

Evaluation of bone turnover markers and biochemical analysis in developmental metabolic bone diseases in pediatric Aksaray Malakli breed dogs

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Abstract

Pediatric dogs are predisposed to skeletal disorders during growth, with rickets, hypertrophic osteopathy, and nutritional secondary hyperparathyroidism being the most common. Rickets, usually caused by vitamin D deficiency, leads to bone softening and deformities, whereas hypertrophic osteopathy involves abnormal calcium salt deposition that impairs mobility. This study investigated developmental orthopedic diseases in Aksaray Malakli dogs, focusing on nutritional factors and biochemical markers. Twenty-two pediatric dogs were examined and divided into two groups. Group I (n=11) showed gait abnormalities and postural deformities, whereas Group II (n=11) included clinically healthy dogs. Clinical, radiographic, and biochemical assessments were performed, including cortical index, parathormone, osteocalcin, vitamin D3, calcium, and phosphorus measurements. Nutritional history revealed that Group I dogs were fed exclusively with “yal,” a grain-based diet, likely leading to calcium deficiency and impaired skeletal development. Group II received a balanced diet including animal-based products and commercial feed. Clinical examinations indicated no pain in either group, but Group I showed abnormal posture and forelimb curvature. Radiographs revealed bone structural changes in Group I, while Group II maintained normal alignment. Biochemical tests demonstrated imbalances in Group I, particularly in vitamin D and phosphorus levels, and statistical analysis confirmed significant intergroup differences. These findings indicate that nutrition, vitamin D status, and calcium-phosphorus balance are key contributors to metabolic bone disorders in Malakli dogs. Proper nutritional regulation during early growth may help prevent rickets and other metabolic bone diseases in this breed.

Keywords: calcium, metabolic bone diseases, osteocalcin, parathormone, phosphorus, vitamin D

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Introduction

The skeletal system diseases of young animals during the developmental period occur for various reasons. The most common metabolic bone diseases seen in the developmental period include hypertrophic osteopathy and nutritional secondary hyperparathyroidism, but the most common disease is rickets (Dittmer and Thompson, 2011). Rickets is characterized by the formation of soft and flexible bone due to impaired calcium (Ca) and phosphorus (P) metabolism due to vitamin D deficiency (Cline, 2012). In rickets, leg bones take an "X" or "O" shape due to curvatures in radius, ulna, and tibia (Buyukpamukcu *et al.*, 1985; Kul *et al.*, 1996; Dittmer and Thompson, 2011). Nutritional secondary hyperparathyroidism is a bone disease characterized by deficient formation of osteoclast tissue in bone substrate (Samsar *et al.*, 2000). It is seen in young animals fed with low Ca, high P meat, or fed with foods with normal or low levels of Ca and insufficient vitamin D3 (Yurdakul *et al.*, 2017).

Hypertrophic osteopathy is a bone disease that occurs because of the accumulation of Ca salts in the subperiosteal layer of bones and is characterized by an increase in bone-specific gravity (Samsar *et al.*, 2000). Although the etiology of this disease is not known exactly, it is reported that this disease is related to D hypervitaminosis and excess Ca and P. Affected animals have difficulty walking and their appearance is atypical. Growth pauses, anorexia, stagnation, and weakness are observed in affected animals (Samsar *et al.*, 2000; Yurdakul *et al.*, 2017).

Osteocalcin is the most common non-collagenous protein found in bone. It is released from osteoblasts during osteoid synthesis. Newly synthesized osteocalcin is largely present in the extracellular bone matrix, but small amounts are released into the circulation (Brown *et al.*, 2009). This allows it to be used as a bone formation marker. Osteocalcin is a late marker of osteoblastic activity compared to alkaline phosphatase bone isoenzyme and type 1 collagen. Serum levels are thought to correlate well with the rate of bone formation. Like other markers of bone destruction, osteocalcin shows a circadian rhythm (reaching peak levels at 04.00 am) (Boomer *et al.*, 1976). Its circulating levels are not affected by food intake, etc., so fasting is not required before sampling. Elimination occurs via kidneys (Brown *et al.*, 2009; Hacimustafaoglu, 2023).

Vitamin D is a group of sterols that have hormone-like functions. It is classified in the group of fat-soluble vitamins. Vitamin D is also known as calciferol. Up to ten different compounds showing vitamin D effects are reported. The most biologically and chemically important of these compounds is cholecalciferol (vitamin D3) and ergocalciferol (vitamin D2) (Ongen *et al.*, 2008). Since cholecalciferol and ergocalciferol are metabolized similarly, they are referred to as vitamin D (Hatun *et al.*, 2003).

The general functions of 1,25-dihydroxy vitamin D3 (1,25(OH)₂D), the active metabolite of vitamin D, include maintaining plasma calcium levels. 1,25-dihydroxy vitamin D3 increases Ca absorption from the duodenum and P absorption from the ileum. It also inhibits calcium loss from the kidneys and increases

bone resorption. 1,25-dihydroxy vitamin D3 also decreases parathormone synthesis and increases insulin production (Ongen *et al.*, 2008).

Aksaray Malakli is a shepherd dog breed bred especially in and around Aksaray in Turkey. Although this breed is similar to Kangal shepherd dogs, the purebred Aksaray Malakli is distinguished by its larger body weight, higher body structure, and head structure with more sagging lips compared to the Kangal breed (Ograk *et al.*, 2018). To determine the different characteristics of Aksaray Malakli dogs and to register this breed as a breed specific to Aksaray, cooperation is carried out between Aksaray Governorship, Aksaray Municipality, some universities and Federation of Dog Breeds and Cynology (Aslim and Sinmez, 2017; Anonymous, 2018). This breed is thought to be prone to developmental orthopedic diseases due to its strong musculature and its definition as a large shepherd dog. According to our clinical experience, the care and feeding conditions of Aksaray Malakli dogs also increase the rate of developmental orthopedic diseases. However, there is no study on developmental orthopedic diseases in the literature on this breed.

This study aimed to evaluate developmental metabolic and orthopedic diseases such as overactive parathyroid gland (hyperparathyroidism), excessive bone tissue formation (hypertrophic osteopathy), joint laxity, and rickets in Aksaray Malakli breed dogs during infancy/pre-adolescence.

Malakli breed dogs with developmental bone disease, osteocalcin, which shows bone turnover; serum calcium, phosphorus, magnesium, parathormone, and 1,25-dihydroxy vitamin D3 levels, which are related to bone metabolism, were evaluated. Due to their large body size, rapid growth, and breed-specific feeding and management practices, Aksaray Malakli dogs may be predisposed to developmental metabolic bone disorders; however, objective data regarding bone metabolism in this breed are limited.

The mechanisms of increasing bone turnover were determined based on the values of the parameters obtained for developmental bone diseases such as joint laxity and rickets, which cause problems in the adult and geriatric periods. Therefore, this study aimed to integrate clinical, radiographic, and biochemical findings to clarify the role of nutrition and empirically applied supplementation on bone metabolism in Aksaray Malakli dogs. This study was designed as a prospective observational study of bone health during the developmental period.

Materials and Methods

Case selection: The study material consisted of a total of 22 Aksaray Malakli breed dogs of different genders (60% female, 40% male) and aged 4–6 months, presented to the Aksaray University Faculty of Veterinary Medicine Animal Hospital. The cases were divided into two groups. Group I (n=11) consisted of dogs presented with complaints of gait disorder, posture abnormalities, lameness, curvature of the extremities, and pain, and diagnosed with developmental bone disease. Group II (control group) consisted of clinically healthy Aksaray Malakli dogs

with no evidence of systemic or orthopedic disease based on clinical examination.

Dietary information was recorded for each group based on owner reports. Dogs in Group I were reported to be fed predominantly with “yal” (a traditional feed consisting of grains such as bran, wheat, or barley flour mixed with water), whereas dogs in Group II were reported to receive a mixed diet including “yal,” animal-derived products, and commercial dog food.

Clinical examination: Patients with gait disturbance, postural disturbance, and lameness were considered in Group I. Patients with fractures detected on palpation or radiologic examination were excluded from the study. Healthy dogs that presented for routine general examination, vaccination, and parasitic application were evaluated in Group II.

Radiographic examination: The affected extremities were evaluated by taking bilateral radiographic images. Two-way radiographs of the affected extremities were taken as mediolateral and anteroposterior. The cortical index of the involved extremity was evaluated radiologically in terms of metabolic bone diseases. The evaluation of the cortical index was performed on the mediolateral radiograph. Cranial cortical thickness (A) (cm), caudal cortical thickness (B) (cm), and intramedullary space (C, cm) were determined and measured on the radiograph (Fig. 1). After the measurements were completed, index values were obtained for each group of dogs using the following formula (Cortical index= (A+B)/C) (Nazem *et al.*, 2015).

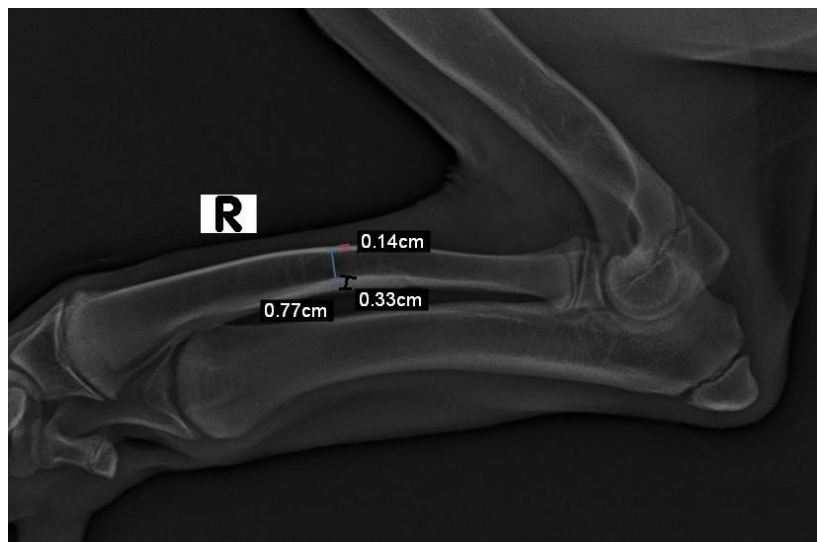


Figure 1 Measurement of the cortical index value on the mediolateral radiograph of case 9. Red line: Cranial cortex thickness (0,14 cm). Black line: Caudal cortex thickness (0,33cm). intramedullary cavity (0,77 cm). R: Right.

Biochemical analysis: The blood samples were taken from the antebrachial cephalic vein in anticoagulant and non-anticoagulant tubes to evaluate routine whole blood and serum electrolyte parameters for general examination from the dogs in Group I and Group II. Blood samples were centrifuged at 5000 rpm for 10 minutes and serum electrolyte values were measured from the serum portions and the remaining portions of the serum were transferred into 1.5 ml microcentrifuge tubes. Serum samples in 1.5 ml microcentrifuge tubes were first stored at -20°C and then at -80°C until measurement.

Parathormone and osteocalcin levels were measured with ELISA, and 1,25-dihydroxy vitamin D3 was measured with an immunofluorescence assay method and sent to a private biochemistry laboratory for blind measurement. Serum Electrolyte parameters (calcium, phosphorus, and ALP) were measured using specialized commercial kits (MNCHIP® Electrolyte kit).

Statistical analysis: Cortical index, cranial cortex thickness, caudal cortex thickness, intramedullary space, parathormone, and vitamin D values between the groups were evaluated by t-test. The correlation of parathormone and vitamin D levels with medullary

cavity, cranial, and caudal cortex thickness was evaluated. Statistical analyses were performed with the Minitab® 16 (Minitab® Inc., 2010) software.

Results

Clinical examination findings: Based on information obtained from the owners, it was learned that the dogs in Group I were fed only “yal”, a food consisting of grains such as bran, wheat, or barley flour mixed with water, whereas the dogs in Group II were fed “yal” in addition to animal-derived products (meat, bone marrow broth, etc.) and commercial dog food.

Clinical examination revealed no pain and crepitation. In the normal posture, a compression disorder was observed: although only the sole pad should touch the floor in the forelimbs, the metacarpals were also touching the floor (n=5). No other anomalies were observed except for the posture and stance abnormalities. It was learned that the owners used vitamins A, D, E, and calcium to prevent this posture and stance disorder seen in Group I. The cases in Group I showed curvature in the distal antebrachium region (Fig. 2).

The cases in Group II were admitted to our hospital for routine parasite and vaccine administration and no

anomalies were found in posture, stepping, and gait. Articulatio (art.) humeri, art. cubiti, and art. carpi were found to be in a good anatomical alignment.

Radiographic findings:

Group I: Mediolateral radiographs revealed that the radius and ulna should have continued as a straight line, but in the distal part, there was a significant cranial bulge. Especially, the caudal cortex thickness was found to be thicker than the cranial cortex. At the same time, line-shaped fluctuations were seen in certain regions with differentiated bone radiodensity.

According to the data, the average cranial cortex thickness was 0.16 cm and caudal cortex thickness was 0.35 cm (Table 1). Especially in cases no: 3, 5, 8, 9, 10, 11, caudal cortex thickness was more than cranial. This was thought to be due to the loss of the normal plane of the radius cranially in the distal region of the cortex close to the growth plate (Fig. 3).

Group II: According to the radiographic findings, mediolateral radiographs showed that the radius and ulna continued as a straight line and parallelism of the cortex line was not disturbed. According to the data, the mean cranial cortex thickness was 0.21 cm and caudal cortex thickness was 0.22 cm (Table 1). There was no specific difference in cranial and caudal cortex thicknesses compared to group I. No increase in the radio opacity of the medullary canal was observed.

Biochemical analysis findings: Osteocalcin concentrations were below the assay detection limit (<2 ng/ml). Therefore, a specific value could not be obtained for both groups. The mean parathormone and vitamin D values were 33.5 pg/ml and 28.82 ng/ml in Group I, respectively, whereas they were 24.0 pg/ml and 16.35 ng/ml in Group II (Table 1).

According to the results of biochemical tests, sodium, potassium, chlorine, calcium, and magnesium values were within the reference range for both groups. However, Group I phosphorus values were numerically higher than the reference range.

Statistical Analysis Results: For Group I and II A values (cranial cortical thickness), a significant difference between the groups ($P = 0.031$) was observed. For the A value, the mean value for Group I was lower than that of Group II. Similarly, for value B (caudal cortex thickness), the difference between Groups I and II was also found statistically significant ($P = 0.019$). The mean of Group I for the B value was higher than that of Group II. In contrast, for the C value (medullary canal thickness), no significant difference was found between Groups I and II ($P = 0.652$). No significant difference between the groups was found in the cortical index value ($P = 0.765$).

Although parathormone values in Group I were higher than Group II, no significant difference was observed ($P = 0.227$). The difference between Groups I and II for vitamin D was significant ($P < 0.001$) and the mean value of Group I was significantly higher than that of Group II (Table 1).

According to the correlation analysis, a negative correlation was found between Group I A and parathormone, but this correlation was not statistically significant ($P = 0.126$). A positive correlation was found between Group I B and the Cortical Index ($r = 0.916$, $P < 0.001$), indicating a strong relationship between the two variables. A significant negative correlation was found between Group I C and the Cortical Index ($r = -0.706$, $P = 0.015$). Positive correlations were found between Group II A, B, and C, and these correlations were statistically significant ($P = 0.075$ and $P = 0.044$).

Table 1 Results of the two-sample t-test and the mean measurement values of the groups.*

A. Cranial cortex thickness B. Caudal cortex thickness C. Intramedullary cavity. *Osteocalcin is <2.0 ng/ml for all groups.

Variable(s)	Mean (Group I)	Mean (Group II)	Mean difference	t-values	P-values
Group I & Group II A (cm)	0.16	0.21	-0.05	-2.42	0.03
Group I & Group II B (cm)	0.35	0.22	0.13	2.67	0.01
Group I & Group II C (cm)	0.80	0.75	0.04	0.46	0.65
Group I & Group II Cortical index	0.67	0.64	0.03	0.30	0.76
Group I & Group II Parathormone values (pg/ml)	33.50	24.00	9.50	1.25	0.22
Group I & Group II vitamin D (ng/ml)	28.82	16.35	12.47	5.00	0.00



Figure 2 Physical examination of Aksaray Malakli dogs of different age and sex. A. Side and front view of normal / correct posture. B. Posture disorder in a 3-month-old Malakli dog C. 'O' leg image in a 3-month-old Malakli dog. Flexion and swelling in the distal radius ulna region. D. Posture / stepping disorder (Carpal Laxity) in a 6-month-old Malakli dog.



Figure 3 Obtaining cortical index values on the mediolateral radiograph image of the cases. A. Cranial curvature in the distal radius ulna of case 1, increased radiodensity of the medullary cavity. B. Mediolateral radiograph of case 7 showing increased radiodensity of the medullary cavity at the level of the proximal radius ulna.

Discussion

Diseases of the skeletal system occur in young animals during the developmental period due to various reasons. Although hypertrophic osteopathy and nutritional secondary hyperparathyroidism are among the metabolic bone diseases seen in the developmental period, the most common disease is rickets (Buyukpamukcu *et al.*, 1985; Dittmer *et al.*, 2011).

The body weight, head, and body measurements of Aksaray Malakli breed dogs have higher values compared to Kangal, Kars, and Akbaş dogs (Atasoy *et al.*, 2014). This study aimed to evaluate developmental metabolic bone diseases in Aksaray Malakli dogs. The findings, supported by bone turnover markers and

biochemical analyses, suggest that bone health in these dogs may be influenced by dietary habits and environmental factors during the developmental period.

Parathormone and vitamin D levels in Group I were expected to be lower than in Group II; however, higher values were observed according to the obtained data. One possible explanation for this finding may be related to vitamin supplementation practices reported by the owners.

According to our study, although parathormone levels in Group I were not statistically significant, it was observed that the values were high, as in vitamin D levels. This finding may indicate that Aksaray Malakli breed dogs could be predisposed to metabolic

bone disorders during rapid growth. The increasing effect of parathormone on bone resorption is thought to lead to mineral loss in the bones and may predispose to the formation of bone deformations in the future.

Nutritional secondary hyperparathyroidism develops mainly due to inadequate calcium and vitamin D intake or overstimulation of the parathyroid glands (Cline, 2012). At the same time, high dietary phosphorus intake leads to hyperphosphatemia, stimulating the parathyroid gland. These conditions lead to the weakening of bone tissue and result in bone deformities (Krook *et al.*, 2010). In a study conducted in German shepherd puppies with nutritional secondary hyperparathyroidism, significant bilateral dorsal flexion and swelling of the carpal joints resulted in horizontal orientation of the metacarpal bones (Kawaguchi *et al.*, 1993). Similar results were observed in our study, suggesting comparable skeletal responses, but the increased cortical thickness and bone deformations observed in Group I may be associated with secondary hyperparathyroidism and elevated vitamin D levels. These findings emphasize the importance of nutritional and care-related factors on bone health in Aksaray Malakli dogs. Elevated parathormone levels indicate increased bone breakdown and may reflect unbalanced development of bone structure in these dogs.

According to the necropsy findings of the same study by Kawaguchi *et al.* (1993), cortical bones of long bones were found to be weak. When we examined the dogs in Group I radiographically, an increase in radiodensity and line-shaped fluctuations were observed in the medullary region between the two cortices, and unhealthy bone structure was observed. These findings are consistent with previously reported radiological alterations associated with metabolic bone disorders. Tal *et al.* (2018) reported that nutritional secondary hyperparathyroidism caused compression fractures in a large breed puppy because of hypocalcemia and hyperphosphatemia. In our study, although parathormone did not have a statistically significant relationship, it was numerically higher with phosphorus compared to the control group. However, no compression fractures occurred. Only swelling and a marked curvature were observed in the distal radius and ulna of the forelimb.

Bellavia *et al.* (2016) reported that high vitamin D intake disrupts the calcium-phosphorus balance and this imbalance causes excessive growth of bone tissue (periosteal proliferation), which can disrupt bone metabolism and lead to diseases such as hypertrophic osteopathy. While a low vitamin D value was expected in Group I, it was found to be higher than anticipated. This finding may be related to owner-reported vitamin D supplementation practices rather than a controlled dietary intervention. Unconsciously applied high vitamin D supplementation may lead to an imbalance in Ca/P metabolism. A numerical increase was observed in the P value.

The higher vitamin D levels observed in Group I may reflect uncontrolled supplementation practices reported by the owners. Shahraki *et al.* (2024) reported that vitamin D intake at a daily dose of 50 IU/kg body weight caused an increase in serum phosphorus levels. Similar to the findings of that study, we observed that

vitamin D and phosphorus levels in dogs in Group I were numerically higher than the reference values. The relationship between vitamin D and serum phosphorus levels could not be analyzed statistically because the low values of serum phosphorus levels obtained were not recorded. Only serum phosphorus levels above the normal value were recorded.

In previous studies, although calcium imbalance is not usually observed in dogs with hypercortisolism, it has been stated that increased PTH levels are not due to phosphatemia or vitamin D imbalances (Corbee *et al.*, 2012; Ramsey *et al.*, 2005). There were no dogs with hypercortisolism in our study, and calcium imbalance was not observed. The circulating total calcium levels were not largely affected, suggesting that calcium imbalance is not a direct cause of PTH increase. However, the lack of statistically significant differences highlights the need for further studies on metabolic bone diseases is needed.

The cortical index is an effective and useful parameter for assessing bone health (Hiney *et al.*, 2004). In various studies, cortical index was used in radiologic morphometric examinations of extremities (Nazem *et al.*, 2015; Dogan *et al.*, 2007; Kushwaha *et al.*, 2012). In our study, the bone health of Aksaray Malakli dogs was evaluated by cortical index. Alterations in cortical thickness and bone deformation observed in Group I suggest an imbalance in bone remodeling, indicating developmental bone disorders associated with nutrition.

In a study on dogs with rickets, it was reported that osteocalcin levels were low compared to healthy dogs (Sharma *et al.*, 2017). In a study using bone turnover markers, Mooney *et al.* (2020) reported that the serum osteocalcin value was not significantly different (Mooney *et al.*, 2020). Osteocalcin values could not be measured because they were less than 2 in our study. Low osteocalcin levels may indicate insufficient bone formation activity, suggesting an imbalance between bone formation and resorption processes.

The findings of the study also reveal the critical role of dietary habits and environmental factors on bone health in dogs. The fact that Aksaray Malakli dogs have a genetically large and bulky structure increases the importance of proper nutrition and care in these dogs. Ensuring the correct balance of calcium, phosphorus, and vitamin D, which support bone metabolism, is of great importance in preventing such developmental bone diseases. The findings suggest that improper feeding practices and uncontrolled supplement use may contribute to bone disorders in these dogs.

In conclusion, this study suggests that developmental metabolic bone disorders in Aksaray Malakli breed dogs are associated with factors like vitamin D levels, calcium-phosphorus imbalance, and cortical index. Appropriate nutritional management and controlled supplementation during growth may help reduce the risk of metabolic bone diseases in this breed.

This study suggests that developmental metabolic bone disorders may occur in Aksaray Malakli dogs and may be influenced by nutritional and management-related factors. Alterations in parathormone and vitamin D levels may be associated with impaired bone metabolism; however, a direct causal relationship

cannot be established based on the present data. The findings emphasize the importance of appropriate nutritional management and controlled supplementation during the growth period, which may help reduce the risk of metabolic bone disorders. Overall, this study contributes to a better understanding of skeletal health in Aksaray Malakli breed dogs and highlights the need for further research in this area.

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References

- Aslim G and Sinmez ÇÇ 2017. Aksaray ili folklorunda Aksaray Malaklısı yetiştiriciliği. (Breeding Aksaray Malaklısı in folklore of Aksaray Province). *Eurasian J Vet Sci.* 33: 148-157.
- Atasoy F, Erdogan M, Ozarslan B, Yucer B, Kocakaya A and Akcapinar H 2014. Some morphological and genetic characteristics of Malaklı Karabash dogs. *Ankara Univ Vet Fak Derg.* 61: 125-132.
- Anonymous 2018. "Aksaray Malaklısı ırk tespit ölçüm çalışması yapıldı." [Online]. Available: http://www.aksaraykulturturizm.com/tr/haberlerduyurular/aksaray-malaklisi-irk-tespit-olcumcalismasi-yapildi_15-05-2016. Accessed May 15, 2016.
- Bellavia D, Costa V, De Luca A, Maglio M, Pagani S, Fini M and Giavaresi G 2016. Vitamin D level between calcium-phosphorus homeostasis and immune system: new perspective in osteoporosis. *Curr Osteoporosis Rep.* 14: 110-121.
- Bommer J, Ritz E and Gengenbach E 1976. Parathyroid activity in hyperthyroidism. In: *Calcified Tissue Research*. S Pors Nielsen and E Hjørtting-Hansen (eds). Heidelberg: Springer Berlin. 288-293.
- Brown JP, Albert C, Nassar BA, Adachi JD, Cole D, Davison KS, Dooley KC, Don-Wauchope A, Douville P, Hanley DA, Jamal SA, Josse R, Kaiser S, Krahn J, Krause R, Kremer R, Lepage R, Letendre E, Morin S, Ooi DS, Papaioannou A and Ste-Marie LG 2009. Bone turnover markers in the management of postmenopausal osteoporosis. *Clin Biochem.* 42(10-11): 929-942.
- Buyukpamukcu M and Senay B 1985. Kemik hastalıkları. In: *Veteriner Patoloji IV*. Cilt. A.Ü. Basımevi (ed). Ankara: Nadir Kitap. 123-156.
- Cline J 2012. Calcium and vitamin D metabolism, deficiency, and excess. *Top Companion Anim Med.* 27: 159-164.
- Corbee RJ, Tryfonidou MA, Meij BP, Kooistra HS and Hazewinkel HA 2012. Vitamin D status before and after hypophysectomy in dogs with pituitary-dependent hypercortisolism. *Domest Anim Endocrinol.* 42: 43-49.
- Dittmer KE and Thompson KG 2011. Vitamin D metabolism and rickets in domestic animals: a review. *Vet Pathol.* 48: 389-407.
- Dogan A, Uslu M, Aydinlioglu A, Harman M and Akpınar F 2007. Morphometric study of the human metatarsals and phalanges. *Clin Anat.* 20: 209-214.
- Hacimustafaoglu AS 2023. Tirotoksikozlu hastalarda kemik turnover belirteçlerinin tiroid fonksiyon testleri ile korelasyonu. Uludağ Univ, Specialty Thesis, Bursa.
- Hatun S, Bereket A, Calikoglu AS and Ozkan B 2003. Vitamin D deficiency and nutritional rickets today. *Cocuk Sagligi ve Hastalik. Derg.* 46: 224-241.
- Hiney KM, Nielsen BD, Rosenstein D, Orth MW and Marks BP 2004. High-intensity exercise of short duration alters bovine bone density and shape. *J Anim Sci.* 82: 1612-1615.
- Kawaguchi K, Braga IS, Takahashi A, Ochiai K and Itakura C 1993. Nutritional secondary hyperparathyroidism occurring in a strain of German Shepherd puppies. *Jpn J Vet Res.* 41: 89-96.
- Krook L and Whalen JP 2010. Nutritional secondary hyperparathyroidism in the animal kingdom: Report of two cases. *Clin Imaging.* 34: 458-461.
- Kul M 1996. Konya yöresindeki buzağılarda şekillenen metabolik kemik hastalıklarının teşhisinde biyokimyasal ve radyolojik kriterlerin önemi. PhD Thesis, Selçuk Univ, Konya.
- Kushwaha RB, Aithal HP, Kinjavdekar P, Amarpal and Kumar K 2012. Incidence of skeletal diseases affecting long bones in growing dogs: A radiographic survey. *Intas Polivet.* 13: 337-344.
- Mooney CT, Shiel RE, Sekiya M, Dunning M and Gunn E 2020. A preliminary study of the effect of hyperadrenocorticism on calcium and phosphate concentrations, parathyroid hormone and markers of bone turnover in dogs. *Front Vet Sci.* 7: 311.
- Nazem MN, Sadeghi A and Mostafavi A 2015. Radiographic assessment of bone cortex to bone diameter ratio of radius, tibia, metacarpus, metatarsus and proximal phalanx of fore and hindlimbs in miniature donkey. *Iran J Vet Surg.* 10: 49-56.
- Ograk YZ, Ozturk N, Akin D and Ozcan M 2018. Comparison of various body measurements of Aksaray Malakli and Kangal dogs. *J Istanbul Vet Sci.* 2: 86-91.
- Ongen B, Kabaroglu C and Parildar Z 2008. Biochemical and laboratory evaluation of vitamin D. *Türk Klin Biyokimya Derg.* 6: 23-31.
- Ramsey IK, Tebb A, Harris E, Evans H and Herrtage ME 2005. Hyperparathyroidism in dogs with hyperadrenocorticism. *J Small Anim Pract.* 46: 531-536.
- Samsar E and Akin F 2000. Genel Cerrahi. Özkan Matbaacılık Ltd. Şti., Ankara.
- Shahraki RG, Shomali T, Taherianfard M, Derakhshandeh N, Nazifi S and Abhaji E 2024. A study on the effects of vitamin D supplementation on hematological parameters and serum 25-hydroxy vitamin D in healthy dogs. *BMC Vet Res.* 20: 221.
- Sharma N, Sing R, Mohindroo J and Sharma A 2017. Evaluation of vitamin D3-calcium therapy in rachitic dogs. *J Anim Res.* 7: 515-521.

- Tal M, Parr JM, MacKenzie S and Verbrugghe A 2018. Dietary imbalances in a large breed puppy, leading to compression fractures, vitamin D deficiency, and suspected nutritional secondary hyperparathyroidism. *Can Vet J.* 59: 36–40.
- Yurdakul I and Bakır B 2017. Radiological and biochemical diagnosis of skeletal developmental disorders due to growth in Van cats. *Van Vet J.* 28: 131–136.