Effects of limited food consumption on the incidence of hip dysplasia in growing dogs

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Summary: *Forty-eight 8-week-old Labrador Retrievers were allotted to 2 groups of 24 dogs each; 1 group was fed ad libitum and the other group was given 25% less of the same feed until the dogs were 2 years old. Radiography of the hip joints was done when the dogs were 30, 42, 54, 78, and 104 weeks old. Subluxation was measured by the Norberg angle on radiographs made with the dog in the standard (extended limb) position. Independent of age at which the radiography was done, there was less subluxation of the femoral heads in the limit-fed dogs. Using the Swedish method of hip joint evaluation on the same radiographs, it was found that fewer dogs on limited food intake had signs of hip dysplasia.*

Radiographs done when dogs were 2 years old, for all the methods used (Norberg angle in standard and frog-limb position, the Orthopedic Foundation for Animals [OFA] score, and the Swedish score), revealed less hip dysplasia (less joint subluxation and less degenerative joint disease) in the limit-fed dogs. Using the OFA method, 7 of the 24 limit-fed dogs and 16 of the 24 ad libitum-fed dogs were diagnosed as having hip dysplasia. Similarly, using the Swedish method, 5 of the 24 limit-fed dogs and 18 of the 24 ad libitum-fed dogs were diagnosed as having hip dysplasia. The food-intake-related differences were significant both for the OFA score and for the Swedish score. There was a significant correlation between the Norberg angle measured on radiographs made with the dog in the standard position when it was 30 weeks old and the result obtained when the dog was 2 years old by the OFA and Swedish methods. The findings support the clinical recommendation to avoid overfeeding of growing dogs, particularly in breeds prone to canine hip dysplasia.

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Canine hip dysplasia (CHD), a developmental abnormality of the coxofemoral joint, has been shown to be hereditary, but the frequency and severity are influenced by environment.[1-4] Dogs that develop hip dysplasia are born with apparently normal hip joints, but after the dogs have reached a few weeks of age, joint laxity can be demonstrated at necropsy.[1,5,6] Estimates of heritability vary from 0.2 to 0.6, with phenotypic expression occurring along a continuum from normal to severely affected.[1,3,4,7,8] Phenotypic expression is recognized radiographically as femoral head subluxation, often followed by progressive degenerative joint disease. Femoral head subluxation is a static phenomenon that indicates a dynamic phenomenon, joint laxity. Only a joint with laxity will allow the femoral head to be subluxated.

Femoral head subluxation has pathologic consequences that include abnormal loading in weight bearing and remodeling of cartilage and bone. The end result of this self-perpetuating cycle of subluxation and remodeling is degenerative joint disease, characterized by joint cartilage erosion, synovitis, increased joint fluid, elongation and edema of the round ligament, thickening of the joint capsule, and osteophyte formation.[6,9]

The first report of a correlation of early rapid growth and weight gain to severity of CHD was published in 1964.[10] In a later study,[11] it was found that dogs delivered by cesarean section and that were hand reared at greatly reduced rates of growth had a low incidence of hip dysplasia, whereas 2 groups of naturally born and bitch-fed dogs, which grew optimally, had a high incidence. In a study of Great Danes,[12] it was shown that excessive intake of food accelerated growth thereby contributing to the development of hip dysplasia. In a study[13] of 31 dogs from 5 litters (2 of German Shepherds Dogs, 2 of Golden Retrievers, and 1 of Labrador Retrievers), with a high parental frequency of hip dysplasia, it was found that CHD was more frequent, developed earlier, and became more severe in dogs with rapid weight gain caused by increased caloric intake, compared with dogs with low weight gain because of restricted feeding.

During the last 3 decades, various organizations in many countries have introduced measures to control CHD.[14,15] Radiography is the accepted way to diagnose and to grade hip dysplasia. The criteria for hip evaluation differ somewhat between countries and are, to a certain extent, subjective. A more objective means to quantify subluxation (laxity) is the Norberg angle measurement used on pelvic radiographs with the dog in standard (extended limb) position. This measurement is a modification of a method introduced by Norberg and described by Olsson.[16] The modified Norberg method first mentioned in writing by Hickman[17] has been used for diagnosis[18-20] and as a research tool.[21-23]

The primary objectives of the 2-year study reported here were to examine the effects of limited food intake on subluxation of the femoral heads and the radiographic appearance of secondary changes, and to study the correlations among 4 methods of evaluating hip joint conformation in relation to femoral head subluxation on radiographs over time. The 4 methods used were the Norberg angle measurements (standard[17] and frog-limb position[16]), the hip scoring method used by the veterinary division of the Swedish Kennel Club,[14] and the hip scoring method used by the OFA for dogs when they are 2 years old.[15]

Materials and Methods

Dogs and housing—Forty-eight Labrador Retrievers from 7 litters were included in the investigation. Their family lines had a high prevalence of CHD. Using the OFA rating, both sires had normal hips, 3 dams had normal hips, 3 had dysplastic hips, and 1 dam had unknown hip rating. On the basis of our experience and previously published results, the expected incidence would be 26 to 51% dysplastic offspring.[24] The dogs were born during a 7-month period and were maintained at a research facility. The dogs were weaned when they were 6 weeks old. During the first 2 weeks after weaning, the dogs were copenned with littermates and were fed ad libitum. When the dogs were 8 to 16 weeks old, they were fed and housed individually in pens. After they reached 16 weeks of age, paired littermates were copenned in indoor/outdoor runs (approx 2 × 19 m) with concrete floors, but they were fed individually in feeding stalls.

Animal health and monitoring—Body weight, blood values, and blood serum chemical profiles, including electrolytes, were determined for all dogs when they were 6, 11, 16, 26, 30, 42, 54, 78, and 102 weeks old. Routine vaccinations and antiparasite drugs were administered.

Diet and feeding regimens—The term "diet" refers to the formulation of the feed presented to

Table 1—Mean composition of diet

Diet Component	No. of batches	Mean	SD
Metabolizable Energy (kcal/kg)		3,585*	
Moisture (%)	19	8.9	(0.7)
Protein (%)	19	27.5	(0.6)
Fat (%)	19	11.4	(0.6)
Fiber (%)	17	1.7	(0.3)
Ash (%)	17	5.9	(0.5)
Carbohydrate (%)	...	44.6*	...
Calcium (%)	19	1.36	(0.22)
Phosphorus (%)	19	0.99	(0.07)
Sodium (%)	19	0.32	(0.02)
Potassium (%)	18	0.49	(0.08)
Chloride (%)	18	0.62	(0.03)

*Calculated value

the dogs. All dogs received the same diet, which was a dry, extruded product (Table 1). Nineteen batches were used during the 2-year test period. Samples of each batch were analyzed by use of methods approved by the Association of Official Analytical Chemists before the batch was fed. Carbohydrate content was estimated by calculation of nitrogen-free extract, which was computed as the difference between 100% and the sum of the protein, fat, fiber, ash, and moisture contents.

The term "feeding regimen" refers to the amount of the diet presented to the dog. The experiment consisted of 2 feeding regimens—ad libitum feeding and limited-intake feeding. At weaning, littermates of the same sex and approximate weight were paired. Within each pair (block), dogs were assigned at random to the feeding regimens. Each dog fed ad libitum was provided with an unlimited supply of food in an enclosed 1.4 × 1.4-meter cubicle for 15 minutes a day. This amount of time was more than sufficient to let the dogs of the ad libitum group be sated. The food and bowl were weighed before and after feeding of each dog to allow calculation of food consumption. Seventy-five percent of the amount eaten was fed the next day to the pairmate on the regimen of limited feeding. In other studies,[11,12] 67 to 70% of ad libitum consumption was provided to limit-fed dogs, but these levels of limitation were considered extreme for general acceptance by dog owners.

Infrequently, a dog on the ad libitum regimen would refuse to eat for a day or more. At first, the protocol called for the pairmate on the limited regimen to not be fed the first day, thereafter to be provided with the actual amount given the day before the food was withheld until food consumption was resumed by the ad libitum pairmate. This protocol was implemented only briefly before it was changed. The revised protocol specified that if the dog on the limited regimen was to receive 180 g of food or less, then that dog would instead receive 75% of the ad libitum pairmate's mean daily consumption for the 7-day period prior to the day the dog refused to eat.

One other protocol change was made during

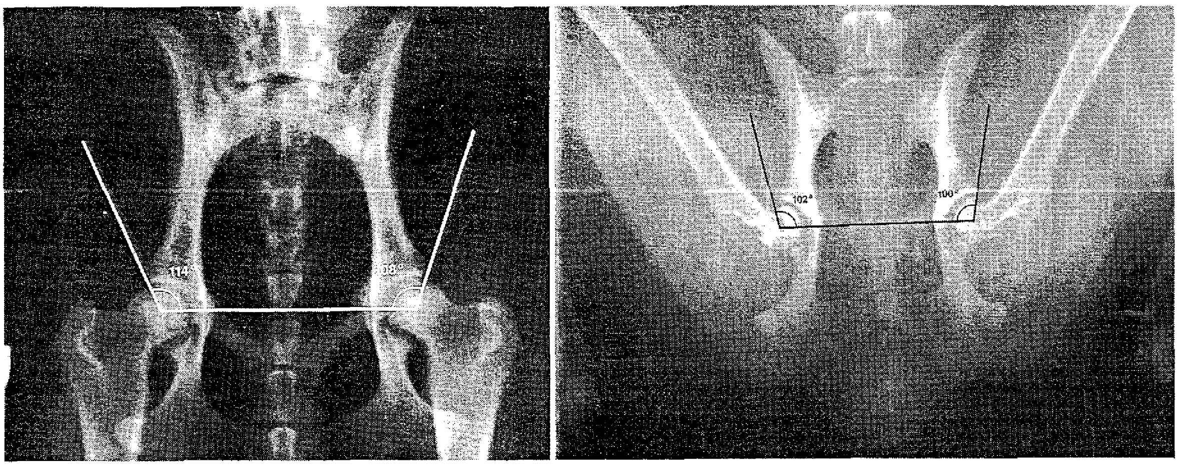

Figure 1—Dorsoventral radiographic views of hips of dogs. Examples of positioning and measurement of Norberg angles, using the standard (left) and "frog-limb" (right) positions.

the study. To allow for any neophobic reactions to cubicle feeding initiated at 16 weeks of age, each dog on the limited-intake regimen was fed the actual amount consumed by the pairmate, instead of 75% of that amount, for the first 2 weeks of individual stall feeding. However, it became obvious that the dogs in the first 2 litters adjusted so well to cubicle feeding that the limited-intake group of the subsequent 5 litters was maintained without a 2-week adjustment period.

Hip evaluations—Radiography of the hip joints was done when the dogs were 30, 42, 54, 78, and 104 weeks old. Two radiographic views were used with the dogs in supine position under general anesthesia,[a] the standard position[15] and the frog-limb position (Fig 1).[16] In the original Norberg frog-limb position, the hind limbs were maximally flexed and abducted. The radiographic examinations of the dogs were made by the same personnel during the entire study, and great care was exercised to ensure uniformity in the radiographic procedure.

The hip joints radiographed in the standard position were evaluated by 1 person (SEO) by use of the modified Norberg angle measurement and the Swedish system. Additionally, the standard-position radiographs made when the dogs were 2 years old were evaluated by 1 person (DNB), using the OFA criteria. The hip joints in the frog-limb position were measured by 1 person (SEO), using the method of Norberg. Radiographs, marked in such a way that identity was only known to the statistician (KLM), were scrutinized independently by the radiologists without knowledge of the result of previous readings or of the dog's feeding regimen.

Both the right and left hip joints were measured by use of the Norberg method. For statistical analysis, the average of the 2 hip values and the minimal (worse) value were both used. An ordinal scale was designed to reflect the criteria for the Swedish system and the OFA system. Both scales used a coded score of "1" for an excellent hip, with the poorer joints being assigned higher codes to a maximum of "6" for the Swedish system and "7" for the OFA system.

Statistical analyses—Because littermates were assigned to feeding regimens in pairs by weight and sex, food intake effects were evaluated within pairs (blocks), using paired *t* tests. Wilcoxon's signed-rank test was used when the residuals from the *t* test indicated nonnormality. Additionally, Pearson product-moment correlation coefficients quantified the association between different hip joint scores from radiographs taken at the same age of the dogs as well as the association between hip joint scores taken at different ages.[25] Frequency of dysplasia was analyzed by use of a McNemar's test.[26]

Results

All dogs grew and remained healthy during the study (Fig 2). Hematologic and blood chemical analyses revealed no abnormalities. Dogs from the 2 groups had the same mean weight (3.9 kg) at the age of 6 weeks when they were weaned and assigned to treatment. When food limitation was initiated when the dogs reached 8 weeks old, the mean weight of the dogs in the 2 groups had increased, but was still the same (5.4 kg). The mean weight gain of the dogs on limited intake was 78.3% of the mean weight gain of the dogs fed ad libitum from the age of 8 to 30 weeks; the percentage was 74.8% for the period of 8 weeks to 2 years (Table 2).

Although the limited-intake dogs had a mean weight gain of approximately 75% of their ad libitum-fed pairmates during 2 key cumulative time intervals (8 weeks to 30 weeks, 8 weeks to 2 years), the range was quite wide (Table 2). Weight gain from 8 to 30 weeks for the dogs on limited food intake ranged from 70.8 to 89.6% of the gain for the pairmate in the 24 pairs of dogs studied. Weight gain from 8 weeks to 2 years for the limited-intake dogs ranged from 53.0 to 95.9% of their pairmates.

[a]Thiamylal sodium, Biotal Bio-ceutic Division, Boehringer—Ingelhelm Health Inc, St Joseph, Mo.

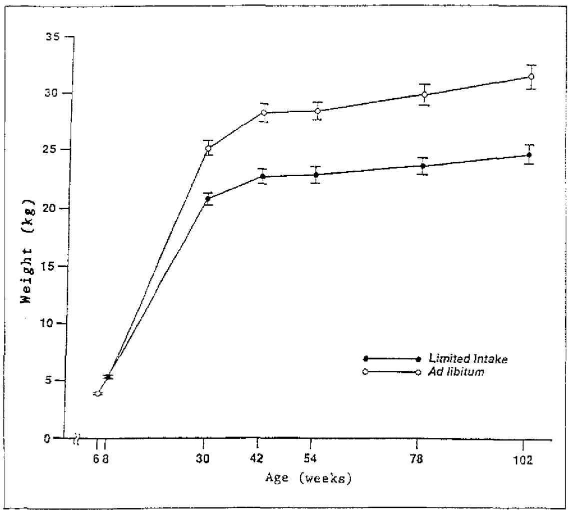

Figure 2—A comparison of body weight gain of dogs receiving food ad libitum vs those with limited food intake.

Table 2—Weight gain and food/caloric consumption for dogs receiving food ad libitum vs those with limited food intake

Interval /regimen	Weight change (kg) Mean (SD)	Daily gain kg Mean (SD)	Daily food consumption (kg) Mean (SD)	Daily caloric consumption (cal) Mean (SD)
8 to 30 weeks				
Limited	15.3 (1.9)	0.099 (0.013)	0.40 (0.04)	1,435 (147)
Ad libitum	19.7 (3.0)	0.127 (0.020)	0.53 (0.05)	1,889 (192)
L/A*	78.3 (5.35)	78.3 (5.35)	76.0 (3.0)	76.0 (3.0)
8 to 102 weeks				
Limited	19.5 (3.7)	0.029 (0.006)	0.42 (0.04)	1,493 (144)
Ad libitum	26.3 (4.5)	0.039 (0.007)	0.55 (0.06)	1,978 (197)
L/A*	74.8 (12.2)	74.8 (12.2)	75.5 (0.75)	75.5 (0.75)

*Value for the dog on limited food intake as (L) a percentage of the value for its ad libitum-fed (A) pairmate, averaged over 24 pairs of dogs.

Mean food (metabolizable calorie) consumption by the dogs on limited intake was 76.0% of that of dogs fed ad libitum (Table 2) from the age of 8 to 30 weeks; the percentage was 75.5% for the age from 8 to 102 weeks. At the onset of the test, the ad libitum-fed dogs consumed approximately 24% more calories/kg of body weight than did the limit-fed dogs (Fig 3). The difference in metabolizable energy (ME) intake per kg of body weight decreased to approximately a 3% mean difference when dogs were 78 to 102 weeks old (adult; Fig 3).

Metabolizable energy requirements (kcal/kg of body weight/d), estimated on the basis of 3 breeds of large dogs,[27] were between the observed means for the 2 groups of dogs studied during the 9- to 45-week-age period (Fig 3). Thereafter, the same estimated calorie requirements were lower than the observed average metabolizable calories per kg of body weight per day of both the limit-fed and ad libitum-fed groups of dogs.

The following formula for average daily ME requirement in the adult dog has been proposed:[28]

$$\text{ME (kcal/d)} = 132 \times \text{kg of body weight}^{0.75}$$

The calculated estimate of the adult daily caloric requirements of dogs in this study, based on the above formula, was 56.2 kcal of ME/kg/d for the ad libitum-fed dogs and 59.7 kcal of ME/kg/d for the

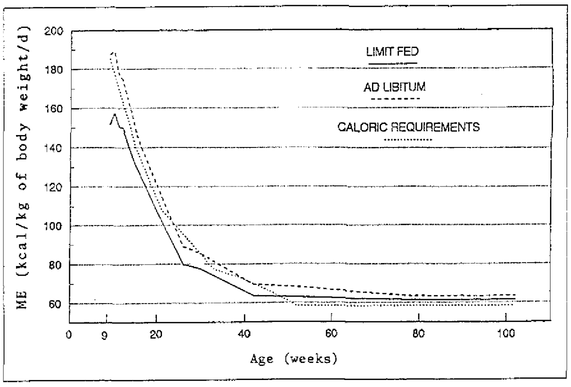

Figure 3—Metabolizable calorie (ME) intake per kilogram body weight per day.

Table 3—Selected times and hip measurements for dogs on each feeding regimen

Measurement	Limited intake*	Ad libitum*	Difference*	P-value† for difference
30-week				
Norberg angle (standard position)				
Average hip	100.7 (0.8)	96.8 (1.5)	4.0 (1.6)	0.050
Worse hip	98.9 (1.0)	94.7 (1.6)	4.2 (1.8)	0.042
2-Year				
OFA§	3.3 (0.3)	4.7 (0.3)	−1.4 (0.4)	0.004
Swedish score§	2.2 (0.2)	3.4 (0.3)	−1.2 (0.3)	0.002
Norberg angle (standard position)				
Average hip	102.3 (1.1)	96.1 (1.7)	6.2 (1.6)	0.001
Worse hip	100.1 (1.4)	94.1 (1.8)	6.0 (1.8)	0.003

*Data expressed as mean (SE) of 24 observations;
†P value from the Wilcoxon ranked sum test;
‡The Orthopedic Foundation for Animals (OFA) scores are 1 (excellent), 2 (good), 3 (fair), 4 (borderline), 5 (mild dysplasia), 6 (moderate dysplasia), and 7 (severe dysplasia)[15];
§Swedish hip joint classification system includes excellent, normal, 1 (borderline), 2 (mild dysplasia), 3 (moderate dysplasia), and 4 (severe dysplasia) grades. These grades were reclassified as 1, 2, 3, 4, 5, 6, respectively, for analyses.[14]

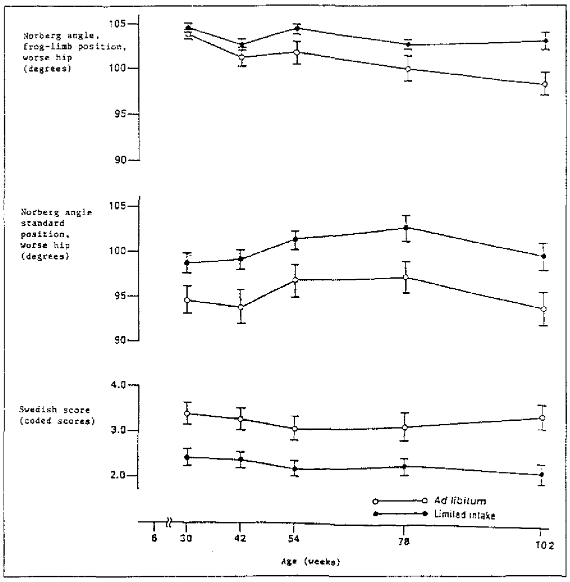

Figure 4—Hip joint evaluations made on radiographs of dogs on two feeding regimens at five ages.

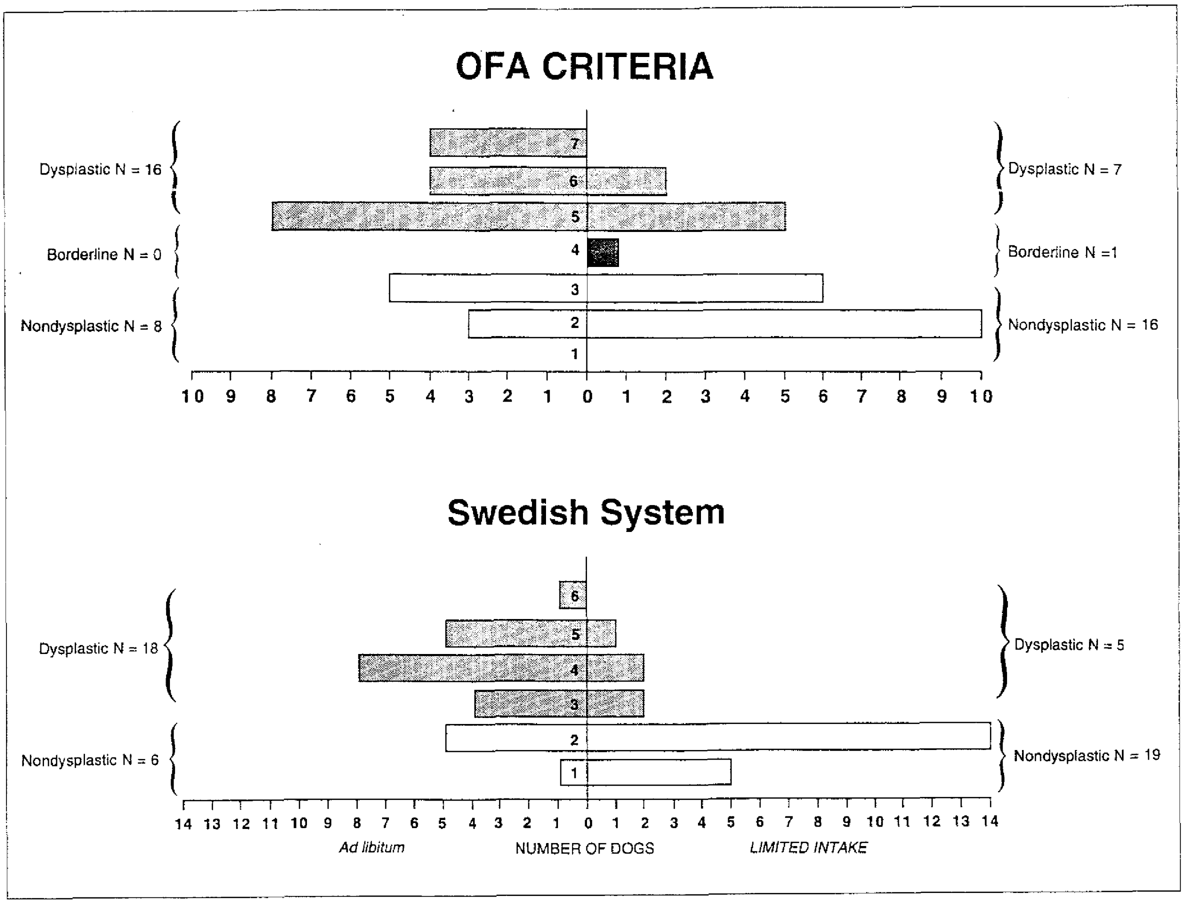

Figure 5—Effect of ad libitum vs limited food intake on hip joint conformation on the basis of Orthopedic Foundation for Animals (OFA) and Swedish scoring systems.

Table 4—Pearson product-moment correlation coefficient between different hip measurements of dogs when they were 30 weeks old and 2 years old

Technique of hip evaluation	Hip evaluation: 30 weeks old — Norberg angles — Standard position: Average	Worse	Frog-limb position: Average	Worse	Swedish score	2 years old — Norberg angles — Standard position: Average	Worse	Frog-limb position: Average	Worse	Swedish	OFA
30 weeks old											
Norberg (standard position)											
Average		0.97	0.51	0.59	−0.81	0.87	0.84	0.69	0.67	−0.79	−0.73
Worse			0.43	0.53	−0.82	0.84	0.84	0.67	0.66	−0.80	−0.75
Norberg (Frog-limb position)											
Average				0.88	−0.35	0.50	0.44	0.43	0.41	−0.30*	−0.25*
Worse					−0.46	0.55	0.49	0.53	0.51	−0.39	−0.33*
Swedish											
2 years old											
Norberg—Standard											
Average							0.97	0.79	0.76	−0.86	−0.78
Worse								0.76	0.74	−0.85	−0.77
Norberg—Frog											
Average									0.96	−0.70	−0.65
Worse										−0.69	−0.59
Swedish											0.83

*$P < 0.10$. For all other correlations, $P < 0.01$. If $|r| \geq 0.53$, $P < 0.0001$.
See Table 3 for key.

limit-fed dogs. A published formula to estimate puppy caloric requirements was not available.

Food-intake-related differences in hip joint subluxation were apparent as early as 30 weeks of age ($P \leq 0.05$; Fig 4, Table 3). The food-intake-related differences by either the Swedish method or the Norberg method, in the standard radiographic position (both average and worse hips), were significant ($P < 0.05$) at all time periods evaluated. Using the frog-limb position, the food-intake-related differences in hip joint evaluations were significant for both the average and worse hip only for dogs at 2 years of age ($P < 0.004$). The OFA system evaluations also demonstrated food intake-related differences in hip joint status, with the mean OFA score at 2 years of age for the limited-intake dogs being 3.3, compared with 4.7 for the ad libitum-fed dogs ($P < 0.004$). The OFA results at 2 years demonstrated food intake-related differences of approximately the same magnitude seen in the results from the Swedish method, for which the mean scores were 2.2 and 3.4 for the limit-fed and ad libitum-fed dogs, respectively.

The frequency and severity of hip dysplasia at 2 years of age according to the OFA and the Swedish scores were tabulated for each group of dogs (Fig 5). According to the OFA system, 17 of 24 dogs on limited intake had normal hip joints whereas only 8 of 24 dogs on the ad libitum regimen had normal hip joints ($P < 0.0225$). Similarly, using the Swedish system, 19 of 24 dogs on limited intake had normal hip joints, compared with only 6 of 24 dogs on the ad libitum regimen ($P < 0.0002$).

Food-intake-related differences tended to increase slightly from 30 weeks until 2 years of age when either the Swedish method or the Norberg method, standard position, was used. However, these differences increased markedly when the Norberg method, frog-limb position, was used.

Norberg angle measurements (standard position) of femoral head subluxation in dogs when they were 30 weeks old were correlated with the OFA and Swedish evaluations of hip joint status at 2 years of age ($|r| \geq 0.73$, $P < 0.0001$; Table 4). The worst hip Norberg angle measurement was more closely correlated with the Swedish scores at all ages and with the 2-year OFA scores than was the mean hip Norberg score.

Discussion

On the basis of our findings in the long-term study reported here, limited food intake has a beneficial effect on development of the hip joints in growing and adolescent dogs. Labrador Retrievers fed 25% less food than those fed ad libitum had less hip joint laxity when they were 30 weeks old than their ad libitum-fed counterparts. Furthermore, by maintaining the dogs on the same feeding regimen until they were 2 years old, this beneficial effect was still present at that age, as demonstrated by the significantly lower frequency of hip dysplasia in the limit-fed dogs. Our findings confirm what has been suggested in previous studies that used fewer dogs, but that included Labrador Retrievers, Golden Retrievers, and German Shepherd Dogs.[11,13]

The protocol of this investigation specified that 75% of the food eaten by each ad libitum-fed dog was to be presented to its pairmate. This goal was achieved with great accuracy (Table 2). The small variability in the percentage actually fed was attributable to rounding and to the fact that, in 2 litters, the dogs assigned to the limited intake group received 100% of their pairmates' feed during an initial 2-week adjustment period.

The metabolizable caloric intake per kg of body weight per day of the limit-fed dogs (Fig 3) can be used as a guideline for feeding large breed dogs to achieve a leaner conformation. However, given that the metabolizable caloric requirements are individualistic, influenced by metabolic and environmental factors,[28] it is suggested that the conformation of the dog be the determining factor in regulating food intake. One approach is to regulate food intake to provide a slender figure.

The study also demonstrated 2 important sets of correlations among the measurements taken. First, the significant correlation ($|r| > 0.73$, $P < 0.0001$; Table 4) of 30-week Norberg angles to 2-year Swedish and OFA scores emphasized the predictive value of early subluxation to later CHD in dogs maintained in a constant environment. On the basis of these data, it is reasonable to conclude that, in the presence of an otherwise constant environment, a difference of 4° in Norberg angle observed between experimental groups at 30 weeks of age would be associated with a substantial difference in the frequency of hip dysplasia at 2 years of age as measured by the Swedish and OFA systems. Second, the correlations of the Norberg angle at 2 years of age (standard position) to both the OFA and the Swedish scores at 2 years of age were high, ranging from -0.73 to -0.80 ($P < 0.0001$; Table 4). Thus, the modified Norberg angle may be useful as a measure of femoral head subluxation reflecting underlying joint laxity, even in some cases in which secondary changes in joint diseases are present.

The Norberg angle measurement in the frog-limb position reflects the depth of the acetabulum rather than joint laxity as the femoral heads are actually pushed into the acetabula when this position is used. The result, therefore, indicated that the acetabula were secondarily becoming more shallow because of remodeling under the influence of joint laxity, which was greater in the dogs on ad libitum feeding.

The mechanism of the dietary effect on the development of the hip joints is unknown. The fact that there is a correlation between rapid weight gain and development of hip dysplasia does not necessarily mean that increased weight as such is the damaging factor.

The environmental factor of restricted feeding has the potential to improve individual phenotype and thus overshadow the genotype of CHD. The improving of the phenotype by altering environmental factors is open to some criticism. On the one hand, breeders and veterinarians have been attempting to eliminate hip dysplasia genetically by mass selection or progeny testing. There may be opposition to manipulating an environmental factor that results in less severe disease. In fact, some suggest imposing environmental stress to magnify the phenotypic expression. On the other hand, many owners may believe it is desirable to delay the onset or lessen the severity of CHD by any available environmental management. The question of quality of life is important and efforts to minimize the progression of hip dysplasia seem both reasonable and necessary.

On the basis of our findings, limited feeding has a beneficial inference on the phenotypic expression of hip dysplasia. These findings should not justify abandoning efforts to reduce or eliminate the disease via appropriate selective breeding practices. Hopefully, this study will stimulate others to identify and investigate other environmental factors that have a potential to influence hip dysplasia. The findings of this study raise the need for a CHD diagnostic test not influenced by environmental factors.

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