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Skeletal development in the dog results from an interaction of genetic, environmental, and nutritional factors. The genetic component can be influenced when the populations are well controlled, accurate breeding records are kept, and a desire to improve the breed exists. Environmental factors such as housing and activity level are under the owner's influence. **Nutrition is one of the single most important factors affecting development of the musculoskeletal system**, and energy, protein, and calcium are some of the more critical nutritional components affecting skeletal development. When given in excess, they can be detrimental to normal skeletal growth.(1-7) Most pet owners in the United States feed commercially prepared diets, which are balanced and complete. The vast majority of developmental skeletal disorders diagnosed in veterinary practice occur in large and giant breeds and are associated with excess (i.e., inappropriate) intake of a commercial diet and/or supplementation. The most prevalent developmental orthopedic disorders are hip dysplasia and osteochondrosis.

**CANINE HIP DYSPLASIA**

Canine hip dysplasia (CHD) is the most frequently encountered orthopedic disease in veterinary medicine practice. **This extremely common heritable disorder of the growing dog can be influenced by nutrition.** The period from 3 to 8 months of age appears to be important in the development of CHD, with the first 6 months generally thought to be the most critical. Early developmental findings of CHD, including joint laxity and coxofemoral anatomic changes, have been documented within 2 weeks of birth. Rapid weight gain in German shepherds during the first 60 days after birth has been associated with CHD at a later age. **Frequency and severity of CHD are influenced by weight gain in growing dogs**, especially if sired by parents with CHD or with a high incidence of CHD in their offspring. Dogs with weight gains exceeding breed standards have a higher frequency of CHD as well as more severe CHD than dogs with weight gain below the standard curve.(8)In one colony of fast growing Labrador retrievers, the triradiate growth plates of the acetabula fused at 5 months as determined by conventional radiography; normal closure of these growth plates in pups growing at conventional rates has been reported to occur at 6 months. Early fusion in the acetabulum is speculated to result in bone/cartilage disparities in the future and to predispose to dysplastic changes.(9) Limiting food intake in growing Labrador retriever puppies has been associated with less subluxation of the femoral head and fewer signs of hip dysplasia.(10)

**OSTEOCHONDROSIS**

Osteochondrosis (OCD) is a focal area of disruption in endochondral ossification. OCD occurs in the physis and/or epiphyseal regions of growth cartilage. This disease can be generalized or systemic and is widespread among young, rapidly growing, warm blooded, domesticated species and in humans. In all species the etiology is considered multifactorial. In the dog, OCD risk factors are associated with age, gender, breed, rapid growth, and nutrient (primarily calcium) excesses.(1,11-14)

All large and giant breeds are at increased risk for OCD, with Great Danes, Labrador retrievers, Newfoundlands, and rottweilers having the highest risk.(14) Males have an increased risk of OCD in the proximal humerus, but gender relationships are not found with OCD involving other joints.(14)

Osteochondrosis lesions are routinely found in pigs as young as 25 days of age.(15) These findings would help substantiate that OCD may be caused by a localized, primary effect on the chondrocyte rather than secondary effects of biomechanic force because rapid growth and weight gain are much less of a factor at this age. Regardless of the pathogenesis of OCD, the underlying role of nutrition is still a factor. In the growing puppy, over nutrition can result in a mismatch between body weight and skeletal growth, which can lead to overloading of skeletal structures. Nutrition of the mother may also play a role in the development of OCD in the offspring.(16)

Although generalized nutrient excesses have been blamed for OCD lesions, there is increasing evidence implicating specific nutrients. Excessive calcium intake resulting in a hypercalcitoninism and hypoparathyroidism(2) manifests as retarded bone maturation, inhibition of osteoclastic activity, and slowed cartilage maturation. These effects on bone and cartilage increase the incidence of osteochondral lesions in articular and physeal cartilage.(2) Osteochondrosis of the acetabular rim has been proposed to lead to a shallow acetabulum and subsequent CHD in the dog. Most of the studies evaluating the effect of vitamin C on OCD have used the pig as a research model and agree that vitamin C supplementation has no effect on the incidence of OCD.(8,17)

**OVERNUTRITION**

**Overnutrition intended to maximize growth rate is incompatible with optimal skeletal development in many species**. An early study suggesting a role of overnutrition in the development of skeletal disease in dogs was that of Hedhammer and colleagues in 1974(1); in an effort to study the influence of food consumption on the incidence of skeletal disease, these researchers performed an experiment comparing ad libitum versus restricted dietary intake in Great Dane puppies. The resultant skeletal pathology was markedly increased in the ad libitum group. This study heightened the awareness of the critical role nutrition plays in bone development.

**NUTRIENTS AND SKELETAL DISEASE**

**Energy**

Energy (calories) is needed for normal development; however, needs vary based on breed, age, neuter status, and activity level. Energy is essential for growth (osteoid formation) and remodeling (resorption) of bone. A variety of methods are advocated to determine energy requirements, and, consequently, estimates of correct energy intake vary.(18) In general, growth requires twice the energy needs of maintenance. As the dog approaches adult body weight, energy needs decrease and are arbitrarily reduced to 1.6 times maintenance energy requirements when the dog reaches 40% of adult body weight.

**Rapid velocity of growth in large and giant breeds increases their risk of skeletal disease**.(7,13) Excess energy per se in an otherwise balanced diet is not a direct contributor to skeletal disease in the growing dog(8,19); the link appears to occur when energy contributes to rapid growth rates and excessive body weight.

Differences in energy requirements may exist within breeds as well as among individuals. Newfoundlands and huskies may require less energy for growth whereas Great Danes have a greater than average growth energy requirement.(20) Although energy calculation estimates still provide an excellent reference point, they must be modified according to nutritional condition and level of physical activity.

No statistically significant effect has been seen on the incidence of CHD when a primarily carbohydrate energy source was included or excluded from an otherwise nutritionally adequate diet. Hip joint laxity, thought to be a predictor of CHD, does not seem to be influenced directly by dietary energy. Increased growth rate on a high-calorie diet stresses the tight hip and creates the potential for increased laxity around the joint and subsequent changes consistent with hip dysplasia. Similarly, an incongruent hip in a rapidly growing, overweight puppy may not mature with the musculature. Other than reduction of overall food consumption by restricting intake, dietary energy has minimal or no influence on the production or prevention of CHD.

**Protein**

Like excess energy, protein has been thought to be associated with skeletal disease. A study by Nap and coworkers reported on the role of protein in disturbances of skeletal development(21,22): Three groups of Great Dane puppies were fed three levels of protein (31.6%, 23.1%, and 14.6% on a dry matter basis) in an isoenergetic dry dog food from 7 weeks through 18 weeks of age. No demonstrable effects were noted on calcium metabolism or skeletal development. These levels of dietary protein are unlikely to cause a disturbing role in canine endochondral ossification.

Investigators have felt they were able to produce normal hip growth and reduce CHD in mixed-breed puppies by feeding a high- or all-meat diet. Subsequent studies in purebred animals known to be dysplastic (German shepherds, golden retrievers, and Labrador retrievers) and in female beagles have not shown similar results.(8) High protein intake does not appear important for development of normal hip joints.

While not directly responsible for skeletal disease in the growing dog, protein provided in excess of metabolic requirements is deaminated by the liver and used for energy, increases plasma levels of insulin-like growth factors, and contributes to an increased rate of growth.(23) If requirements for essential amino acids are met, there are no known benefits to feeding excess protein to healthy, young, growing dogs.

The minimum level of protein in a diet depends on digestibility, amino acid composition, proper ratios among the essential amino acids, and amino acid bioavailability from the protein source. Energy density of the food and the physiologic state of the dog play a role as well. A growth diet should contain more than 28% protein (dry matter basis) of high biologic value that supplies at least 16% of the dietary energy. In the normal dog, dietary protein requirements decrease with age.

**Calcium**

Plasma calcium concentration is tightly regulated by the body. This regulation is needed for the many calcium-dependent biologic processes, such as muscle contraction, hormonal release, and blood coagulation. The release of calcium-regulating hormones (parathyroid hormone [PTH], calcitonin [CT], and 1,25- dihydroxycholecalciferol [1,25 vitamin D]) is influenced by plasma calcium concentration. These hormones regulate calcium dynamics in the intestine, kidneys, and bone.

Calcium excess is routed primarily to bone through the influence of the calciotropic hormones on target organs. Chronic, high intake of calcium in large breeds has been associated with hypercalcemia, concomitant hypophosphatemia, rise in serum alkaline phosphatase, retarded bone maturation, higher percentage of total bone volume, retarded bone remodeling, decrease in osteoclasts, and retarded maturation of cartilage. These changes cause disturbances in endochondral ossification (articular and epiphyseal).(6) When high calcium intake (calcium excess) is coupled with relatively little absorption from bone, severe pathologic changes occur in the young, growing skeleton that is unable to respond by normal remodeling and endochondral ossification. The clinical diseases associated with these changes are osteochondrosis, retained cartilage cones, radius curvus syndrome, and stunted growth.(1,6) Therefore, calcium excess is a major causative or contributing factor in the pathogenesis of skeletal disease in the growing giant-breed dog.(3-6)

It is the absolute level of calcium, rather than the calcium/phosphorus ratio, that most influences skeletal disease.(11) Young, giant-breed dogs fed a diet containing 3.3% calcium (dry matter basis) and 0.9% or 3% phosphorus have significantly increased incidence of developmental bone disease. These dogs seem to be unable to protect themselves against the negative effects of chronic excess levels of calcium.(26) Calcium levels for a growth diet should be between 1% and 1.6% (dry matter basis). Often puppies are switched from growth to maintenance diets to avoid calcium excess and skeletal disease. However, because maintenance diets are generally of much lower energy density than growth diets, the puppy must consume more dry matter volume to meet its energy requirement. If the calcium levels (dry matter basis) are similar between the two diets, the puppy will actually consume more calcium on the maintenance diet. This is exemplified in the case of switching a 13-week-old Great Dane puppy from a typical growth diet (4.2 kcal/g and 1.6% calcium on a dry matter basis) to a typical maintenance diet (3.2 kcal/g and 1.4% calcium on a dry matter basis). The puppy would consume approximately 638 g of the growth diet containing 10.2 g calcium. To meet energy needs of 2680 kcal/day, this same puppy would consume approximately 838 g of the maintenance diet containing 11.7 g of calcium.

Feeding treats containing calcium or providing calcium supplements further increases daily calcium intake. If the same 13- week-old, 20 kg Great Dane puppy were given two level teaspoons of a typical calcium supplement (calcium carbonate) in addition to the growth diet, it would more than double its daily calcium intake. This level is well beyond that shown to increase the risk for developmental bone disease.(11)

Recent investigations produced osteochondrosis in the fetuses of ewes fed high levels of dietary calcium.(24) Because of the rapid growth rate of giant-breed dogs, they become "sentinels" for nutritionally influenced skeletal disease such as is seen with excesses in dietary calcium. Similar changes may be slower to surface and are not as easily identified in the smaller breeds. Regardless of the risks of high calcium intake, dietary calcium is a highly influential nutrient for skeletal development.

**Vitamin C**

L-Ascorbic acid (vitamin C) is integral to hydroxylation of proline and Iysine during biosynthesis of collagen. Type I collagen is the most widely distributed in connective tissue (primarily in bone and ligaments). In puppies fed diets devoid of vitamin C for 147 to 154 days, growth was not affected and skeletal lesions were not noted.(25) There are no dietary requirements for vitamin C in the dog.(25)

Vitamin C supplementation in pigs has produced elevations in plasma levels; however, articular concentrations of hydroxyproline were unchanged. Similar studies in dogs demonstrated transient elevation of plasma vitamin C concentrations, and long-term supplementation did not increase concentrations much above normal.(8) Excess vitamin C supplementation is generally considered to have little or no effect on the skeleton. The relationship between vitamin C and developmental disorders of the skeletal system in the dog is as yet unproven.

Megadoses of ascorbate fed to the bitch during pregnancy and provided to the offspring until young adulthood have been reported to eliminate CHD.(26) Ascorbate therapy was rationalized as an antistressor, a detoxicant, a metabolite necessary for maintaining biochemical homeostasis in the body, and a component in collagen synthesis. Eight litters of German shepherd puppies from known dysplastic parents or from parents that had produced dysplastic offspring were studied. The bitch received 2 to 4 g sodium ascorbate crystals per day during pregnancy. The puppies received calcium and vitamin supplements from birth to 3 weeks, 500 mg ascorbate per day from 3 weeks to 4 months, and I to 2 g ascorbate per day from 4 months up to 2 years. No CHD was reported in any of the offspring. However, no radiographs were taken to document presence or absence of dysplastic changes, and no long-term follow- up studies have been published. Neither this nor any other study has verified ascorbic acid levels, much less deficiencies, in dogs with hip dysplasia.(8) If CHD were to be associated with a low vitamin C level, lower concentrations would be more likely in younger animals undergoing the stresses of growth. No other studies have demonstrated a positive effect of oral supplementation of vitamin C in preventing CHD in growing dogs that are genetically at risk for the disease. Decreased levels of hydroxyproline found in arthritic cartilage from CHD joints are probably a reflection of degradation changes rather than lack of production .

Finally, the relationship between vitamin C, joint laxity, and CHD in the dog is suspect because a decrease in systemic vitamin C levels could be expected to affect other joints. Canine hip dysplasia is often associated with degenerative disease in multiple joints; however, joint laxity other than in the hips is not reported.

**Electrolyte Balance**

Dietary electrolytes have been proposed as a preventative for CHD.(27,28) The dietary anion gap (DAG) was associated with the radiographic changes of subluxation in the coxofemoral joints of several breeds. The basic premise is the anions and cations (specifically Na+, K+, and Cl ) in the diet influence the electrolytes and osmolality in the joint fluid. Higher osmolality and increased fluid volume have been noted in the joint fluid of dysplastic dogs when contrasted to disease-free hips in the same breed.(28) The observed changes in osmolality and volume could be a result rather than a cause of CHD. A DAG of (Na+ + K+ Cl ) <23 mEq/100 g of food was fed to large-breed dogs and resulted in less femoral head subluxation, on average, at 6 months of age. This beneficial effect was also thought to be maintained at 2 years of age. The effect (slowed progression of subluxation) was also observed in dogs fed lower DAG from 33 to 45 weeks of age.(28) However, changes in synovial fluid osmolality and electrolyte concentrations were not reported. Hip joint laxity was determined using the Norberg hip score computed from radiographs. Significant correlation between radiographic findings (e.g., Norberg hip scores) and progression of CHD, either radiographically or clinically, is not proven. The studies suggesting an association between DAG and joint laxity did not prove a mechanism of action.

**Other Nutrients**

Vitamin D metabolites are important in the regulation of calcium metabolism and, subsequently, skeletal development in dogs. They aid in the absorption of calcium and phosphate, increase bone cell activity, and influence endochondral ossification and calcium excretion.(29) Unlike other omnivores, the dog seems to be dependent on dietary vitamin D sources. Dietary sources of vitamin D are either of plant (vitamin D2) or animal (vitamin D3) origin. Commercial pet foods contain from 2 to 10 times the National Research Council (NRC) recommended amounts of vitamin D.(30) Clinical cases of vitamin D deficiency (rickets) are extremely rare. Diagnosis of a deficiency can be made by measuring circulating levels of vitamin D metabolites(31) and by measuring growth plate width. Increased width is not associated with low-calcium/high- phosphate diets but is a strong indicator of rickets.(29) Excess vitamin D can cause hypercalcemia, hyperphosphatemia, anorexia, polydipsia, polyuria, vomiting, muscle weakness, generalized soft tissue mineralization, and lameness. In the growing dog, supplementation with vitamin D can result in marked disturbance of normal skeletal development, primarily as a result of increased calcium and phosphate absorption.(29)

The trace mineral elements copper and zinc have been implicated in normal skeletal development. Supplementing a mare's dietary copper intake during the late stages of pregnancy and supplementing the foal's diet from 90 to 180 days of age have been associated with a reduced prevalence and severity of developmental cartilage lesions.(32) Copper deficiency in the dog has been associated with hair depigmentation, hyperextension of the distal phalanges, and tissue copper decreases in the hair, liver, kidney, and heart muscle. However, copper concentration in bone was not influenced by dietary treatment, and developmental skeletal abnormalities associated with a deficiency of dietary copper were not described.(33) Similarly, long-term studies of dietary zinc levels on canine growth and reproduction showed no significant clinical influence on skeletal development.(34)

**CONCLUSION**

The large and giant breeds are the most susceptible to skeletal disease. Genetics, environment, and nutrition play key roles. Nutritionally, rate of growth, feed consumption, specific nutrients, and feeding methods influence our ability to optimize skeletal development and minimize skeletal disease.

**MAXIMIZING THE GROWTH RATE IN YOUNG, GROWING PUPPIES DOES NOT CORRELATE TO MAXIMAL ADULT SIZE;**

**HOWEVER, IT DOES INCREASE THE RISK OF SKELETAL DISEASE!**

The growth phase of 3 to 8 months and possibly the phase prior to weaning are integral to ultimate skeletal integrity. The giant breeds may be limited in their ability to cope with excesses of minerals such as calcium, and the results are abnormal bone remodeling and skeletal disorders. This apparent increased sensitivity makes these breeds somewhat of a monitor of dietary influences.

Nutritional management alone will not be sufficient to manage developmental bone diseases. However, we can prevent some skeletal disease by appropriately feeding diets with optimized nutrients. Dietary deficiencies are of minimal concern in this age of commercial diets that are specifically prepared for young, growing dogs. The potential for harm is in overnutrition from excess consumption and supplementation.