Case Report

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Clinical Characteristics of Trauma-Related Chronic Osteomyelitis in 3 Wild Raccoon Dogs (*Nyctereutes procyonoides*)

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Abstract Osteomyelitis typically occurs because of the direct inoculation of bacteria or fungi after penetrating trauma or surgical contamination or, by extension, from soft tissue infection. Osteomyelitis is rarely reported in wildlife animals, though severe chronic osteomyelitis cases do exist in wildlife owing to the scarcity of medical support in the wild environment. This report describes three cases of chronic osteomyelitis in wild raccoon dogs related to trauma. The typical symptoms of three reported cases were ataxia, stiffness, muscle atrophy, and lethargy. All three cases were relevant to traumatic or severe external injury, and skin infestation caused by ectoparasites was apparent on an ocular inspection. In the radiographic examination, diffuse sites of osteolytic lesions and remarkable periosteal responses were demonstrated around the injured limb in all three cases. Apparent neutrophilia with a left shift, lymphocytosis, and monocytosis in hematological examinations generally indicated chronic infection as shown in case 1 and 3. Treatment was attempted with broad-spectrum antibiotics and non-steroidal anti-inflammatory drugs, such as amoxicillin/clavulanic acid, enrofloxacin, clindamycin, and meloxicam. These treatment options helped improve the overall prognosis of chronic osteomyelitis, but the outcomes did not meet the treatment goal entirely. Osteomyelitis can be extremely challenging to treat, particularly in wild animals, because of their distinctive traits, such as masking phenomenon and uncontrolled exposure to ectoparasites. Earlier diagnosis with a radiographic examination, hematological examinations, and careful patient monitoring, followed by prolonged antibiotic therapy and restricted exercise, are the key factors leading to a better prognosis.

Key words osteomyelitis, osteolysis, raccoon dog, wild animals, anti-bacterial agents.

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Introduction

Osteomyelitis is an inflammatory disease caused by an infection of the bone and related tissues, such as soft tissue, periosteum, and endosteum, leading to necrosis and dissolution of bone (21,26). The disease can affect all ages, including bone, develop into a chronic disease and cause insistent morbidity (18). The main causes of osteomyelitis are frequently infectious agents, such as bacteria or fungi. Treating osteomyelitis is particularly challenging when complicated multi-resistant bacterial flora has already been set (18). Bacterial flora in infection sites perseveres in a low metabolic stage, triggering insistent infection because of the increased resistance to antibiotics (18). The treatment of osteomyelitis requires increased doses of antibiotics through intravenous and oral routes for longer phases compared to a widespread bacterial infection.

The acute onset of osteomyelitis is occasional and generally does not show obvious radiographic distinctions until five to 10 days after osteoarticular inoculation (21). Chronic osteomyelitis in domestic species can occur as a complication of orthopedic surgery, an extension of tooth infections into the bone (with periodontal disease), or from nail bed infections. In wildlife cases, the condition is generally observed from severe traumatic cases, especially in the forelimbs or hind limbs. Osteomyelitis can imitate several diseases, such as hypertrophic osteodystrophy, panosteitis, and neoplasia. Therefore, it is essential to be differentiated from others (21).

Trauma-related osteomyelitis originates mainly from a direct infection of the bone, from either surgery or trauma. Damage to the blood supply of the bone and the adjacent soft tissue frequently occurs in these cases (16). Decreased focal blood flow affects the capability of host immune cells to infiltrate the affected tissue and expand the additional dead space and necrotic tissue, which intensifies the risk of infection (16,37).

The treatment goal of osteomyelitis is to offer an appropriate focal condition that is beneficial to granulation tissue formation, soft callus formation, and eventually the regeneration of new bone. Chronic bacterial osteomyelitis is more common than acute osteomyelitis and fungal osteomyelitis (21). On the other hand, open fractures, acute postoperative orthopedic infections, and deep bite wounds should be considered predisposing factors to acute osteomyelitis, which if improperly treated, could cause chronic osteomyelitis (21). In wildlife cases, patients with osteomyelitis are generally rescued at the end-stage of the disease because their nature of hiding the signs of illness from predators (masking phenomenon) exists (4). Therefore, treating patients with chronic conditions with a poor prognosis is extremely challenging. On top of that, osteomyelitis occurred in wild raccoon dogs has not been reported earlier in the literature to the best of authors knowledge; thus, its diagnosis and treatment trials reported on this paper may provide extensive discussion on the causes, diagnosis, and treatment of osteomyelitis in raccoon dogs.

This paper reports the treatment trials of three raccoon dog cases referred to the Seoul Wildlife Center, Seoul, South Korea, with disseminated osteomyelitis, which was assumed to be chronic post-traumatic osteomyelitis.

Case Report

Case 1

On February 2nd, 2018, a raccoon dog with severe parasitic skin infection was referred to the Seoul Wildlife Center. The raccoon dog had a history of lethargy for more than 48 hours and severe scabs on its whole skin, which was attributed to a scabies infection. On the first examination, the measured body condition score (BCS) was three out of nine, indicating cachexia as an underlying cause. The animal's weight was 3.2 kg; it was a male and had dehydration of more than 10% measured from the capillary refill time (CRT) to be longer than 1.5 seconds. The animal also had a laceration on the right lateral side of its hip, approximately 2 cm caudal to the hip joint. The wound was 1.3 cm long, 0.3 cm wide, and 0.2 cm deep. Exudation existed on the wound, and the partial thickness was found. Pale granulation tissue also existed, and muscle necrosis was suspected. Ataxia was also observed during the physical examination. The hematological examination revealed pronounced neutrophilia with a left shift. The pain reactions were not evident on deep palpation of the hind limbs.

Since the laceration wound around the hip was dirty and purulent, secondary intension wound healing was the choice of treatment. Open wound management was performed accordingly. The wound was intensively cleaned daily with 7.5% povidone-iodine and hydrocolloid dressing was applied.

On radiology, severe pneumonia was considered, and broadly, disseminated osteolysis was shown on the coccygeal vertebrae (Fig. 1).

As an emergency therapy upon arrival of the patient, 10 mL/kg/hour of Hartmann's solution was administered intravenously for the first five hours. Cefazolin (10 mg/kg, Cefazolin, Jonggeundang) was also administered intravenously for prophylactic effect. Heat support and oxygen therapy were provided additionally. After stabilization of the patient, the treatment consisted of Hartmann's solution (5 mL/kg

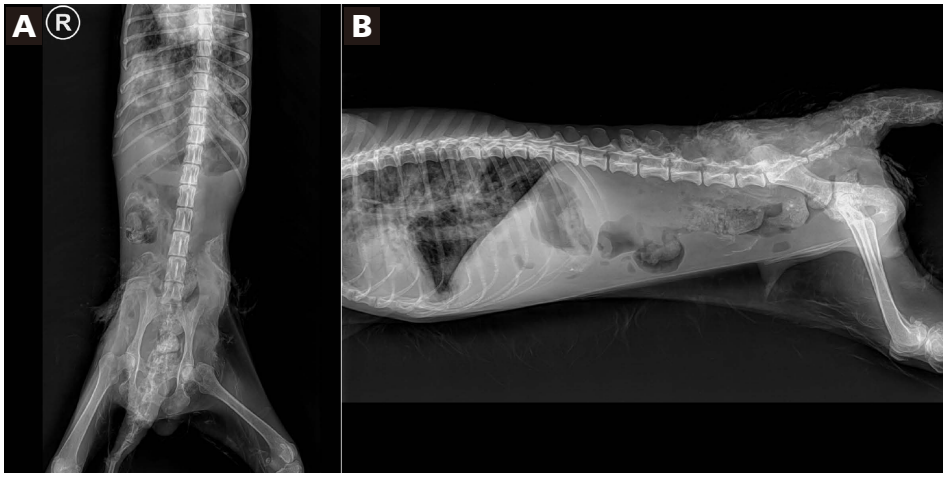

Fig. 1. Right lateral (A) and ventrodorsal view of a case of osteomyelitis in a raccoon dog (*Nyctereutes procyonoides*). Severe osteolytic changes are seen on the fifth coccygeal vertebra, extending to one or two more proximal and distal coccygeal vertebrae with irregular periosteal reaction. Artifacts due to a wet and dirty coat are superimposed on the vertebrae on lateral view mimicking osteolytic changes. On the thoracic region (B), the caudal part of the lung shows a bronchointerstial appearance to patch alveolar infiltrates, which could be compatible with potential pneumonia.

intravenously), amoxicillin/clavulanic acid (12.5 mg/kg P.O. twice daily; Clavamox; Pfizer), and meloxicam (0.2 mg/kg P.O. daily; Metacam; Boehringer Ingelheim).

After two weeks of treatment, on February 25th, euthanasia was decided due to the poor prognosis from the therapy.

Case 2

A male raccoon dog weighing 3.6 kg was presented on November 4th, 2018, with 36 hours of lethargy, anorexia, and pyrexia associated with left hind limb lameness. On the initial physical examination, ataxia, dehydration of more than 10% according to CRT, cachexia, and signs of parasite infection on the skin were found. The measured BCS was four out of nine.

The radiology examination confirmed the closed fracture on the right humerus and right femur. Traumatic fracture was highly suspected from the radiologic examination. A mass on the right humerus around the fracture site was also observed. Blood analysis was performed on the next day after the initial referral. The complete blood count (CBC) showed a higher WBC (125,600/μL), neutrophils (15,400/μL), monocytes (2,200/μL), and lymphocytes (8,500/μL) than reference proposed by Kaneko et al., 2008 (25). The serum chemistry, alkaline phosphatase (213 U/L), creatine kinase (1,530 U/L), and lactate dehydrogenase (459 U/L) were higher than reference presented by Latimer, 2011 (27). The radiology examination and blood analysis indicated a diagnosis of osteosarcoma that developed from severe osteomyelitis. Cytologic examination through fine needle aspiration confirmed the osteosarcoma.

As an emergency therapy upon arrival of the patient, 10 mL/kg/hour of Hartmann's solution was administered intravenously for the first six hours. Cefazolin (10 mg/kg, Cefazolin, Jonggeundang) was also administered intravenously for prophylactic effect. Heat support and oxygen therapy were provided additionally. After stabilization of the patient, the treatment consisted of amoxicillin/clavulanic acid (12.5 mg/kg P.O. twice daily; Clavamox; Pfizer) and meloxicam (0.2 mg/kg P.O. twice daily; Metacam; Boehringer Ingelheim). Surgical excision, debridement, or drainage was not performed during the treatment process. During the treatment, the prognosis was relatively poor. The mental status was relatively depressed, and physical activity was low. After 23 days of treatment, the raccoon dog died, supposedly from sepsis, multiple organ failure, and cancer progression.

Case 3

On June 11th, 2019, a raccoon dog weighing 3.75 kg was referred to Seoul Wildlife Center. The initial physical examination revealed tachypnea, debility, hypothermia (35.2°C), dehydration of more than 10% according to CRT, and ataxia. The raccoon dog exhibited signs of pain evidently on the right side of the forelimb.

A routine radiographic examination proceeded directly. There were extensive osteolytic changes with cortical loss and irregular periosteal reactions on the right radius and ulna, and multifocal punctate bony lyses were observed on the left proximal humerus and ulna. Multifocal bony lyses also existed on the bilateral femur and tibia. It appeared to be more severe on the right limb. A miliary nodular pattern was evident throughout the entire lung area, which is most likely a fungal infection. The loss of serosal detail on the abdomen was attributed to emaciation, but possible ascites could not be ruled out (Fig. 2). The fracture was assessed to be the initial problem, and secondary periosteal changes were assumed to be occurred according to the radiographic signs.

A hematological examination revealed a pronounced neu-

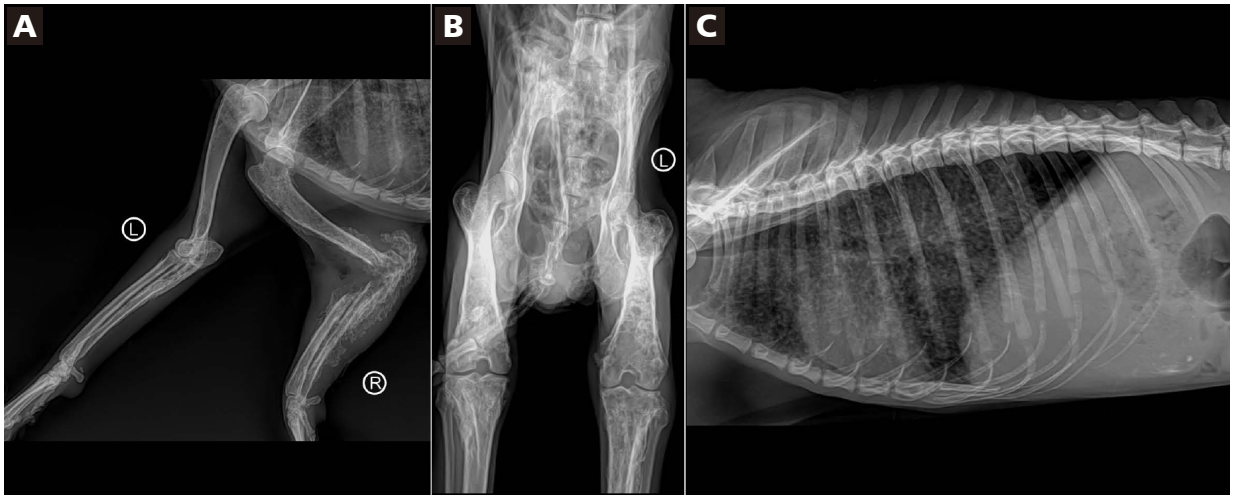

Fig. 2. Lateral view of the forelimb (A) and ventrodorsal view of the hindlimb (B), and lateral view of the thorax and abdomen (C). On the forelimb, the right radius and ulna, there is extensive osteolytic changes with cortical loss and irregular periosteal reaction, and there are multifocal punctate bony lyses on the left proximal humerus and ulna. On the hindlimb, multifocal bony lyses are seen on the bilateral femur and tibia, and it appears more severe on the right limb. On the right lateral thoracic radiograph, a miliary nodular pattern is evident throughout the entire lung area, which is most likely a fungal infection. On the abdomen, serosal detail loss is found, potentially due to emaciation, but possible ascites could not be ruled out.

trophilia with a left shift, lymphocytosis, and monocytosis. Band neutrophils were also increased. The biochemical abnormalities included lower albumin (1.7 g/dL), higher blood urea nitrogen (51.8 mg/dL), and higher creatine kinase (1926 U/L). Table 1 displays serum chemistry and enzyme values.

A cytological examination of the synovial fluid aspirated from the right revealed chronic infection signs, such as increased neutrophil and basophil. The toxic changes were presented on neutrophils, such as cytoplasmic basophilia, Döhle bodies, cytoplasmic vacuolation, nuclear immaturity, and toxic granulation. For example, these signs could lead to a chronic infection status.

As an emergency therapy upon arrival of the patient, 10 mL/kg/hour of Hartmann's solution was administered intravenously for the first four hours. Cefazolin (10 mg/kg, Cefazolin, Jonggeundang) was administered intravenously for prophylactic effect. Heat support and oxygen therapy were provided additionally. After stabilization of the patient, the treatment consisted of Hartmann's solution (5 mL/kg intravenously), enrofloxacin (5 mg/kg intravenously twice daily; Baytril; Elanco), amoxicillin/clavulanic acid (12.5 mg/kg intravenously twice daily; Clavamox; Pfizer), clindamycin (10 mg/kg intravenously twice daily; Fullgram; Samjin), tramadol (2 mg/kg intravenously twice daily; Tridol; Yuhan), and meloxicam (0.1 mg/kg intravenously twice daily; Metacam; Boehringer Ingelheim).

After four days of treatment, the raccoon dog died, presumably from chronic fungal infection, secondary bacterial infection, sepsis, and multiple organ failure.

Table 1. Serum chemistry and enzyme values of a raccoon dog with osteomyelitis

Parameter	Results	Unit
Albumin	1.7	g/dL
Total protein	5.9	g/dL
Globulin	4.2	g/dL
Calcium	10.5	mg/dL
Glucose	73	mg/dL
Blood urea nitrogen	51.8	mg/dL
Potassium	6.43	mg/dL
Amylase	2524	U/L
Cholesterol	348	mg/dL
Alanine aminotransferase	67	U/L
Total bilirubin	0.34	mg/dL
Alkaline phosphatase	16	U/L
Creatinine	0.64	mg/dL
Creatine kinase	1926	U/L

Discussion

Osteomyelitis typically emerges by the straight inoculation of bacteria or fungi after penetrating trauma, surgical contamination, or by extension from a soft tissue infection. The disease has been described in humans (8,11,41) and in small and large animals, particularly young foals (36). In large animals, infection is frequently preceded by, or associated with, omphalophlebitis, tail-bite abscess formation (piglets), pneumonia, or some other systemic infection (13). A study of 233 cases among large animals with osteomyelitis showed

that most bacteria isolated from osteomyelitis were aerobic or facultatively anaerobic, and only 9% were anaerobic (9,31). In foals, the proliferation of infection from the metaphyseal regions of the long bones to the physes and epiphyses, and then eventually to the joints, is usual (13). Therefore, most foals with suppurative polyarthritis also have polyosteomyelitis of the bones adjacent to the affected joints (30). The prognosis is generally less favorable because of the higher incidence of joint involvement in large animals. Moreover, surgical intervention, in the form of curettage and drainage, is frequently more effective than medical therapy alone (13). Osteomyelitis in companion animals, such as dogs and cats, is relatively uncommon as in other animals, which can be problematic to be cured (1,3,9). Similar to the other species, osteomyelitis can occur through either hematogenous infiltration in the neonate because of trauma or through iatrogenic circumstances, most commonly secondary to surgical intervention (1,3,9).

In wildlife, osteomyelitis in wild mammals occurs mainly from traumatic injuries. They commonly hide their illness status (masking phenomenon), potentially leading to severe outcomes. In addition to osteomyelitis, some cases may have superinfection, sepsis, or osteosarcoma. Hence, it may be extremely challenging to treat osteomyelitis in wildlife cases.

Regardless of the species, the metaphyseal vessels form capillary loops that extend and branch into dilated venous sinusoids on the metaphyseal side of the growth plate (13). Blood flow through these sinusoids is sluggish and provides an ideal environment for bacterial growth (9,13,21). Seeding of the infection to the metaphyses of the long bones might increase after a bacteremic episode. As the infection diffuses, the development of septic thrombi may further inhibit blood flow within the metaphyses (13,24). If untreated, the infection spreads from the metaphyses via the Haversian and Volkmann canals to the periosteum, soft tissues, and adjacent joints (34).

In immunocompetent patients with a bone infection, immune responses are generally inclined to 'wall off' the infected site by abscess formation (6,15,35). The exudate might raise the periosteum producing a subperiosteal abscess or a sequestrum, and then an elevated pressure within the abscess in common with the osteoclastic activity might cause propagation of the bone infection (23). In case 1, exudation and abscess were observed around the injured site of the raccoon dog when referred to the wildlife center, which may have strong relevance with presented osteomyelitis.

Cases 2 and 3 presented with bone destruction and secondary periostitis. In case 2, an increase in serum lactate dehydrogenase and serum alkaline phosphatase could indicate osteosarcoma along with a radiographic examination (38). A radiographic examination of case 2 revealed osteomyelitis signs and osteosarcoma signs, such as neoplasm around the infected bones. In case 3, however, there were no significant changes in serum chemistry examination except for hypoalbuminemia and increased creatine kinase. A radiographic examination was performed on case 3 with a suspected fungal infection. The differences in serum chemistry could result from the underlying causes of osteomyelitis originating from bacteria or fungi. There also are possibilities that the distinguishing characteristics in the prognosis of the disease depend on the pathogenetic aspect. Further studies will be needed to verify these relationships.

The clinical signs related to osteomyelitis usually include pyrexia, lethargy, local swelling, severe lameness, and pain. Neurological signs may be noted when vertebral osteomyelitis or discospondylitis is present (7), as in case 1. The pathological fractures or septic arthritis might also be found (14,22). A radiographic examination frequently showed soft tissue edema first while a bone infection progresses; osteolysis and new bone formation may only become apparent in the later stages. Hence, bone neoplasia cannot be excluded clinically or by medical imaging (6,17). In the present report, malignant neoplasia was suspected in case 2, but it was presumed that neoplasia was developed secondary to osteomyelitis because the infectious signs were already disseminated, affecting the joints and other organs.

Antibiotic therapy must be based on the isolation, identification, and antibiotic sensitivity pattern of the causative agent. In humans, the most typical isolate from osteomyelitis cases is *Staphylococcus aureus* (10,13). Bacteriocidal antibiotics that reach therapeutic levels in the bone should be used; penicillin and cephalosporins satisfy both conditions (9,13,18,21). Penicillins leave the vascular space and enter the interstitial fluid space of osteomyelitis tissue readily, and the concentration of penicillin in the serum reflects that in the bone (20). Immobilization is also an essential and critical key of the therapeutic protocol. Surgical intervention is only indicated if there is any signalment of a subperiosteal abscess or sequestrum formation (13). Antibiotics with demonstrated in vitro activity against anaerobic bacteria may also be useful for managing osteomyelitis associated with these organisms (21,32,40). There are several studies regarding the relationships between osteomyelitis and anaerobic bacteria. In one survey of osteomyelitis in domestic animals, obligate or facultative anaerobes were involved in 74 percent of cases, most of which were of a suspected traumatic origin (40). *Bacteroides* spp. and *Actinomyces* spp. were the most common species (32,40), and *E. coli* and *Staphylococcus* sp. were

frequent among the aerobic bacteria in the study (32).

Treatment with a six-week course of amoxicillin/clavulanic acid in combination with metronidazole successfully treated osteomyelitis in canine species (13). In another report, cephalosporin (cefalexin) showed medical efficacy (35). These drugs have proven activity against anaerobic bacteria, including those that produce β-lactamase; amoxicillin/clavulanic acid is effective against aerobic organisms, including β-lactamase-producing strains of staphylococci (33). Amoxicillin/clavulanic acid was the drug of choice as a broad-spectrum antibiotic in the present three cases. Metronidazole is effective in treating infections caused by β-lactamase-producing anaerobes (40). The drug penetrates the bone in amounts adequate to exceed the minimal inhibitory concentrations for most anaerobic bacteria (39). Similarly, clindamycin also penetrates the bone with sufficient efficacy to exceed the minimal inhibitory concentration for most anaerobic bacteria even though it is a bacteriostatic drug (5,39). Clindamycin was chosen to cover anaerobes in a case of this report. However, it is still unclear if these penetrating traits are maintained in osteomyelitic bone.

A treatment combination of amoxicillin/clavulanic acid, enrofloxacin, and clindamycin was attempted in a case in this report, but the prognosis was not as expected. There could be several reasons, but the main cause of death was sepsis. Although a proper combination of antibiotics was chosen and applied, the treatment must be attempted as soon as possible to contribute to the regression of bacterial proliferation.

On the other hand, managing fungal osteomyelitis is challenging both in human and animals because it is a rare condition (2,28). Hence, studies of the pathophysiology and treatment have been insufficient, and the prognosis is generally unfavorable (2,19). Fungal bone infections arise from direct inoculation, contiguous infection spread, or hematogenous seeding of organisms. The most common isolated fungi are *Candida* and *Aspergillus* in humans (2,28), and few reports describe fungal osteomyelitis in canine species. Organisms known to be isolated from canine species vary, e.g., *Coccidioides*, *Candida*, *Blastomyces*, or *Schizophyllum* (12,19,28,29). There is no clear consensus on the treatment of fungal osteomyelitis; however, routine antifungal therapy may be applicable, such as itraconazole, terbinafine, or amphotericin B (12,19,28).

There may be some limitations in this report. Cytology and cell culture were not performed during the treatment process, and histopathologic examinations were not presented. Therefore, detailed diagnosis of the disease and identification of etiologic agent may have been partial. Also, concurrent surgical treatment was not considered. However, considering that occurrence of osteomyelitis is exceptionally rare in wildlife and investigating clinical prognosis plays an important role in analysing a disease, this paper could provide extensive discussion on the causes, diagnosis, and treatment of osteomyelitis in raccoon dogs.

In conclusion, osteomyelitis in wildlife animals may be extremely challenging to treat due to their natural traits. Moreover, there may be superinfection, sepsis, or osteosarcoma. Earlier diagnosis based on a radiographic examination and cytology, routine hematological examination, careful monitoring of the patient followed by prolonged antibiotic therapy and restricted exercise, and application of concurrent therapies shall be the key factors for treating osteomyelitis in wildlife animals.

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Conflicts of Interest

The authors have no conflicting interests.

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