14.6 ± 0.5	16.5 – 29.5
ADF, %	9.1 ± 0.8[a]	28.3 ± 0.64[b]	20.3 – 35.6
NDF, %	15.3 ± 1.2[a]	41.2 ± 1.0[b]	36.5 – 60.0
Fat, %	2.4 ± 0.7[a]	10.4 ± 0.6[b]	2.7 – 5.6
NSC, %	62.4 ± 0.8[a]	26.5 ± 0.7[b]	6.1 – 23.9
Ash, %	4.9 ± 0.3[a]	7.2 ± 0.3[b]	7.35 – 12.82
Ca, %	0.77 ± 0.08[c]	1.01 ± 0.07[d]	0.36 – 1.04
P, %	0.45 ± 0.03	0.48 ± 0.03	0.26 – 0.46
Mg, %	0.17 ± 0.01[a]	0.23 ± 0.01[b]	0.18 – 0.27
K, %	0.98 ± 0.04[a]	1.30 ± 0.04[b]	1.93 – 3.72
Na, %	.20 ± .02	0.20 ± 0.01	0 – 0.035
S, %	0.17 ± 0.01[a]	0.20 ± 0.01[b]	0.16 – 0.39
Fe, mg/kg	191 ± 31[a]	485 ± 26[b]	0 – 1845
Zn, mg/kg	93.7 ± 7.1	101 ± 6.0	16.8 – 60.0
Cu, mg/kg	41.4 ± 5.2[c]	65.2 ± 4.4[d]	0 – 63.2
Mn, mg/kg	35.6 ± 3.0[a]	59.2 ± 2.5[b]	51.8 – 124.6
Se, mg/kg	0.6[e]	0.6[e]	< 0.08
I, mg/kg	0.6[e]	0.6[e]	< 0.08

[a,b]Values with subscripts c,d are different (P < 0.001).
[c,d]Values with subscripts e,f are different (P < 0.05)
[e] Calculated using NRC (1989) tables.