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THE INFLUENCE OF HIGH PLANES OF NUTRITION ON SKELETAL GROWTH AND DEVELOPMENT OF WEANLING HORSES[1]

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ABSTRACT

Effects of high dietary levels of energy, protein and Ca and deficient levels of Ca on skeletal growth and development in the equine were studied in two experiments. The weanlings were fed grain-based diets. In Exp. 1, Group 1 (Ctl) received all nutrients at NRC recommended levels for growth; Group 2 (HE) received 150% of their digestible energy (DE) requirement; Group 3 (LC) received 150% of DE and 35% of Ca requirements. In Exp. 2, Group 1 (Ctl) again received all nutrients at NRC recommended levels for growth; Group 2 (HEP) received 150% of DE and 275% of CP requirements; Group 3 (HEPC) received 150% of DE, 275% of CP and 500% of Ca requirements. In addition, all groups had access to pasture. The HE treatment resulted in greater ($P < .10$) increases in BW and total cortical width. However, LC weanlings had lower ($P < .10$) gains in third metacarpal length and radiographic bone density. Cumulative increases in BW and wither height were greater ($P < .10$) for the HEP and HEPC weanlings than for the Ctl weanlings. Increases in third metatarsal length also were greater ($P < .10$) for HEP weanlings than for Ctl weanlings. Higher planes of nutrition increased body weight gains and growth rate of several long bones. However, skeletal development (e.g., cortical area) may be compromised by a high rate of growth.

(Key Words: Plane of Nutrition, Skeleton Development, Horses.)

Introduction

Relatively little is known about nutrient requirements for growth and development in the equine. The NRC (1978) recommendations for growth of horses are based largely on research conducted 15 to 20 yr ago. Due to marketing pressure, rapid growth rates are desired, and nutrient requirements for different stages and levels of growth are needed.

From conception to maturity, the equine is growing and developing constantly and requires adequate amounts of nutrients. During the postweaning period, nutrient deficiencies can lead to inadequate growth, and improper feeding practices have been shown to compromise skeletal development (Krook and Lowe, 1964; Olsson, 1978; Lewis, 1979; Hintz and Kallfelz, 1981). Optimal amounts and ratios of energy, protein, Ca and P are required for proper bone, cartilage and muscle formation. Dietary deficiencies and(or) nutrient imbalances decrease weight and height gains, and may contribute to subsequent bone anomalies (Krook and Lowe, 1964; Pulse, 1973; Ott et al., 1979; Meakim et al., 1981a). Excessive dietary levels of protein (Yoakam et al., 1978; Meakim et al., 1981a) and Ca (Whitlock et al., 1970; Schryver et al., 1974; Jordan et al., 1975) have not been shown to have detrimental effects on growth or bone development. However, Glade and Belling (1984) reported that high dietary levels of energy and protein can stimulate the onset of osteochondrosis. Thus, research is needed on different levels of growth and nutrient relationships that may influence quantity and quality of growth.

The objective of this research was to determine the effect of high intakes of energy, protein and Ca on growth and skeletal development of weanling horses.

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Experimental Procedure

Thirty foals of Thoroughbred and Quarter Horse breeding that had been used in a creep-feeding study and weaned at 130 d of age were used in two experiments to measure the effects of high dietary protein, energy and Ca intakes on growth and development.

Experiment 1. Twelve weanlings of mixed breeding, blocked according to sex and preweaning feeding regimen, were randomly assigned to one of three dietary treatments. Each group contained four horses and received a grain-based concentrate mix that was formulated based on NRC (1978) recommendations for that proportion of the DM to be supplied by the concentrate. Therefore, each group received a nutrient level in the concentrate mix according to standard diet proportions of 70% concentrate and 30% forage. Daily nutrient intake was manipulated by adjusting the amount of concentrate mix fed. Forage intake was provided by a grass-legume mixed hay and by free-choice access to a bluegrass-clover mixed pasture. Forage intake was not measured, but the nutrient composition of the pasture was expected to be similar to tabular values (NRC, 1978) for early grazed bluegrass and red clover. Group 1 (Ctl) was fed a concentrate mix that supplied 100% of NRC (1978) recommendations for digestible energy (DE), CP and Ca for growth (Table 1). Group 2 (HE) received a high-energy diet that supplied 150% of the DE requirement. Group 3 (LC) received a high-energy, low-Ca diet that supplied 150% of DE but only 35% of the Ca requirement. Digestible energy intake was increased by increasing the amount of the concentrate mix fed each day. All other nutrients were fed at recommended levels for growth of foals at 130 d of age. Each group was maintained in separate 1.5-ha lots and group-fed twice daily. All weanlings were vaccinated for tetanus and dewormed at 90-d intervals. Initial measurements of BW, wither height (WH), third metacarpal length (McIII) and third metatarsal length (MtIII) were made when the weanlings were put on trial at 130 d of age and at 30-d intervals thereafter for 240 d. Dorsopalmar radiographs of the midpoint of the third meta-

TABLE 1. COMPOSITION AND CHEMICAL ANALYSES OF CONCENTRATES FED IN EXPERIMENTS 1 AND 2

Item	Diet in Exp. 1			Diet in Exp. 2		
	Ctl[a]	HE[a]	LC[a]	Ctl[a]	HEP[a]	HEPC[a]
	%					
Ingredient						
Cracked corn	29.0	33.5	34.2	29.0	20.0	20.0
Rolled oats	36.85	39.0	39.0	36.85	23.4	17.5
Soybean meal (44%)	14.0	8.0	8.0	14.0	38.0	39.0
Dried beet pulp	10.0	10.0	10.0	10.0	10.0	10.0
Molasses	8.0	8.0	8.0	8.0	8.0	8.0
Dicalcium phosphate	1.3	.6		1.3		
Limestone	.2	.1		.2	.1	4.0
Trace mineralized salt[b]	.5	.5	.5	.5	.5	.5
Lysine HCl	.15	.30	.30	.15		
Analyses						
DM, %	83.5	83.3	83.1	83.5	84.9	85.9
DE, Mcal/kg[cd]	3.57	3.62	3.65	3.57	3.52	3.37
CP, %[d]	17.7	15.4	15.4	17.7	30.8	30.0
Ca, %[d]	.70	.45	.20	.70	.44	2.50
P, %[d]	.75	.65	.40	.75	.44	.45

[a]Ctl = control; HE = high energy; LC = low Ca; HEP = high energy and protein; HEPC = high energy, protein and Ca.

[b]Premix provided 35 mg Zn, 34 mg Fe, 20 mg Mn, 3.3 mg Cu, .7 mg I and .5 mg Co per kilogram of concentrate.

[c]DE = digestible energy. Calculated from NRC (1978).

[d]Dry matter basis.

carpal were taken initially at 130 d of age and at 60-d intervals thereafter, using methods described by Meakim et al. (1981b) for an estimate of bone mineral content (RBD) expressed as millimeters AL (mm AL). Measurements of cortical width (CW) were taken from the photometric tracing, and cortical area (%CA) was calculated using methods of Thompson et al. (1988).

Each treatment diet was mixed and samples were collected bi-weekly, frozen at −34°C and later composited by month for analysis. Samples were analyzed at the initiation and completion of the experiment. Feed samples were analyzed for DM and CP contents according to AOAC (1980) procedures. Digestible energy was estimated using tabular values for feed ingredients (NRC, 1978). The Ca analysis was conducted by atomic absorption spectrophotometry, and P was determined by an autoanalyzer procedure as described by AOAC (1980).

Data were analyzed by variance procedures for a repeated measures design. The whole plot was the treatment group, and time was the repeated measures variable. Animal variation was used as the error term for the whole plot. Differences due to time and interaction of treatment × time were tested using the error term of animal within treatment × preweaning treatment. The least significant difference procedure (SAS, 1985) was used to test differences between treatment means.

Experiment 2. Eighteen weanlings of mixed breeding were blocked according to sex and preweaning treatment and randomly assigned to one of three dietary treatments. Each group contained six weanlings; however, during the trial, one animal was removed from Group 3 due to a digital tendon contracture; data from that animal were deleted. Diets were formulated as for Exp. 1. Group 1 (Ctl) was fed a concentrate that supplied 100% of NRC (1978) recommendations for growth (Table 1). Group 2 (HEP) received a high-energy, high-protein diet that supplied 150% of DE and 275% of CP requirements. Group 3 (HEPC) received a high-energy, high-protein, high-Ca concentrate that supplied 150% of DE, 275% of CP and 500% of Ca requirements. As in Exp. 1, DE intake was increased by increasing the amount of concentrate mix fed. All other nutrients were fed at recommended levels for growth of foals at 130 d of age. The methods used in Exp. 2 were identical to those described for Exp. 1 except for the ration formulation described above.

Results and Discussion

Experiment 1. The average DM intake from concentrate was greater for the weanlings receiving both of the high-energy diets (HE, LC), than for those receiving the Ctl diet (Table 2). The higher DM intake increased intake of CP slightly for both the HE and LC groups compared with weanlings receiving the Ctl. Although the difference in intakes of CP was low, it is suggested that a growth response may have been due in part to CP and not to DE intake. The calculated daily DE intakes from concentrates were 50% higher for those weanlings receiving HE and LC diets than for the Ctl weanlings. This resulted in CP:DE ratios for the concentrate mix of 42.5 and 42.3 g CP/Mcal

TABLE 2. INFLUENCE OF NUTRIENT CONTENT OF CONCENTRATE ON DAILY NUTRIENT INTAKE OF WEANLING HORSES (EXP. 1)

	Diet		
Item	Ctl[a]	HE[a]	LC[a]
DM, kg/100 kg BW	1.41	2.08	2.08
CP, kg/100 kg BW	.25	.32	.32
DE, Mcal/100 kg BW[b]	5.04	7.53	7.57
Ca, g/100 kg BW	10.0	9.3	4.5
P, g/100 kg BW	10.5	13.4	8.3
CP, g/Mcal DE	49.6	42.5	42.3
Ca, g/Mcal DE	2.0	1.2	.6

[a]Ctl = control; HE = high energy; LC = low Ca.

[b]DE = digestible energy. Calculated from NRC (1978) table values.

DE for the HE and LC diets, respectively, compared with the suggested ratio of 49.6 for the Ctl group (Table 2). The Ca intakes were similar for the Ctl and HE groups, whereas the LC group received approximately 50% less. Due to an unexpectedly high content of P in the grain, Ca:P ratios in the concentrate mix ranged from .9:1 to .5:1. These inverted ratios are not desirable; however, Schryver et al. (1974) reported that if the Ca level is adequate a ratio as low as .5:1 did not affect bone growth and development. These nutrient intakes represent those from the concentrate mix alone; forage intake may have corrected this imbalance. When mature horses were allowed ad libitum access to pasture, Cantillon (1986) reported that the horses consumed 1.8% of BW in pasture. Ratios of Ca: DE in the concentrate mix were 2.0, 1.2 and .6 g Ca/Mcal DE for the Ctl, HE and LC groups, respectively.

When the experiment began, mean BW of the Ctl, HE and LC groups were 192.5, 201.4 and 196.9 kg, respectively. As shown in Table 3, the weanlings receiving the HE diet gained more ($P < .10$) BW than those receiving the Ctl or LC diets, although gains made by the LC weanlings did not differ ($P > .10$) from those made by the Ctl weanlings. Each group gained faster during the early and late parts of the experiment than during the middle portion. Presumably, cold temperatures depressed daily gains during the winter months and nutrient composition and(or) availability of pasture improved during the last two periods of the experiment.

Initial WH for all groups were similar, the Ctl, HE and LC weanlings averaged 126.3, 126.2 and 126.9 cm, respectively. Cumulative increases in WH were numerically greater throughout the duration of the experiment for those weanlings receiving the Ctl diet than for the HE and LC weanlings (Table 3). Green (1969) and Hintz et al. (1979) reported rates of increase in WH similar to those we observed.

Initial values of McIII were 24.8, 24.9 and 25.0 cm for the Ctl, HE and LC weanlings, respectively. Cumulative increases in McIII were greater ($P < .10$) for the Ctl and HE weanlings than for the LC group (Table 4). An extrapolation of data reported by Fretz et al. (1984) showed an increase of 1.1 cm during a comparable period. The slower growth of the McIII by the LC weanlings may be attributed to the low level of Ca in the concentrate mix, which provided less dietary Ca than was required.

Initial values of MtIII were 28.5, 27.8 and 28.3 cm for the Ctl, HE and LC weanlings, respectively (Table 4). Increases for the HE group were numerically greater than, but not different ($P > .10$) from, those of the Ctl or LC weanlings.

Quality of bone development was assessed using measures of RBD (lateral and medial cortical peaks), CW and %CA. At the initiation of the experiment, the average lateral RBD values for the Ctl, HE and LC groups were 15.2, 15.0

TABLE 3. EFFECT OF HIGH ENERGY AND LOW CALCIUM INTAKES ON MEAN CUMULATIVE BODY WEIGHT (BW) AND WITHER HEIGHT (WH) GAINS (EXP. 1)

	BW, kg			WH, cm		
Age, d	Ctl[a]	HE[a]	LC[a]	Ctl[a]	HE[a]	LC[a]
130–160	25.6	29.5	21.7	3.9	2.7	2.9
130–190	47.1	53.2	41.2	6.6	4.8	5.5
130–220	66.8	76.5	59.7	8.4	7.8	7.9
130–250	78.1	93.2	74.2	10.3	10.0	9.3
130–280	90.6	103.9	88.2	12.3	12.1	11.1
130–310	99.9	125.1	105.9	14.1	13.3	12.4
130–340	111.7	141.8	122.0	15.3	14.4	14.1
130–370	130.4[b]	156.7[c]	144.8[b]	16.4	16.4	15.8
SE[d]	4.2	5.4	5.1	.6	1.8	.3

[a]Ctl = control; HE = high energy; LC = low Ca.

[b,c]Means in the same row within heading without a common superscript differ ($P < .10$).

[d]Standard error of 130–370 d mean.

TABLE 4. EFFECT OF HIGH ENERGY AND LOW CALCIUM INTAKES ON MEAN CUMULATIVE THIRD METACARPAL (McIII) AND THIRD METATARSAL (MtIII) GAINS (EXP. 1)

	McIII, cm			MtIII, cm		
Age, d	Ctl[a]	HE[a]	LC[a]	Ctl[a]	HE[a]	LC[a]
130–160	.35	.50	.33	.15	.0	.10
130–190	.52	.85	.40	.32	.32	.17
130–220	.92	1.07	.75	.40	.47	.25
130–250	1.05	1.12	.77	.52	.55	.42
130–280	1.12	1.37	.82	.57	.80	.55
130–310	1.13	1.52	.88	.65	1.22	.67
130–340	1.30	1.62	.97	.65	1.40	.72
130–370	1.50[b]	1.65[b]	.98[c]	.80	1.40	.73
SE[d]	.15	.18	.18	.25	.24	.20

[a]Ctl = control; HE = high energy; LC = low Ca.

[b,c]Means in the same row within heading without a common superscript differ ($P < .10$).

[d]Standard error of 130–370 d mean.

and 15.3 mm AL, respectively. Increases in lateral RBD for the Ctl and HE weanlings were greater ($P < .10$) than for the LC weanlings (Table 5). Initial values for medial RBD, 15.9, 16.0 and 15.9 mm AL, were similar. Average medial RBD cumulative increases for the LC weanlings were not different ($P > .10$) from the Ctl group, but were lower ($P < .10$) than for the HE weanlings. The CW was greater ($P < .10$) for the HE weanlings than for either the Ctl or LC weanlings (Table 6). This pattern also was observed by Kesel et al. (1983), who noted that CW varied as a function of body size in ad libitum-fed vs restricted-fed pigs. A trend favoring the Ctl over the HE weanlings was observed for %CA.

Experiment 2. Intakes of DM, CP and DE were greater for the weanlings receiving both the HEP and HEPC diets than for those receiving the Ctl diet (Table 7). Calcium intakes were similar for the Ctl and HEP groups at 10.0 g $\cdot$ 100 kg $BW^{-1} \cdot d^{-1}$ each, much lower than for the HEPC group (52.0 g $\cdot$ 100 kg $BW^{-1} \cdot d^{-1}$). The Ca:P ratio for the concentrate mix, approximately 1:1 for both the Ctl and HEP diets, was 5.5:1 for the HEPC diet. As in Exp. 1, forage intake presumably increased total dietary nutrient intake. The ratios of Ca:DE in the concentrate mix were 2.0 and 1.2 g Ca/Mcal DE for the Ctl and HEP diets compared with 7.4 g Ca/Mcal DE for the HEPC diet.

When the trial began, average BW were

TABLE 5. EFFECT OF HIGH ENERGY AND LOW CALCIUM INTAKES ON CUMULATIVE GAINS OF RADIOGRAPHIC BONE DENSITY (RBD) (LATERAL [l] AND MEDIAL [m] PEAKS) (EXP. 1)

	RBD l, mm Al			RBD m, mm Al		
Age, d	Ctl[a]	HE[a]	LC[a]	Ctl[a]	HE[a]	LC[a]
130–190	.2	–.1	–.4	.1	.4	–.6
130–250	.7	.2	–.4	.3	.7	–.5
130–310	1.5	1.3	.5	1.0	1.4	.3
130–370	2.4[b]	2.5[b]	1.7[c]	2.2[b]	2.5[c]	1.9[b]
SE[d]	.97	.63	.36	1.01	.74	.62

[a]Ctl = control; HE = high energy; LC = low Ca.

[b,c]Means in the same row within heading without a common superscript differ ($P < .10$).

[d]Standard error of 130–370 d mean.

TABLE 6. EFFECT OF HIGH ENERGY AND LOW CALCIUM INTAKES ON TOTAL CORTICAL WIDTH (CW) AND CORTICAL AREA (%CA) OF THE THIRD METACARPAL (EXP. 1)

Age, d	CW, mm			%CA (percentage of CW)		
	Ctl[a]	HE[a]	LC[a]	Ctl[a]	HE[a]	LC[a]
130	31.0	33.5	32.5	37.1	38.2	40.1
190	34.1	35.1	35.1	42.3	40.7	47.5
250	34.6	36.9	35.5	45.3	44.6	46.1
310	35.8	39.7	36.9	48.0	46.0	46.1
370	36.7[b]	40.4[c]	37.9[b]	48.2	46.7	46.9
SE[d]	.55	1.06	.53	.85	1.1	.82

[a]Ctl = control; HE = high energy; LC = low Ca.

[b,c]Means in the same row within heading without a common superscript differ ($P < .10$).

[d]Standard error of 370 d mean.

224.5, 234.0 and 221.9 kg for the Ctl, HEP and HEPC weanlings, respectively. The cumulative BW gains were greater ($P < .10$) for the weanlings receiving the HEP and HEPC diets than for the Ctl (Table 8). Weight gains in this experiment were greater than those made in Exp. 1 and gains reported by Hintz et al. (1979). There was 25 cm less rainfall in the summer of Exp. 1 than of Exp. 2, so pasture growth was more limited during Exp. 1.

Increases in WH were greater ($P < .10$) for both the HEP and HEPC weanlings than for the Ctl group (Table 8). Initial WH were 128.0, 128.6 and 129.5 cm for the Ctl, HEP and HEPC weanlings, respectively. Increases in WH were greater than those reported by Hintz et al. (1979) and by Green (1969) for similar periods. Increases in WH for the HEP and HEPC weanlings were much higher than for the Ctl weanlings early in the experiment, but this difference decreased as the trial progressed.

No differences ($P > .10$) were noted for increases in McIII (Table 9). Initial measurements of McIII were 25.3, 25.3 and 25.4 for the Ctl, HEP and HEPC weanlings, respectively, and cumulative gains tended to be numerically higher for weanlings in the HEP and HEPC groups. Increases by both high energy and protein groups generally were in agreement with the data reported by Fretz et al. (1984).

Initial measurements of MtIII were 28.6, 28.3 and 28.8 cm for the Ctl, HEP and HEPC weanlings, respectively. There was a treatment effect noted for average gains of MtIII; weanlings in the HEP group had greater ($P < .10$) increases than weanlings in the Ctl and HEPC groups (Table 9).

There were no differences ($P > .10$) due to

TABLE 7. INFLUENCE OF NUTRIENT CONTENT OF CONCENTRATE ON DAILY NUTRIENT INTAKE OF WEANLING HORSES (EXP. 2)

Item	Diet		
	Ctl[a]	HEP[a]	HEPC[a]
DM, kg/100 kg BW	1.41	2.26	2.08
CP, kg/100 kg BW	.25	.69	.63
DE, Mcal/100 kg BW[b]	5.06	7.95	7.03
Ca, g/100 kg BW	10.0	10.0	52.0
P, g/100 kg BW	10.6	9.8	9.4
CP, g/Mcal DE	49.4	86.8	89.6
Ca, g/Mcal DE	2.0	1.2	7.4

[a]Ctl = control; HEP = high energy and protein; HEPC = high energy, protein and Ca.

[b]DE = digestible energy. Calculated from NRC (1978) table values.

TABLE 8. EFFECT OF HIGH DIETARY INTAKES OF ENERGY, PROTEIN AND CALCIUM ON MEAN CUMULATIVE BODY WEIGHT (BW) AND WITHER HEIGHT (WH) GAINS (EXP. 2)

	BW, kg			WH, cm		
Age, d	Ctl[a]	HEP[a]	HEPC[a]	Ctl[a]	HEP[a]	HEPC[a]
130–160	24.4	35.9	27.9	2.2	3.2	2.9
130–190	50.1	57.2	55.1	5.1	6.0	5.9
130–220	63.3	76.5	73.8	7.1	8.6	8.5
130–250	83.7	98.5	91.1	8.6	11.3	10.4
130–280	96.8	120.7	107.5	11.2	12.9	12.3
130–310	110.8	140.7	126.5	12.8	15.0	14.8
130–340	130.4	157.4	147.9	15.0	16.7	15.7
130–370	162.6[b]	181.9[c]	176.2[c]	16.9[b]	18.3[c]	17.9[c]
SE[d]	9.4	8.2	9.8	.77	.86	1.07

[a]Ctl = control; HEP = high energy and protein; HEPC = high energy, protein and Ca.

[b,c]Means in the same row within heading without a common superscript differ ($P < .10$).

[d]Standard error of 130–370 d mean.

treatment for either lateral or medial RBD (Table 10). At the initiation of the trial lateral RBD values for Ctl, HEP and HEPC were 15.5, 15.2 and 15.2 mm AL. Increases in medial RBD values followed a pattern similar to lateral RBD. During the last 60 d of the experiment, RBD increased fastest. This was concurrent with a reduction in growth rate in length and width of the third metacarpal. This increase in bone density presumably was due to a reduction in rate of growth because Ca intake had not increased.

The CW tended to be greater ($P > .10$) for the high energy and protein groups (Table 11). No difference ($P > .10$) was noted for %CA; however, the high energy and protein groups had greater numerical increases in %CA than the Ctl group. The horses in the HEPC and HEP groups had greater protein:calorie ratios than those in Exp. 1, suggesting that these nutrients should remain in balance for proper skeletal development.

The results of these experiments indicate that skeletal development can be altered by high dietary levels of energy, protein and Ca, or by varying the nutrient:calorie ratio. In Exp. 1, the high intake of energy, without a concurrent increase in protein, may have caused protein to

TABLE 9. EFFECT OF HIGH DIETARY INTAKES OF ENERGY, PROTEIN AND CALCIUM ON MEAN CUMULATIVE THIRD METACARPAL (McIII) AND THIRD METATARSAL (MtIII) GAINS (EXP. 2)

	McIII, cm			MtIII, cm		
Age, d	Ctl[a]	HEP[a]	HEPC[a]	Ctl[a]	HEP[a]	HEPC[a]
130–160	.10	.16	.20	.28	.31	.16
130–190	.48	.26	.44	.28	.48	.20
130–220	.51	.51	.54	.33	.65	.28
130–250	.55	.61	.68	.50	.70	.38
130–280	.66	.68	.82	.50	.75	.48
130–310	.76	.80	.86	.61	.91	.52
130–340	.78	.91	1.10	.63	.98	.54
130–370	.80	1.01	1.12	.66[b]	.98[c]	.54[b]
SE[d]	.19	.18	.22	.09	.10	.14

[a]Ctl = control; HEP = high energy and protein; HEPC = high energy, protein and Ca.

[b,c]Means in the same row within heading without a common superscript differ ($P < .10$).

[d]Standard error of 130–370 d mean.

TABLE 10. EFFECT OF HIGH ENERGY, PROTEIN AND CALCIUM INTAKES ON CUMULATIVE GAINS OF RADIOGRAPHIC BONE DENSITY (RBD) (LATERAL [l] AND MEDIAL [m] PEAKS) (EXP. 2)

	RBD l, mm AL			RBD m, mm AL		
Age, d	Ctl[a]	HEP[a]	HEPC[a]	Ctl[a]	HEP[a]	HEPC[a]
130–190	.1	.4	.5	.1	.6	.7
130–250	.5	1.0	.5	.4	.9	.7
130–310	1.2	1.3	.8	1.1	1.2	.9
130–370	2.1	2.4	2.4	2.2	2.5	2.6
SE[b]	.21	.17	.58	.29	.27	.78

[a]Ctl = control; HEP = high energy and protein; HEPC = high energy, protein and Ca.

[b]Standard error of 130–370 d mean.

limit bone formation. Although weight gain was stimulated by a high caloric intake, it had very little effect on skeletal growth. Ott et al. (1986) also reported no increase in WH or hip height in yearlings fed a concentrate mix ad libitum. Although high-energy intake led to a greater CW, the %CA was less. This was similar to results of Moser et al. (1982), who reported that the %CA was less for growing pigs fed high-energy diets. Lepine et al. (1985) and Kesel et al. (1983) compared ad libitum-fed with restricted-fed pigs and reported that ad libitum-fed pigs had a greater CW; however, when corrected for BW differences, the two groups did not differ.

A deficient level of Ca in the concentrate inhibited growth in length of bone and decreased bone mineral content as estimated by RBD. This was similar to previous observations of Doige et al. (1975) for pigs and Krook and Lowe (1964) for horses.

In Exp. 2, increased intakes of both energy and protein increased BW gain and skeletal growth. The increased protein:calorie ratio increased both WH and bone length above those of the Ctl group, which was fed at recommended (NRC, 1978) levels. This was similar to results reported by Ott et al. (1979), but in contrast to those reported by Yoakam et al. (1978) and Meakim et al. (1981a). In the latter studies, energy and protein intakes were lower than those of the present study; this may explain the differences in results. However, the increase in protein:calorie ratio did not enhance bone quality. This was similar to the results reported by Kesel et al. (1983) for ad libitum-fed pigs, and by Saville and Lieber (1969) for ad libitum-fed rats. The authors in the latter study con-

TABLE 11. EFFECT OF HIGH ENERGY, PROTEIN AND CALCIUM INTAKES ON TOTAL CORTICAL WIDTH (CW) AND CORTICAL AREA (%CA) OF THIRD METACRAPAL (EXP. 2)

	CW, mm			%CA (percentage of CW)		
Age, d	Ctl[a]	HEP[a]	HEPC[a]	Ctl[a]	HEP[a]	HEPC[a]
130	32.5	34.3	33.7	46.3	39.1	40.2
190	35.6	35.6	35.7	53.0	45.8	46.2
250	36.8	37.4	38.4	53.9	47.7	49.8
310	37.7	39.3	40.2	53.9	51.2	50.9
370	40.3	40.6	41.8	53.3	53.1	52.5
SE[b]	.49	.71	.69	.94	1.02	1.27

[a]Ctl = control; HEP = high energy and protein; HEPC = high energy, protein and Ca.

[b]Standard error of 370 d mean.

cluded that maximal weight gain is not compatible with optimal skeletal growth.

From the present study, we concluded that growth rate and skeletal development may be altered by manipulating feed intake and by protein:calorie ratio. High intakes of energy and protein elicited faster rates of growth in length of several bones in the horse. Additionally, the protein:calorie ratio of the concentrate mix was found to influence skeletal growth. When metacarpal cortical area was used as a measure of skeletal development, it appeared that high rates of growth or a low protein:calorie ratio compromised skeletal development, because cortical area tended to be lower in fast-growing animals. To maintain skeletal quality during rapid periods of growth, protein intake needs to be increased proportionally to energy intake. Further studies are needed to determine the levels and ratios required to produce optimal skeletal growth and development.

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