# Lessons from a non-domestic canid: joint disease in captive raccoon dogs (*Nyctereutes procyonoides*)

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**Summary**

The purpose of this study was to describe pathological changes of the shoulder, elbow, hip and stifle joints of 16 museum skeletons of the raccoon dog (*Nyctereutes procyonoides*). The subjects had been held in long-term captivity and were probably used for fur farming or research, thus allowing sufficient longevity for joint disease to become recognisable. The prevalence of disorders that include osteochondrosis, osteoarthritis and changes compatible with hip dysplasia, was surprisingly high. Other changes that reflect near-normal or mild pathological conditions, including prominent articular margins and mild bony periarticular rim, were also prevalent. Our data form a basis for comparing joint pathology of captive raccoon dogs with other mammals and also suggest that contributing roles of captivity and genetic predisposition should be explored further in non-domestic canids.

**Keywords**

Canidae, Hip dysplasia, Joint disease, *Nyctereutes procyonoides*, Osteoarthritis, Osteochondrosis, Raccoon dog.

## Lezioni da canide non domestico: patologia articolare in cani procioni (*Nyctereutes procyonoides*) in cattività

**Riassunto**

*Lo studio ha avuto l'obiettivo di descrivere le alterazioni patologiche riscontrate in spalla, gomito, anca e ginocchio da una collezione di 16 scheletri di* Nyctereutes procyonoides *(cane procione). I soggetti, tenuti a lungo in cattività e impiegati probabilmente come animali da pelliccia o per ricerca, hanno consentito per la loro longevità l'individuazione di casi di patologia articolare. La prevalenza della malattia, che ha incluso anche osteocondrosi, artrosi e alterazioni compatibili con la displasia dell'anca, è risultata sorprendentemente alta. Molto diffuse anche altre alterazioni attribuibili a condizioni quasi normali o lievemente patologiche, inclusi i margini articolari prominenti e lievi bordi ossei periarticolari. I dati ottenuti costituiscono una base per comparare la patologia articolare di cani procioni in cattività con quella di altri mammiferi e suggeriscono un approfondimento sul ruolo dello stato di cattività e della predisposizione genetica di Canidi non domestici.*

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**Parole chiave**
Cane procione, *Canidae*, Displasia dell'anca, Malattia articolare, *Nyctereutes procyonoides*, Osteoartrite, Osteocondrosi.

## Introduction

The raccoon dog (*Nyctereutes procyonoides*) is a medium-sized, fox-like member of the family Canidae, so named because the colour pattern of its facial hair resembles the raccoon (*Procyon lotor*). Historically, the raccoon dog was regarded as a more basal member of Canidae, related most closely to the grey fox (*Urocyon cinereoargenteus*) and the bat-eared fox (*Otocyon megalotis*), which occupy basal positions among extant Canidae (33). However, according to more recent data, the raccoon dog is phylogenetically closer to the red fox (*Vulpes vulpes*) and the arctic fox (*V. lagopus*), as revealed by chromosome painting (7).

The raccoon dog has been very successful as a free-ranging species, probably as a result of interacting factors that include efficient reproduction and an adaptable, omnivorous nature (33). Wild raccoon dogs prefer moist areas that provide dense ground cover, but they may invade and damage crops or prey on human-preferred fowl species. The relationship between humans and raccoon dogs has an additional and important One Health component because a number of zoonotic infections can be transmitted between the two species (28). For example, rabies, *Toxocara canis* and *Uncinaria stenocephala* are among approximately three dozen known infectious agents of raccoon dogs (33). Anti-*Toxoplasma gondii* antibodies have been reported in *Nyctereutes procyonoides viverrinus* in Japan (16). More recently, raccoon dogs have been identified as potential zoonotic vectors of the severe acute respiratory syndrome (SARS) coronavirus (6). These various concerns have led to raccoon dogs often being regarded as a pest species where they coexist with humans, especially in areas where they are introduced and not native (1, 23, 32).

The appendicular long bones of the raccoon dog are stout and its general conformation is short-legged (32). These phenotypes raise concerns about susceptibility to disorders of appendicular joints and about the possibility that captivity may further influence clinical and subclinical prevalence. Consciousness of these problems and the potential of the raccoon dog as an experimental animal model for osteoporosis research, have prompted new studies of skeletal physiology of this species. For example, bone mineral density and biomechanics have been evaluated in relation to wintertime loss of body mass and adiposity (22).

Here we report an observational study of museum specimens of confined raccoon dogs, focused on the major appendicular diarthrodial joints, under a hypothesis that joints of non-domestic canids express disease phenotypes that are similar to those seen in domestic dogs (*Canis lupus familiaris*).

## Materials and methods

Cleared skeletons from 16 raccoon dogs were available for study of the pathology of diarthrodial joints that included shoulder, elbow, hip and stifle (knee). It is known that the specimens were acquired as adult individuals that had been maintained as a single population. They are thought to have been used for breeding or for other physiological research, but additional specifics of individual signalment, research outcomes, environmental conditions and genetic variation within the population, were unfortunately never made available.

They were seized as a group in Illinois during 1983 and were euthanised following government action to prohibit their presence (known today as the Illinois Dangerous Animals Act). Enforcement officials provided them to the Illinois State Museum in Springfield, for clearing and preservation, as appropriate practices of the time.

Subsequently, the joints were disarticulated as a part of the clearing process. Proximal and distal joint components were evaluated (D.F. Lawler) for normality or pathology of the articular surface and periarticular structures, with magnification (2.5× or 20×) as needed.

 

Hips also were evaluated as a joint unit to examine them for hip dysplasia, a disease that is very common among domestic dogs (15, 29). Pathological observations were recorded by diagnosis, location, and degree (2, 3, 14, 15, 25, 27, 31). All joint components were photographed.

Statistical evaluations were not pursued because of the lack of a control population and the high percentage of observed abnormalities among the specimens. Additionally, the study population was relatively small at $n = 16$ individuals and multiple joint pathology in all of the raccoon dogs indicated that observations within an individual must be considered to be non-independent. Thus, accurate biological interpretation of any statistical outcomes would be tenuous.

## Results

A total of 32 specimens were available for each joint component, except for proximal tibia ($n = 30$), because tibias were not preserved from one individual. Overt pathologies, as well as marginally abnormal changes, were strongly bilateral in all joints. Therefore, data are reported within joint type (shoulder, elbow, stifle, hip), as proximal and distal joint components, and combining left and right. Additionally, hip joints were evaluated as a joint unit (acetabulum and femoral head together). For summary purposes, observations are presented by location as normal or by diagnosis.

### Shoulder

#### Scapula, glenoid fossa

Articular surfaces of the scapular glenoid fossa were normal in 14 specimens. The principal abnormality was osteochondrosis ($n = 11$) (Fig. 1) (Table I). The periarticular surfaces all were abnormal, with a bony rim ($n = 32$), reflecting near-normality to mild osteoarthritis (Fig. 1).

#### Humerus, proximal

The articular surface of the proximal humerus was normal in 20 specimens. The principal abnormality was periarticular osteoarthritis that impinged on the articular surface ($n = 5$) (Table I). Only one periarticular proximal humerus was normal. The principal abnormalities were bony rim ($n = 26$) (Fig. 2) and prominent margins and/or rough floor of the intertubercular groove ($n = 11$), the latter reflecting near-normality to very mild osteoarthritis. Overt osteoarthritis of the intertubercular groove ($n = 9$) and periarticular structures ($n = 7$) (Fig. 3, lateral to arrows) were also observed frequently.

Figure 1
Right scapula, glenoid fossa: osteochondrosis (2 arrows) and bony rim (5 arrows)

### Elbow

#### Humerus, distal

The distal humeral articular surface was normal in 20 specimens. The principal abnormalities were periarticular osteoarthritis that impinged on the articular surface ($n = 11$) (Fig. 4) and prominent articular margins ($n = 7$) (Table II). Only two periarticular distal humeral specimens were normal. The principal abnormalities were osteoarthritis ($n = 20$) (Fig. 4) and bony rim ($n = 12$).

#### Radius, proximal

The proximal articular surface of the radius was normal in 13 specimens. The principal abnormality was periarticular osteoarthritis that impinged on the articular surface ($n = 15$) (Fig. 5) (Table II). No periarticular proximal radius specimens were normal. The principal abnormality was osteoarthritis ($n = 26$).

#### Ulna, proximal

The proximal articular surface of the ulna was normal in 16 specimens. The principal abnormality was periarticular osteoarthritis

Table I
Observations of shoulder joints of 16 raccoon dogs, right and left combined (*n* = 32)

| Anatomical structure | Articular *n* (%) | Periarticular *n* (%) |
|---|---|---|
| Glenoid fossa | | |
| Normal | 14 (44) | |
| Osteochondrosis | 11 (34) | |
| Surface depression or groove | 5 (16) | |
| Ossification centre fusion defect | 2 (6) | |
| Bony rim | | 32 (100) |
| Proximal humerus | | |
| Normal | 20 (63) | 1 (3) |
| Osteoarthritis impinging articular surface | 5 (16) | |
| Prominent caudolateral tip articular surface | 3 (9) | |
| 1-mm depression articular surface | 2 (6) | |
| Artifact articular surface | 1 (3) | |
| Bony rim | | 26 (81) |
| Osteoarthritis | | 7 (22) |
| Bone loss post-mortem | | 2 (6) |
| Osteoarthritis intertubercular groove | | 9 (28) |
| Rough margins or surface intertubercular groove | | 11 (34) |
| Shallow intertubercular groove | | 2 (6) |
| Preserved tendon intertubercular groove | | 1 (3) |

Figure 2
Left proximal humerus, lateral view: osteoarthritis and impinging bony periarticular osteophyte (arrows)

Figure 3
Left proximal humerus, dorsal (superior) view: tendon remnant, intertubercular groove (arrows), and rough groove border

that impinged on the articular surface (*n* = 14) (Table II). No periarticular proximal ulna specimens were normal. The principal abnormalities were osteoarthritis (*n* = 19) and bony rim (*n* = 16) (Fig. 6).

## Hip

### Acetabulum

The acetabular articular surface was normal in 8 specimens. The principal abnormality was periarticular osteoarthritis that impinged on the articular surface (*n* = 24) (Table III). No periarticular acetabulum specimens were

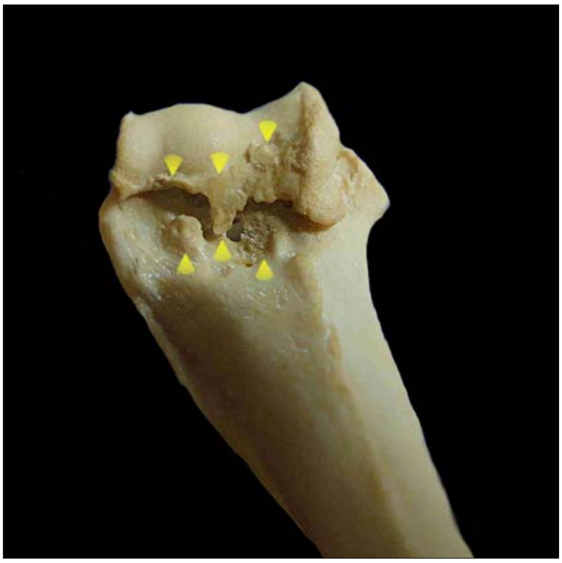

Figure 4
Left distal humerus, anterior view: severe osteoarthritis, impinging on articular surface (arrows)
Appearance suggests earlier physeal separation and secondary osteoarthritis

Figure 5
Right proximal radius, dorsal (superior) view: severe osteoarthritis, impinging on articular surface (arrows)

Table II
Observations of elbow joints of 16 raccoon dogs, right and left combined (*n* = 32)

| Anatomical structure | Articular *n* (%) | Periarticular *n* (%) |
|---|---|---|
| Distal humerus | | |
| Normal | 20 (63) | 2 (6) |
| Osteoarthritis impinging articular surface | 11 (34) | |
| Prominent margins articular surface | 7 (22) | |
| Bony rim | | 12 (38) |
| Osteoarthritis | | 20 (63) |
| Proximal radius | | |
| Normal | 13 (41) | |
| Rough articular surface | 1 (3) | |
| Osteoarthritis impinging articular surface | 15 (47) | |
| Bone loss post-mortem articular margin | 4 (13) | |
| Prominent margins articular surface | 4 (13) | |
| Thickening periarticular margin | | 1 (3) |
| Bony rim | | 6 (19) |
| Osteoarthritis | | 26 (81) |
| Proximal ulna | | |
| Normal | 16 (50) | |
| Osteochondrosis medial coronoid | 1 (3) | |
| Osteoarthritis impinging articular surface | 14 (44) | |
| Prominent margins articular surface | 1 (3) | |
| Bone loss post-mortem articular surface | 1 (3) | |
| Bony rim | | 16 (50) |
| Osteoarthritis | | 19 (59) |

Figure 6
Right proximal ulna, medial and slightly posterior view: bony rim (arrows)

normal. The principal abnormalities were bony rim (*n* = 27) (Fig. 7) and osteoarthritis (*n* = 15).

## Femur, proximal

The proximal femur articular surface was normal in only five specimens. The principal abnormalities were flattened femoral head (*n* = 20) (Fig. 8), periarticular osteoarthritis that impinged on the articular surface (*n* = 10) and circumferential femoral head osteophyte (CFHO) impinging on the articular surface (*n* = 7) (Fig. 8) (Table III). No periarticular proximal femur specimens were normal. The principal abnormalities were osteoarthritis presenting as CFHO (*n* = 32) and as linear or curvilinear osteophytes (*n* = 21) (Figs 8 and 9).

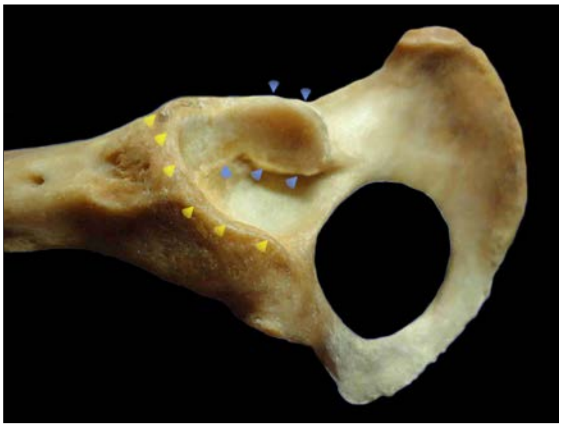

Figure 7
Left acetabulum, ventrolateral view: bony rim, impinging on craniolateral (yellow arrows) and medial, caudal, and caudolateral (blue arrows) aspects of articular surface

Table III
Observations of hip joints of 16 raccoon dogs, right and left combined (*n* = 32)

| Anatomical structure | Articular *n* (%) | Periarticular *n* (%) |
|---|---|---|
| Acetabulum | | |
| Normal | 8 (25) | |
| Osteoarthritis impinging articular surface | 24 (75) | |
| Bone loss post-mortem articular surface | 2 (6) | |
| Bony rim | | 27 (84) |
| Osteoarthritis | | 15 (47) |
| Proximal femur | | |
| Normal | 5 (16) | |
| Flattened femoral head | 20 (63) | |
| Osteoarthritis impinging articular surface | 10 (31) | |
| Impinging circumferential osteophyte | 7 (22) | |
| Circumferential femoral head osteophyte | | 32 (100) |
| Osteoarthritis | | 21 (66) |
| Femoral neck severe remodelling | | 2 (6) |
| Hip articulation | | |
| Normal | 0 (0) | |
| Compatible with hip dysplasia | 25 (78) | |
| Compatible with joint degeneration | 32 (100) | |

### Hip joint articulation

When each femoral head and its corresponding acetabulum were digitally articulated and viewed, none were normal. The principal new abnormal findings included osteoarthritic degeneration of the joint as a unit (*n* = 32) and morphological compatibility with hip dysplasia (*n* = 25) (Fig. 9) as it is recognised in the domestic dog (Table III).

## Stifle

### Femur, distal

The distal femur articular surface was normal in 23 specimens. The principal abnormality was prominent articular margins (*n* = 21) (Table IV). Only two distal femur periarticular specimens were normal. The principal abnormality was bony rim (*n* = 18).

### Tibia, proximal

The proximal tibia articular surface was normal in 26 specimens. The principal abnormality was post-mortem bone loss on the proximal articular surface (*n* = 4) (Table IV). Eight proximal tibia periarticular specimens were normal. The principal abnormality was bony rim (*n* = 19).

Figure 8
Right proximal femur, anterior view: flattened femoral head (blue arrows), circumferential femoral head osteophyte, and periarticular osteoarthritis (yellow arrows)

Figure 9
Articulated right hip joint, posterior view: shallow acetabulum, large bony rim (large arrows), and femoral head periarticular osteoarthritis (small arrows)
Compatible with hip dysplasia as observed in other Canidae (15, 29)

## Discussion

Pathological changes that include osteoarthritis, osteochondrosis and compatibility with hip dysplasia, occurred at surprisingly high prevalence in joints that are susceptible to these disorders in other Canidae. Those changes that represent near-normality or mild pathology, including prominent articular margins and mild bony periarticular rim, were also more prevalent than we expected. The fact that the observed abnormalities were distributed across the appendicular joints that we examined suggests uniformly applied insult(s) and a population basis, whether genetic, physiological but non-genetic, environmental, aging-related, or resulting from combined effects.

The ecological success of wild raccoon dogs is evident from their wide and rapid distribution after escaping confinement or being introduced into the wild by humans (23). While we are unaware of systematic studies of appendicular joint pathology in free-ranging raccoon dogs, the disorders that we observed among captive animals tend to worsen with advancing age in domestic dogs, but often are not age-limited in their onset (27).

Table IV
Observations of stifle joints of 15-16 raccoon dogs, right and left combined (*n* = 30 or 32)

| Anatomical structure | Articular *n* (%) | Periarticular *n* (%) |
|---|---|---|
| Distal femur | | |
| Normal | 23 (72) | 2 (6) |
| Prominent margins articular surface | 21 (66) | |
| Bone loss post-mortem articular surface | 2 (6) | |
| Osteoarthritis impinging articular surface | 5 (16) | |
| Bony rim | | 18 (56) |
| Osteoarthritis | | 2 (6) |
| Injury-related deformity | | 1 (3) |
| Proximal tibia | | |
| Normal | 26 (87) | 8 (27) |
| Bone loss post-mortem articular surface | 4 (13) | |
| Osteoarthritis impinging articular surface | 1 (3) | |
| Bony rim | | 19 (63) |
| Bone loss post-mortem | | 2 (7) |
| Osteoarthritis | | 2 (7) |

Chronic orthopaedic disorders that influence mobility adversely and are likely to be painful at some point, are not theoretically compatible with successful competition in the wild. The appearance of articular cartilage (that once overlaid the visible bony lesions during life) cannot be reported from our data. Therefore, observations similar to those that we report here should be evaluated and compared between wild and contemporary confined raccoon dogs. Advanced imaging technologies will probably be suitable to accomplish these studies initially, although it is not clear at this point whether very early stage or subtle abnormalities, as we observed from cleared skeletal specimens, will be consistently definable in living subjects.

A study of osteochondrosis of the humeral head in the Bernese mountain dog revealed quantitative heritability of 0.40 for the phenotype (8). Whether captive breeding selection practices concentrate these phenotypes in non-domestic canids, such as the raccoon dog, is not known, but continued breeding of related, susceptible individuals could clearly be a predisposing factor in this respect.

Radiological studies of the Portuguese water dog indicate quantitative heritability of 0.30 for hip joint osteoarthritis, with approximately one-half of the surveyed population (*n* = 431) having at least some degree of osteoarthritis (3). Radiographic phenotypes for evaluating hip dysplasia in the domestic dog yield quantitative heritability between about 0.16 and 0.60, varying by method. Degrees of breed dependence also are observed (30).

Some heritable autoimmune diseases can lead to polyarthropathies, both similar and dissimilar to those that we observed (27). However, one would not expect these disorders to occur pervasively in a successful free-ranging population, or in a captive setting that generally reflects successful reproduction and growth. In addition, the autoimmune polyarthropathies are typically erosive in nature and would cause much more subchondral bone loss.

Historically, spatial conflict with humans often leads to hunting and killing of free-ranging species to reduce their numbers, including raccoon dogs (19). An unresolved issue with respect to purposeful reduction of animal population sizes is the genetic constitution of the remaining population. A very important question, often unaddressed, is whether post-intervention survival of members of target species favours vertical transmission of traits that further improve survivability through selection for human-avoiding behaviours. Other post-intervention effects to be considered include the impact on local to regional ecology, as well as density-related risk for horizontal transmission of zoonoses for both predator species and for their prey, the latter at increasing densities in the absence of predators.

The ages at death of the specimens that we studied were not recorded, but it is known that they were maintained as a group of 16 adults (8 males, 7 females, 1 unrecorded), each individual being several years of age. This information aligns with the given general history that this colony was used for fur production (breeding) or research, either of which would necessitate long-term maintenance in confinement. Ages attained by raccoon dogs in captivity may range up to 14 years and beyond (32), while ages of 320 wild-trapped raccoon dogs reached 5.5 years for males and 7.5 years for females (24). However, it has also been observed that this maximum age is seldom attained; in a later study, the average life expectancy at birth for raccoon dogs in the wild was only 0.7 years (9). In sheltered environments, increased longevity is expected, but length and quality of life may not occur in parallel, depending on environmental circumstances. Our observations are compatible with the latter idea.

Might captivity-related, forced alterations in natural behaviours and biology introduce sufficient chronic stress to facilitate expression of deleterious quantitatively inherited phenotypes, such as joint disease? The natural biology of *Nyctereutes procyonoides* includes habitats that provide dense cover, and winter sleep that seems to be unique among Canidae (32). Naturally occurring physiological fattening during autumn and winter sleep has been reported, perhaps regulated by seasonal endocrine rhythms that are supervised by melatonin (20). In further studies, farmed raccoon dogs maintained constant protein catabolism for 60 days of seasonal fasting, using stored fat as the principal energy source (18). Another study indicated that fatty acid mobilisation during fasting is selective according to the structure of the fatty acid molecules and the anatomical location of fat depots (17). Considered together, these studies indicate that winter sleep with fasting is a natural physiological phenomenon in raccoon dogs and is not deleterious (21). One interesting question is whether perturbations of this natural biology by interfering humans might indirectly disrupt healthy stress modulation and predispose to worsening of disease phenotypes that have stress components, such as osteoarthritis. To our knowledge, this possibility has not been explored in raccoon dogs.

Presumably, a successful, free-ranging, omnivorous species such as the raccoon dog adequately satisfies nutritional requirements to support growth, daily and seasonal activity and reproduction. However, whether nutritional management in captivity produces a metabolic status consistently similar to that of free-ranging raccoon dogs is another difficult question. It is recognised that energy restriction produces increased longevity and also delays clinical onset of many species- and breed-specific diseases (10, 11, 13). These indications of plasticity of genetic stress-response programming are commonly reflected in the outcomes of calorie restriction studies (11, 13).

It is also recognised that maintaining non-domestic mammals in captivity can result in alterations of bone morphology (26). The many decades of study of the calorie restriction aging model clearly demonstrate the possibility of non-genetic or epigenetic influences on many physiological processes (13). Our observations certainly allow for non-genetic or epigenetic causes for differences between captive and free-ranging members of the same species that may include, in addition to nutrition, effects of geography, climate, age, and forced behavioural alterations. Thus, physiological processes can suffer from various perturbations that modify molecular signalling through the epigenome and can lead to modulations of disease phenotypes (12). Clearly, then, a number of potentially causative possibilities for our observations will require investigation.

Raccoon dogs are farmed in captivity for their pelts, which are used in the human clothing industry (32). Questions are often raised about the ethics of husbandry of non-domestic species in captivity. We now add the observation that, due to osteoarthritis, raccoon dogs maintained long-term could experience significant chronic pain at some point during life, especially if the ecological needs of this species are not considered. This is an important potential welfare-associated consequence that cannot be ignored.

## Conclusion

The raccoon dog in Eurasia, similar to the coyote (*Canis latrans*) and feral cat (*Felis silvestris catus*) in North America, is an example of the need for more advanced understanding of the environmental biology of free-roaming and captive members of some species. Specifically, continued ecological success of animal populations that compete with human interests suggests that interventions towards population control must be considered and designed much more carefully, to avoid pointless loss of life.

Evident susceptibility to orthopaedic disorders that are common in other Canidae suggests the need for new population genetic studies among members of this family. Genetic predispositions that result from genomic flexibility and facilitate environmentally directed expression of deleterious phenotypes may be far older phylogenetically than has been understood heretofore within Canidae.

Animal models are important to osteoarthritis research and the domestic dog has been recognised as a valuable osteoarthritis model for humans (5). However, emerging knowledge on cytokines, enzymes, the synovium and cartilage, and inflammatory responses of osteoarthritis, has benefits that extend well beyond human applications, and represent perhaps one of the best One Health processes of today. Raccoon dogs could be a species of choice, not only for studies of bone mineral density, but also of joint pathology, given the high prevalence of osteological findings with similarities to age-related or hereditary diseases of companion animals (2, 25, 27) and humans (4).

Finally, the implications of our observations illustrate how museum studies can yield new recognition and understanding of biological problems, re-emphasise known problems and suggest applications towards solutions.

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