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Nutritional osteodystrophy in South American birds of prey[1]

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ABSTRACT.- Oliveira LGS, Boabaid FM, Lorenzett MP, Almeida PR, Ehlers LP, Sonne L, Cruz CEF, Driemeier D. **Nutritional osteodystrophy in South American birds of prey.** *Pesquisa Veterinária Brasileira 45:e07592, 2025*. Setor de Patologia Animal, Faculdade de Veterinária, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves 9090, Porto Alegre, RS 91540-000, Brazil. E-mail: davetpat@ufrgs.br

Nutritional osteodystrophy is a metabolic bone disease characterized by increased bone resorption and replacement by fibrous connective tissue, resulting from a diet with excess phosphorus or deficient in calcium or vitamin D. In this retrospective study, we describe the clinical and pathological findings from six raptor chicks with metabolic bone disease. Included are a southern caracara (*Caracara plancus*), a black vulture (*Coragyps atratus*), three barn owls (*Tyto furcata*) and a Stygian owl (*Asio stygius*) presenting poor development, prostration, locomotor disorders and deformed bones. All birds were free-living orphaned juveniles that were rescued and fed by lay keepers, who inadvertently provided inadequate diets in the form of boneless meat or homemade food. During the clinical care, birds were supplemented with oral and/or parenteral calcium and given supportive treatment. The birds died spontaneously or were euthanized due to poor prognosis. At necropsy, birds revealed poor body condition, skeletal deformities, soft bones with multiple fractures, and enlarged parathyroid glands. At histopathology, bones of all birds presented thin bone trabeculae surrounded by numerous osteoclasts or plump osteoblasts, with diffuse replacement by fibrous connective tissue. Additionally, parathyroid glands were hyperplastic and hypertrophied. The diagnosis of secondary osteodystrophy of nutritional origin was determined based on clinical and pathological data and a history of apparent unbalanced calcium food supply. The aim of this study was to gather information on the pathological aspects of fibrous osteodystrophy in different species of neotropical birds of prey and to review the condition with emphasis on wild birds. The results obtained reinforce the need for adequate feeding of these species in captivity.

INDEX TERM: Metabolic bone disease, nutritional osteodystrophy, neotropical raptors, Tytonidae, Strigidae, Falconidae, Cathartidae.

RESUMO.- [Osteodistrofia nutricional em aves de rapina da América do Sul.] A osteodistrofia nutricional é uma doença óssea metabólica caracterizada por aumento da reabsorção óssea e substituição por tecido conjuntivo fibroso, resultante de uma dieta com excesso de fósforo ou deficiente em cálcio ou vitamina D. Neste estudo retrospectivo são descritos os aspectos clínicos e patológicos da doença óssea metabólica em seis filhotes de aves de rapina. São parte do estudo um carcará (*Caracara plancus*), um urubu-preto (*Coragyps atratus*), três suindaras (*Tyto furcata*) e um mocho-diabo (*Asio stygius*) que apresentaram baixo desenvolvimento corporal, prostração, desordens locomotoras e deformidades ósseas. Todas as aves

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eram filhotes órfãos que foram resgatadas e alimentadas por criadores leigos, que lhes forneceram inadvertidamente carne desossada ou comida caseira. Durante o atendimento clínico as aves foram suplementadas com cálcio oral e/ou parenteral e receberam tratamento suporte. As aves morreram naturalmente ou foram submetidas à eutanásia devido ao prognóstico desfavorável. À necropsia as aves apresentavam condição corporal ruim, deformidades esqueléticas, ossos frágeis com múltiplas fraturas e paratireoides aumentadas. Ao exame histopatológico constatou-se que os ossos apresentavam trabéculas delgadas contendo numerosos osteoclastos ou osteoblastos volumosos, com substituição difusa por tecido conjuntivo fibroso. Adicionalmente as paratireoides estavam hiperplásicas e hipertróficas. O diagnóstico de osteodistrofia secundária de origem nutricional foi determinado em base aos dados clínicos e patológicos, associado aos dados históricos de fornecimento de dieta desequilibrada em cálcio. O objetivo deste trabalho foi de reunir informação sobre os aspectos patológicos da osteodistrofia fibrosa em diferentes espécies de aves de rapina neotropicais e revisar a condição com ênfase em aves silvestres. Os resultados obtidos reforçam a importância de uma alimentação adequada para rapinantes em cativeiro.

TERMOS DE INDEXAÇÃO: Doença óssea metabólica, osteodistrofia nutricional, aves de rapina neotropicais, Tytonidae, Strigidae, Falconidae, Cathartidae.

INTRODUCTION

Nutritional osteodystrophy is a type of fibrous osteodystrophy, under the definition of metabolic bone diseases, which is pathologically characterized by extensive bone resorption and proliferation of fibrous connective tissue and immature bone resulting from a dietary excess of phosphorus or a deficiency of calcium or vitamin D. The mechanism involved in those events is linked to a decrease in plasma levels of ionized calcium, due to excess levels of dietary phosphorus, resulting in parathyroid stimulation with hypertrophy and eventual hyperplasia of the parathyroid chief cells and increased secretion of parathyroid hormone (PTH) (Capen 2007, Craig et al. 2016).

This disease is reported in a wide range of species, including horses, goats, pigs (Bandarra et al. 2011, Ospina et al. 2014, Craig et al. 2016), dogs (Kawaguchi et al. 1993), cats (Tomsa et al. 1999), wild felids (Krook & Whalen 2010, Asi et al. 2014), antelopes (Boulay et al. 1972, Grandi et al. 2011), dromedaries (Lynch et al. 1999), neoptropical primates (Fowler 1986), lizards, iguanas, crocodilians and chelonians (Anderson & Capen 1976, Fowler 1986). In birds, the condition is described in different taxa, such as psittacines (Arnold et al. 1974, Harcourt-Brown 2003), corvids (Tangredi & Krook 1999), ardeids (Phalen et al. 2005), anatids (Ewbank et al., 2013), and spheniscids (Palmieri et al. 2021), among others. In birds of prey, osteodystrophy is seen especially in young raptors fed on all-meat diets devoid of bone (Keymer 1972, Cooper 1975, 2002). This kind of diet has a low calcium-to-phosphorus ratio (Capen 2007). The clinical signs seen in birds of prey include soft, pliable bones, frequently associated with spontaneous fractures (Wallach & Flieg 1970, Cooper 2002).

Despite the common denominator of carnivory, birds of prey are indeed an assemblage of distinct taxa with common adaptations for their lifestyle. The relationship among these birds is still in debate, but a classical taxonomy divides the group in the orders Strigiformes, composed of the owls (families Tytonidade and Strigidae) and the Falconiformes, with the New World vultures (family Cathartidae), the falcons (family Falconidae), the hawks, eagles and Old World vultures (family Accipitridae), the osprey (family Pandionidae), and the Secretary-bird (family Sagittariidae) (Cooper 2002, McClure et al. 2019). Additionally, some authors maintain that seriemas (order Cariamiformes) should also be considered part of the group (McClure et al. 2019). Birds of prey are among the most threatened birds in the world, and tropical representatives have, at the same time, the highest diversity and the lowest amount of information (Beuchley et al. 2019).

Major efforts to conserve many species, either *in situ* or in the wild, such as the California condor (*Gymnogyps californianus*) and the African and Eurasian vultures (Johnson et al. 2010, Botha et al. 2017) are in progress. Other projects have involved translocation of wild-produced young to locations from which they have been extirpated, such as the recovery programs of bald eagles (*Haliaeetus leucocephalus*) (Grier et al. 1983), ospreys (*Pandion haliaetus*) (Martell et al. 2002); others have entailed captive propagation and release, such as peregrine falcons (*Falco peregrinus*) (Weaver & Cade 1991), Taita falcons (*Falco fasciinucha*) (Hartley et al. 1993) and aplomado falcons (*Falco femoralis*) (Hunt et al. 2013). As these efforts involve considerable rearing of young in captivity prior to release as well as provisioning post-release, meeting their specialized dietary requirements is paramount to ensuring their development and survival. Owls, New World vultures and caracaras are characteristic components of the neotropical avifauna and play an important role in several ecosystems of the continent. While owls are specialized nocturnal predators, vultures are scavengers, and caracaras are opportunistic predators or scavengers (Sick 1997a, 1997b); regardless, all are obligate carnivores. The aim of this retrospective study was to describe the clinical and pathological findings of nutritional osteodystrophy in six young hand-reared raptorial birds of four different species native to Brazil, and finally, to provide a short review of the disease in wild birds.

MATERIALS AND METHODS

Ethical approval. In this study we did not perform any animal experiments. All data were obtained from the files of the "Setor de Patolgia Veterinária" at the "Universidade Federal do Rio Grande do Sul" (UFRGS).

Clinical cases. Six juvenile birds of prey were brought to the Veterinary Faculty Hospital, located in Porto Alegre, Rio Grande do Sul State, Brazil, from January 2009 to January 2019 for clinical evaluation and treatment of a similar apparent locomotor disorder. Included were one southern caracara (*Caracara plancus*), one black vulture (*Coragyps atratus*), one Stygian owl (*Asio stygius*) and three barn owls (*Tyto furcata*) (Table 1). The birds were brought at different times and from different origins, except for the three barn owls, which were found together on a roadside. All chicks were hand-fed with boneless beef, and the black vulture received cooked rice and beans. The birds received parenteral treatment with calcium as follows: the black vulture was treated with intramuscular calcium gluconate 10% (100 mg/kg). The remaining birds received oral tricalcium phosphate. Additionally, the owls were immobilized with

splints on their legs (Fig. 1). A radiographic evaluation of the skeletal alterations has been performed in one bird (Case 2) (Fig. 2). No data on dietary changes or supplements were provided. The birds were treated for 24 to 72 hours, but did not respond to treatment efforts and eventually died or were euthanized due to poor prognosis.

Necropsy. Immediately after natural death or euthanasia, the six raptors were sent for *post mortem* evaluation at the Veterinary Pathology Section and representative fragments of the organs were collected.

Histopathology. Tissue sections from the esophagus, crop, proventriculus, gizzard, small and large intestines, pancreas, liver, kidneys, spleen, bursa of Fabricius, lung, trachea, air sacs, heart, skeletal muscle, brain, gonads, thyroids, parathyroid glands and tibiotarsal bones were collected and fixed in 10% buffered formalin. Of the six birds, the growth plate has not been sampled in two cases (Cases 1 and 2). After fixation, the bones were decalcified in 8% nitric acid. All samples were routinely processed for histological evaluation and stained with hematoxylin and eosin (HE), as well as Masson's trichrome stain for further histological study of the bones.

RESULTS

Clinical cases

At the clinical evaluation, birds showed prostration, locomotor impairment, severe skeletal deformities, and soft, pliable bones associated with multiple incomplete fractures, with one side of the cortical bone exhibiting loss of continuity and the opposite side only bent (greenstick fractures). The radiographic study performed on the black vulture (*Coragyps atratus*) (Case 2) revealed deformities of the limb bones and fractures in the diaphysis of the tarso-metatatarsal bones.

Despite treatment, the clinical course worsened in a few days, and all birds died spontaneously or were euthanized due to poor prognosis.

Necropsy

At necropsy, all chicks exhibited poor body condition with scant internal body fat and diffuse muscular atrophy. All chicks presented with severe deformities of the appendicular skeleton, with deviation of bone shafts associated with multiple non-consolidated fractures and calluses (Fig. 3 and 4). When manipulated, bones showed a soft and pliable consistency, particularly the maxillary, mandibular and long bones (Fig. 5 and 6). A slight enlargement of the parathyroid glands was observed in four cases.

Histopathology

At the tibiotarsal metaphysis and diaphysis, in sections distant from fractures, the cortical and trabecular bones were markedly thin. Between the disorganized trabeculae, there was intense proliferation of fibroblasts, with severe deposition of amorphous connective matrix (Fig. 7), which was evidenced by Masson's trichrome staining (Fig. 7 inset). Surrounding many trabecular surfaces in Howship's lacunae, there were numerous osteoclasts (Fig. 8) or plump osteoblasts. In sections of bone sampled at fracture sites, there were also areas of break in the continuity of the bone, with hemorrhage and deposition of cellular debris, as well as mild infiltration of immature fibroblasts and mild neovascularization. In Cases 2, 3, 4 and 5, besides fractures, there was a mild proliferation of an unorganized meshwork of woven bone with peripheral deposition of fibrous connective tissue and cartilaginous matrix

Table 1. Signalment and gross findings of the juvenile birds of prey with nutritional osteodystrophy

Case	Species	Sex	Diet	Gross findings
1	Southern caracara (*Caracara plancus*)	NA	Boneless meat	Poor body condition, severe deformities of the appendicular skeleton. Soft pliable bones, mainly of the digits, maxilla and mandible. Simple complete fractures of the left and right tarsometatarsus.
2	Black vulture (*Coragyps atratus*)	M	Home made food*	Poor body condition, severe deformities of the appendicular skeleton and tortuous cervical spine. Soft pliable bones, especially of the maxilla and mandible. Complete simple fractures of the right humerus and right tibiotarsus. Bone callus on the left and right humerus. Shaft deviation of the left and right tarsometatarsus. Parathyroids mildly increased.
3	Barn owl (*Tyto furcata*)	M	Boneless meat	Poor body condition. The bones of the mandible and maxilla, ribs, forelimbs and pelvic limbs were soft and pliable. Complete simple fractures were seen bilaterally in the tibiotarsus and the right tarsometatarsus. The third, forth, fifth and sixth ribs had fracture calluses. Parathyroids were mildly increased.
4	Barn owl (*Tyto furcata*)	M	Boneless meat	Poor body condition. The bones of the mandible, maxilla, ribs, forelimbs and pelvic limbs were soft and pliable. There was a simple fracture of the distal portion of the right radio and ulna, next to the carpus. Fracture calluses were seen in the right coracoid bone and in the third and forth rib of the right side, adjacent to the spine. Parathyroids were mildly increased.
5	Barn owl (*Tyto furcata*)	M	Boneless meat	Poor body condition. Bones of the mandible, maxilla, appendicular and axial skeleton were soft and pliable. There were bilateral simple fractures of the proximal portion of the tibiotarsus. The right tarsometatarsus had one proximal fracture callus. Parathyroids were mildly increased.
6	Stygian owl (*Asio stygius*)	F	Boneless meat	Poor body condition. There was a compound fracture of the left humeral bone. The mandibular, maxillary and appendicular bones were soft and pliable.

NA = not available, F = female, M = male; * cooked rice and beans.

(callus). Of the four cases in which the growth plates were analyzed, none presented lesions compatible with rickets. Along with the skeletal lesions, the parathyroid glands were mildly enlarged, with cellular proliferation and exhibiting a finely vacuolated cytoplasm (hyperplasia and hypertrophy). The remaining organs showed no significant histological changes.

DISCUSSION

Based on clinical and pathological changes, combined with the history of an imbalanced diet, we concluded that the birds developed fibrous osteodystrophy due to nutritional secondary hyperparathyroidism, similar to other reports in captive birds of prey (Wallach & Flieg 1970, Cooper 1973, 1975, Toyoda et al. 2004). Nutritional fibrous osteodystrophy can result from either calcium or vitamin D deficiency, or from an imbalance between calcium and phosphorus in the diet of a variety of animal taxa (Fowler 1986). The same pathogenesis is associated with rickets in juveniles of different bird and mammal species, and by definition, it is associated with vitamin D deficiency (Toyoda et al. 2004, Ewbank et al. 2013).

The major cause of fibrous osteodystrophy in birds of prey is nutritional secondary hyperparathyroidism, resulting from a relatively low dietary calcium intake (Cooper 1975, Phalen et al. 2005, Carciofi & Oliveira 2007). A diet composed of skeletal or heart muscle, for instance, has a calcium:phosphorus ratio of approximately 1:20 to 1:30 (Cooper 1975, Craig et al. 2016), while the optimum ratio for raptors is estimated at 1.5:1 (Wallach & Flieg 1970, Cooper 1975). Apart from its structural function in bones, calcium plays an important role in neuromuscular function, and its plasma concentrations are strictly controlled (Carciofi & Oliveira 2007). High dietary levels of phosphorus decrease plasma availability of ionized calcium, which in turn triggers secretion of parathyroid hormone (PTH). PTH, in turn, increases the production of receptor-activator of nuclear kappa beta ligand (RANKL) on osteoblasts, leading to osteoclast differentiation, activation and survival, which results in enhanced bone resorption (Wright et al. 2009). The result of such imbalance is a deficient bone mineralization with subsequent replacement by fibrous tissue in the bone space that may or may not be accompanied by neuromuscular signs (Cooper 1975, 2002). Skeletal deformities, such as rickets, can develop within five to 15 days in birds of prey fed on an all-meat diet (Graham 1976). However, the development of nutritional secondary hyperparathyroidism can occur much more rapidly, as seen in a case involving a two-week-old Cooper's hawk (*Accipiter*

Fig. 1-2. (**1**) Barn owl (*Tyto furcata*) chick with severe metabolic bone disease, the bird is prostrate and unable to stand. Splints on the legs were used to ensure stability. (**2**) Ventro-dorsal radiographic imaging, young, Black Vulture (*Coragyps atratus*), presenting generalized loss of radiopacity of the bones and marked thinning of the cortical bone. There are also severe deformities of the long bones of the wings and limbs, as well as a tortuous cervical spine. Bilaterally, there are also partial fractures in the middle portion of the tarsometatarsal bones, characteristic of greenstick fractures.

cooperii) presented to The Raptor Center of the University of Minnesota, which developed bone deformities within two days after starting to receive a diet of beef heart (Redig 2020). Based on the histological abnormalities observed in our cases, we conclude that the primary pathological process in the chicks' bones is fibrous osteodystrophy.

Neurological signs – including muscle spasms known as "cramps", generalized tetany called "fits", or tonic-clonic seizures – can be seen in raptors with critically low serum levels of calcium (5 mg/100 ml of serum) when calcium stores are nearly depleted in bones (Wallach & Flieg 1970, Halliwell et al. 1973). These neurological signs can be precipitated

Fig. 3-6. (**3**) Barn owl (*Tyto furcata*) chick in poor body condition with marked deviation of the bone shafts of the right tibiotarsus and tarsometatarsus. (**4**) Southern caracara (*Caracara plancus*) chick with evident deformities of the long bones of the legs. (**5**) Southern caracara (*C. plancus*), the mandibular bones of the chick are easily bent by hand. (**6**) The tibiotarsus of the young Stygian owl (*Asio stygius*) is soft and pliable.

by stress, such as the sudden appearance of a keeper, a loud noise or when lights are turned on at night (Wallach & Flieg 1970). Neurological signs similar to those induced by calcium deficiency are also seen in carnivorous birds fed only on meat, one-day-old chicks or piscivorous birds receiving thiaminase-containing fish, due to thiamine (vitamin B1) deficiency (Macwhirter 1994). However, none of the cases reported in this paper developed neurological signs, possibly because critical calcium plasma levels were maintained by hormonal mechanisms or through supplemental calcium administration.

In the wild, the disease is considered rare, although it has been reported in nestlings of Old World vultures (*Gyps africanus* and *Gyps coprotheres*) in certain regions of South Africa (Richardson et al. 1986, Abrey 1993). The condition has been associated with the local eradication of hyenas (*Crocuta crocuta* and *Hyaena brunnea*), which are the only scavengers that are able to crush large bones into small fragments that can be swallowed by vulture chicks (Richardson et al. 1986). In northeastern Brazil, metabolic bone diseases have been reported in free-living specimens of a rufous crab-hawk (*Buteogallus aequinoctialis*) and a savanna hawk (*Heterospizias meridionalis*); the former characterized as rickets and the latter as fibrous osteodystrophy (Guerra et al. 2018). The authors could not determine the cause of the events due to the lack of extensive fieldwork; however, an environmental imbalance resulting in an altered diet has been hypothesized (Guerra et al. 2018). In central Texas, the disease was reported in free-living cattle egret chicks (*Bubulcus ibis*), due to the expansion of birds into an area with low vertebrate prey availability, resulting in a diet with insufficient calcium content for the nestlings (Phalen et al. 2005).

It is important to note that some authors argue that feeding juvenile raptors with day-old chicks does not meet the calcium requirements of the growing skeleton, as the immature bones of the chicks have marginal calcium values (Cooper 1975). Other authors, in contrast, consider day-old chicks the ideal staple diet for the majority of raptor species, as they are high in protein, low in fat and have adequate levels of calcium (Forbes 2000). Attention should also be paid to the amount of fat contained in food, as fat can form an insoluble soap with calcium, resulting in low intestinal calcium absorption. Similarly, when dietary phosphorus and manganese contents are too high, these minerals can form salts with calcium, decreasing their intestinal absorption (Wallach & Flieg 1970). Oral vitamin D_3 supplementation is also required for captive birds kept with no access to sunlight, for normal intestinal calcium absorption and skeletal deposition (Wallach & Flieg 1970). Although a dietary calcium:phosphorus imbalance was assumed to be the cause of fibrous osteodystrophy in two hand-fed northern royal albatross chicks (*Diomedea sanfordi*), it may also be assumed that a vitamin D deficiency contributed to the presentation, as the chicks were treated with a rancid sooty shearwater (*Ardenna grisea*) proventricular oil, which can lead to the oxidative degradation of vitamin D (Morgan et al. 2011).

In free-living fledglings of American crows (*Corvus brachyrhynchos*), nutritional secondary hyperparathyroidism developed secondary to low bioavailability of calcium, and/or low vitamin D activation, hypothesized to be due to a competition for hydroxylation between the vitamin D precursors and exogenous chemicals to which birds were exposed (Tangredi & Krook 1999). Although in this study the chemical was not determined, substances like anticonvulsants, aluminum, cholinesterase inhibitors, and DDT have been mentioned as potential causes of metabolic bone disease in humans, amphibians and birds (Tangredi & Krook 1999). Another aspect to have in mind when formulating diets for raptors is the particular requirement of each species, exemplified by the case of growing secretary-birds (*Sagittarius serpentarius*), which may suffer calcium deficiency even if fed on a standard raptor diet. It is thought that the species' requirement for

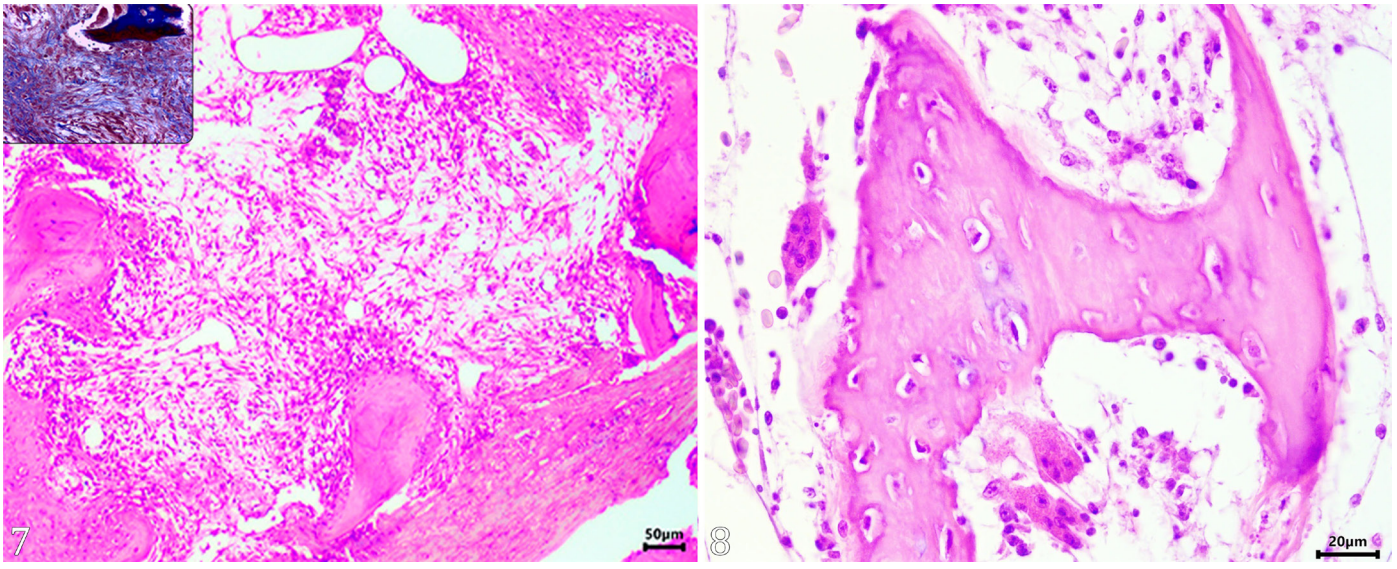

Fig. 7-8. (**7**) Tibiotarsus, proximal, barn owl (*Tyto furcata*) chick, the intertrabecular space is widely replaced by fibrous connective tissue. HE, bar = 50 µm. At the top left, a Masson's trichrome of the same bone highlights the widespread deposition of fibrous connective tissue. (**8**) Tibiotarsus, proximal, barn owl (*Tyto furcata*) chick, at the center is a bone trabecula surrounded by numerous osteoclasts. HE, bar = 20 µm.

calcium may be especially high due to functional adaptation to the elevated levels of calcium phosphate contained in its diet in the wild, which is composed essentially of snakes (Cooper 2002). Likewise, the bones of deceased large mammals make up the bulk of the diet of bearded vultures (*Gypaetus barbatus*) in Africa, Asia and Europe, which represents a highly unusual calcium:phosphorus ratio diet, containing 15-18% calcium (Houston & Copsey 1994). In a recent study, the occurrence of nutritional secondary fibrous osteodystrophy in a captive adult female black-footed African penguin (*Spheniscus demersus*) was attributed to low levels of calcium supplementation during egg laying, probably exacerbated by inadequate photoperiod mimicking daylight pattern, resulting in asynchronous egg-laying cycles and abnormal breeding behavior (Palmieri et al. 2021).

The species of raptors in our study are not specialized in preying on snakes or scavenging bones (Sick 1997a, 1997b). However, the predisposition of juveniles to develop metabolic bone disease after receiving a mineral-unbalanced diet demonstrates that the chicks naturally rely on balanced sources of minerals in their diets.

CONCLUSION

The cases described here demonstrate the clinical and pathological picture of fibrous osteodystrophy in different South American birds of prey. Furthermore, we emphasize the importance of feeding whole bodies of suitable prey-type species, including bone (ground to a mash for very young birds), to meet the mineral requirements of raptors when rearing young birds in captivity.

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Conflict of interest statement.- The authors have no conflicts of interest to declare.

Credit author statement.- LGSO: conceptualization, writing, investigation, methodology and review. FMB: conceptualization, writing, investigation, methodology and review. MPL: conceptualization, investigation, and methodology. PRA: investigation, and methodology. LPE: investigation, and methodology. LS: conceptualization, supervision, writing, investigation, methodology and review. CEFC: writing, and review. DD: conceptualization, supervision, writing, investigation, methodology and review.

Data availability statement.- The entire dataset supporting the results of this study was published in the article itself.

REFERENCES

Abrey ANS. Diseases of wild birds in Southern Africa, p.166. In: Fowler ME. Zoo and Wild Animal Medicine: current therapy. 3rd ed. Philadelphia: Saunders; 1993.

Anderson MP, Capen CC. Nutritional osteodystrophy in captive green iguanas (*Iguana iguana*). Virchows Archiv B Cell Path 1976; https://doi.org/10.1007/BF02899157

Arnold SA, Kram MA, Hintz HF, Evans H, Krook L. Nutritional secondary hyperparathyroidism in the parrakeet. Cornell Vet 1974;64(1):37-46. PMid:4812599

Asi MN, Lodhi LA, Mughal MN, Abbas G, Muhammad G, Saquib M. Nutritional secondary hyperparathyroidism in an African lion cub (*Panthera leo*). Pak Vet J 2014;34(4):554-556.

Bandarra PM, Pavarini SP, Santos AS, Antoniassi NAB, Cruz CEF, Driemeier D. Nutritional fibrous osteodystrophy in goats. Pesq Vet Bras 2011; https://doi.org/10.1590/S0100-736X2011001000007

Beuchley ER, Santageli A, Girardello M, Neate-Clegg MHC, Oleyar D, McClure CJW, Şekercioğlu ÇH. Global raptor research and conservation priorities: Tropical raptors fall prey to knowledge gaps. Divers Distrib 2019; https://doi.org/10.1111/ddi.12901

Botha AJ, Andevski J, Bowden CGR, Gudka M, Safford RJ, Willians NP. Multi-species Action Plan to Conserve African-Eurasian Vultures (VULTURE MSAP). CMS Raptors MOU Technical Publication No. 5, CMS Technical Series No. XX, Abu Dhabi, United Arab Emirates. 2017. Accessed on Sep. 20, 2024. https://www.cms.int/sites/default/files/document/cms_cop12_doc.24.1.4_annex3_vulture-msap_e.pdf

Boulay GH, Hime JM, Verity PM. Spondylosis in captive wild animals. A possible relationship with nutritional osteodystrophy. Br J Radiol 1972; https://doi.org/10.1259/0007-1285-45-539-841

Capen CC. Endocrine glands. In: Maxie MG. Jubb, Kennedy, and Palmer's Pathology of Domestic Animals. 5th ed. Vol 1. Philadelphia: Elsevier; 2007.

Carciofi AC, Oliveira LD. Doenças nutricionais. In: Cubas ZS, Silva JCR, Catão-Dia JL. Tratado de Animais Selvagens: medicina veterinária. São Paulo: Roca; 2007.

Cooper JE. Nutritional diseases including poisoning in captive birds. In: Cooper JE. Birds of Prey: health and disease. 3rd ed. Oxford: Blackwell; 2002.

Cooper JE. Osteodystrophy in birds of prey. Vet Rec 1975; https://doi.org/10.1136/vr.97.16.307-a

Cooper JE. *Post-mortem* findings in East African birds of prey. J Wildl Dis 1973; https://doi.org/10.7589/0090-3558-9.4.368

Craig LE, Dittmer KE, Thompson KG. Bones and joints. In: Maxie MG. Jubb, Kennedy, and Palmer's Pathology of Domestic Animals. 6th ed. Vol. 1. Philadelphia: Elsevier; 2016.

Ewbank AC, Ruder MG, McRuer DL, Armién AG. What Is Your Diagnosis? Chronic severe nutritional osteodystrophy, or rickets. J Avian Med Surg 2013; https://doi.org/10.1647/2012-074

Forbes NA. An outline of readily available raptor food. In: Forbes NA. Raptor Nutrition. England: Honeybrook Farm Animals Foods; 2000.

Fowler ME. Metabolic bone disease. In: Fowler ME. Zoo and Wild Animal Medicine. 2nd ed. Philadelphia: Elsevier; 1986.

Graham DL. Malnutrition in captive birds of prey. In: Page LA. Wildlife Diseases. 1976; https://doi.org/10.1007/978-1-4757-1656-6_11

Grandi F, Pessoa LMB, Lúcio Filho F, Araújo R, Rocha RM, Fava CD. Fibrous osteodystrophy in a captive common eland antelope (*Taurotragus oryx*). Braz J Vet Pathol 2011;4(3):239-242.

Grier JW, Elder JB, Gramlich FJ, Green NF, Kussman JV, Mathisen JE, Mattsson JP. Northern States Bald Eagle Recovery Plan. Denver: U.S. Fish and Wildlife Service; 1983. Accessed on Sep. 20, 2024. https://portal.ct.gov/-/media/ceq/publications/northern-states-bald-eagle-recovery-plan-1983.pdf

Guerra RR, Dias GF, Nascimento HHL, Oliveira Neto TS, Lucena RB. Metabolic bone diseases in a wild crab-eating hawk and a Caboclo hawk in Paraíba. Acta Vet Brasilica 2018; https://doi.org/10.21708/avb.2018.12.2.7618

Halliwell WH, Graham DL, Ward FP. Nutritional diseases in birds of prey. J Zoo Anim Med 1973; https://doi.org/10.2307/20094194

Harcourt-Brown N. Incidence of juvenile osteodystrophy in hand-reared grey parrots (*Psittacus* e *erithacus*). Vet Rec 2003; https://doi.org/10.1136/vr.152.14.438

Hartley RR, Bodington G, Dunkley AS, Groenewald A. Notes on the breeding biology, hunting behavior, and ecology of the Taita falcon in Zimbabwe. J Raptor Res 1993;27(3):133-142.

Houston DC, Copsey JA. Bone digestion and intestinal morphology of the bearded vulture. J Raptor Res 1994;28(2):73-78.

Hunt WG, Brown JL, Cade TJ, Coffman J, Curti M, Gott E, Heinrich W, Jenny JP, Juergens P, Macías-Duarte A, Montaya AB, Mutch B, Sandfort C. Restoring aplomado falcons to the United States. J Raptor Res 2013; https://doi.org/10.3356/JRR-12-52.1

Johnson M, Kern J, Haig SM. Analysis of California condor (*Gymnogyps californianus*) Use of Six Management Units Using Location data from Global Positioning System Transmitters, Southern California, 2004–09—Initial Report: open-file report 2010-1287. Reston: United States Geological Survey (USGS); 2010. Accessed on Sep. 20, 2024. https://pubs.usgs.gov/of/2010/1287/pdf/ofr20101287.pdf

Kawaguchi K, Braga III IS, Takahashi A, Ochiai K, Itakura C. Nutritional secondary hyperparathyroidism occurring in a strain of German shepherd puppies. Jpn J Vet Res 1993; https://doi.org/10.14943/jjvr.41.2-4.89

Keymer IF. Diseases of birds of prey. Vet Rec 1972;90(21):579-594. PMid:5073130

Krook L, Whalen JP. Nutritional secondary hyperparathyroidism in the animal kingdom: report of two cases. Clin Imaging 2010; https://doi.org/10.1016/j.clinimag.2010.08.010

Lynch MJ, Slocombe RF, Harrigan KE, Laing CJ. Fibrous osteodystrophy in dromedary camels (*Camelus dromedarius*). J Zoo Wildl Med 1999;30(4):577-583. PMid:10749449

Macwhirter P. Malnutrition. In: Ritchie BW, Harrison GJ, Harrison LR. Avian Medicine: principles and application. Lake Worth: Wingers; 1994.

Martell MS, Englund JV, Tordoff HB. An urban osprey population established by translocation. J Raptor Res 2002;36(2):91-96.

McClure CJW, Schulwitz SE, Anderson DL, Robinson BW, Mojica EK, Therrien J-F, Oleyar MD, Johnson J. Commentary: defining raptors and birds of prey. J Raptor Res 2019; https://doi.org/10.3356/0892-1016-53.4.419

Morgan KJ, Alley MR, Gartrell BD, Thompson KG, Perriman L. Fibrous osteodystrophy in two northern royal albatross chicks (*Diomedea sanfordi*). N Z Vet J 2011; https://doi.org/10.1080/00480169.2011.596265

Ospina JC, Doncel B, Garcia NV. Maxillofacial fibrous osteodystrophy in equine: case report. Braz J Vet Pathol 2014;7(2):100-105.

Palmieri C, Niemeyer C, Murray MJ, Ewbank AC, Shivaprasad HL. Nutritional secondary hyperparathyroidism and fibrous osteodystrophy in a captive African penguin (*Spheniscus demersus*) similar to osteomalacia in poultry. Avian Dis 2021; https://doi.org/10.1637/aviandiseases-D-20-00077

Phalen DN, Drew ML, Contreras C, Roset K, Mora M. Naturally occurring secondary nutritional hyperparathyroidism in Cattle Egrets (*Bubulcus ibis*) from central Texas. J Wildl Dis 2005; https://doi.org/10.7589/0090-3558-41.2.401

Redig P. The Raptor Center, University of Minnesota. United States of America. Personal Communication. 2020.

Richardson PRK, Mundy PJ, Plug I. Bone crushing carnivores and their significance to osteodystrophy in Griffon vulture chicks. J Zool 1986; https://doi.org/10.1111/j.1469-7998.1986.tb03618.x

Sick H. Ordem Falconiformes. In: Sick H, Pacheco JF. Ornitologia Brasileira. 2ª ed. rev. e ampl. Rio de Janeiro: Nova Fronteira; 1997a.

Sick H. Ordem Strigiformes. In: Sick H, Pacheco JF. Ornitologia Brasileira. 2ª ed. rev. e ampl. Rio de Janeiro: Nova Fronteira; 1997b.

Tangredi BP, Krook LP. Nutritional secondary hyperparathyroidism in free-living fledgling American Crows (*Corvus brachyrhynchos brachyrhynchos*). J Zoo Wildl Med 1999;30(1):94-99. PMid:10367650

Tomsa K, Glaus T, Hauser B, Flückiger M, Arnold P, Wess G, Reusch. Nutritional secondary hyperparathyroidism in six cats. J Small Anim Pract 1999; https://doi.org/10.1111/j.1748-5827.1999.tb03015.x

Toyoda T, Ochiai K, Komatsu M, Kimura T, Umemura T. Nutritional secondary hyperparathyroidism and osteodystrophia fibrosa in a Hodgson's hawk-eagle (*Spizaetus nipalensis*). Avian Pathol 2004; https://doi.org/10.1080/03079450310001636237

Wallach JD, Flieg GM. Cramps and fits in carnivorous birds. Int Zoo Ybk 1970; https://doi.org/10.1111/j.1748-1090.1970.tb01247.x

Weaver JD, Cade TJ. Falcon Propagation: a manual on captive breeding. Boise: The Peregrine Fund; 1991. Accessed on Sep. 20, 2024. https://assets.peregrinefund.org/docs/research-library/manual-propagation-2017-02-28_163913.pdf

Wright HL, McCarthy HS, Middleton J, Marshall MJ. RANK, RANKL and osteoprotegerin in bone biology and disease. Curr Rev Musculoskelet Med 2009; https://doi.org/10.1007/s12178-009-9046-7