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A Critical Analysis of Bumblefoot: Care and Preventative Measures in Captive Penguins

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Abstract

Bumblefoot is a progressive and sometimes deadly infection that afflicts penguins living in human care. The most prominent cause of the disease is the extended amount of time that captive penguins spend standing in comparison to their pelagic and wild counterparts. For years, facilities have treated bumblefoot with surgery and antibiotics. However, this approach is palliative rather than preventative and has become problematic as bacteria develop stronger resistance to antibiotics. To address the behavioral abnormalities underlying the onset of bumblefoot, zoos and aquariums should utilize environmental enrichment. Many forms of environmental enrichment, including the relationship penguins have with their keepers and colored balls or rings, may prove effective at encouraging these aquatic birds to spend more time in the water. However, few studies have worked to determine the effectiveness of environmental enrichment as a preventative measure for bumblefoot. When used in addition to behavioral husbandry, or the training associated with achieving the voluntarily participation of penguins in their daily care, environmental enrichment may be the key to eradicating bumblefoot from the lives of captive penguins while also providing them with a more stimulating and healthier environment.

Keywords: bumblefoot, pododermatitis, penguins, environmental enrichment, behavioral husbandry, prevention

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Penguins have lived in human care for upwards of one hundred years because of the high level of interest that zoo and aquarium visitors express in them (Collins, Quirke, Overy, Flannery, & O'Riordan, 2016; Davis, 1967; Diebold, Branch, & Henry, 1999). They are pelagic birds adapted for life in the water and therefore efficient predators of fish, cephalopods, and crustaceans (Blay & Côté, 2001; Diebold et al., 1999; Larsson, 2012; Martin & Young, 1984). The changing environment and encroachment of humans have put wild populations of the Humboldt (*Spheniscus humboldti)*, Gentoo (*Pygoscelis papua)*, and Magellanic (*Spheniscus magellanicus)* penguin in danger (Blay & Côté, 2001; Collins et al., 2016; Osório, Xavier, Ladeira, Silva-Filho, Faria, Vargas, … & Meireles, 2013). As a result, captive situations may become vital to the perpetuation of these species. However, penguins residing in human care are not free from ailment. A survey of British zoos found that many facilities are not meeting the recommendations for the care and breeding of Humboldt penguins based on measurements of egg productivity, hatching success, and chick productivity (Blay & Côté, 2001; Marshall, Deer, Little, Snipp, Goulder, & Mayer-Clarke, 2016). Captive penguins face diseases in the captive environment as well. Avian malaria (caused by parasitic protozoa in the genera *Plasmodium* and *Haemoproteus*) and aspergillosis (infection caused by fungus Aspergillus) more often afflict penguins living in captivity than the wild (Vanstreels, Silva-Filho, Kolesnikovas, Bhering, Ruoppolo, Epiphanio, … & Catão-Dias, 2015; Xavier, Soares, Cabana, Silva-Filho, Meireles, & Severo, 2011). Captive penguins are also in danger of contracting a disease with one of the highest morbidities: bumblefoot (Osório et al., 2013).

Bumblefoot

Bumblefoot, or pododermatitis, is a progressive infection of the plantar surface of the foot characterized by swelling, calluses, abrasions, and ulcerations (Erlacher-Reid, Dunn, Camp, Macha, Mazzaro, & Tuttle, 2012; Nascimento, Ribeiro, Sellera, Dutra, Simões, & Teixeira, 2015; Osório et al., 2013; Reidarson, McBain, & Burch, 1999; Reisfeld, Barbirato, Ippolito, Cardoso, Nichi, Sgai, & Pizzuto, 2013; Santos, Sakata, Rahal, Nascimento, Melchert, & Teixeira, 2016). The disease is not exclusive to penguins, as it also impacts raptors, but our understanding of bumblefoot in penguins is far less developed (Erlacher-Reid et al., 2012; Reidarson et al., 1999). As a result, no universal classification scheme for the stages of bumblefoot is in existence. Cooper (1978) described type one lesions as mild and localized, type two lesions as chronic and infected with bacteria, and type three lesions as painful and swollen, with the infection spreading to the tendons, joints, or bone. Bumblefoot infections have the capacity to spread to the bloodstream as well as lead to the death of the penguin (Erlacher-Reid et al., 2012; Santos et al., 2016). The lack of a universal description for the progression of bumblefoot prevents facilities from recognizing the early signs of the disease, delaying the timing of treatment to the stages of bumblefoot that are more aggressive.

While many kinds of microorganisms may infect the open wounds associated with bumblefoot lesions, the two most commonly isolated genera are *Staphylococcus* and *Corynebacteria.* Varieties of *Staphylococcus,* such as hemolytic, coagulase positive, and intermedius, may be present in the wounds (Osório et al., 2013). *Escherichia coli* also resides in the lesions during all stages of the disease, but Osório et al. (2013) found them in the greatest numbers when the wounds were infected. Other organisms, like *Aerococcus viridans, Enterococcus faecalis, Clostridium, Streptococcus,* and *Aspergillus* also afflict penguins with bumblefoot (Hawkey, Samour, Henderson, & Hart, 1985; Osório et al., 2013; Reidarson et al., 1999; Santos et al., 2016). The opportunist functioning of these microorganisms allows for more than one species to impose an infection. While the bacteria characteristic of bumblefoot are a part of the natural flora of the captive environment and penguin itself, it is the unbalance of these organisms and their penetrance of the dermal surface that causes infection (Osório et al., 2013).

Penguins with bumblefoot display signs of infection in their blood, such as an increased white blood cell count and the presence of the avian granulocyte, heterophils. There is also an increase in the amount of fibrinogen in the blood to encourage clotting (hyperfibrinogenemia), excessive fluid build-up (oedema), excessive amounts of blood in the vessels (hyperemia), and evidence of necrosis (Hawkey et al., 1985). Although these types of hematological analyses may prove useful as a characterization of the blood response of penguins to pododermatitis, it is important to establish reference levels for each species before using this tool in diagnoses.

The factors contributing to the onset of bumblefoot are related to the husbandry of the penguins and highlight the preventative nature of the disease. Several zoos and aquariums have reported that their penguin populations live sedentary lifestyles, making it a leading cause of bumblefoot (Erlacher-Reid et al., 2012; Marshall et al., 2016; Nascimento et al., 2015; Osório et al., 2013; Reidarson et al., 1999; Reisfeld et al., 2013). As a result of prolonged standing, captive penguins are spending far less time swimming and diving than their wild counterparts, who spend less than twenty percent of their time on land (Erlacher-Reid et al., 2012). The pelagic nature of these birds highlights the abnormality of these behaviors, and therefore indicates that captive penguins have a diminished wellbeing.

The use of inappropriate or undesirable substrate can exacerbate the risk of pododermatitis in penguins who stand for protracted periods of time. Wet and contaminated flooring, as well as smooth concrete surfaces, can also be causative in the development of pododermatitis (Erlacher-Reid et al., 2012; Hawkey et al., 1985; Nascimento et al., 2015; Osório et al., 2013; Reidarson et al., 1999; Reisfeld et al., 2013). In a study of how various factors contribute to the onset of bumblefoot in captive African penguins, Erlacher-Reid et al. (2012) found that weight, substrate type, and activity level all play a role. Male African penguins are more prone to bumblefoot due to their heavier weight. Individuals that spend more than fifty percent of their time standing are more likely to develop bumblefoot as well. In addition, more male and female African penguins residing in and claiming territories with smooth concrete develop bumblefoot each year. Mystic Aquarium reported a sixty-six percent reduction in the occurrence of bumblefoot following a remodel of their penguin enclosure in which the floors were made more abrasive and variable (Erlacher-Reid et al., 2012). It does not appear as though age is a causative variable given that penguins as young as one year old can develop bumblefoot, but other factors like malnutrition, deficiencies in vitamins A and E, and systemic diseases may have a role (Erlacher-Reid et al., 2012; Reidarson et al., 1999).

The use of the traditional treatment approach for bumblefoot has become increasingly discouraged following the progression of antibiotic resistance. For years, facilities have treated bumblefoot with antibiotics such as enrofloxacin, gentamicin, penicillin, and streptomycin following surgical debridement (Nascimento et al., 2015; Reidarson et al., 1999; Reisfeld et al., 2013; Santos et al., 2016). However, penicillin and streptomycin have a local resistance of more than twenty percent to antibiotics and some bacterial strains display a resistance to bacitracin and neomycin as high as ninety percent (Nascimento et al., 2015; Osório et al., 2013). To counter antibiotic resistance, some studies have investigated the use of novel treatment methods such as photodynamic therapy (PDT) and whole-body vibration (WBT). Nascimento et al. (2015) found that PDT had a healing rate of 63.64% across five individuals while treatment with antibiotics had a healing rate of 9.09% across five individuals. PDT uses a non-toxic dye photosensitizer and an LED light in the presence of oxygen to inactivate multiresistant and naïve microorganisms without damaging the surrounding tissues (Nascimento et al., 2015). However, the treatment is palliative rather than curative, and not preventative. WBT induced a warming of the foot pad, which is suggestive of healing, after caretakers placed the penguins on a vibrating platform for five three-minute sessions at twenty hertz. This form of therapy may promote the formation of new blood vessels and vascular tissue, but it is a complement to traditional methods rather than an independent method of treatment (Santos et al., 2016).

Although these unique and revolutionary approaches to the treatment of bumblefoot are useful and counter the issue of antibiotic resistance, they are not preventative. These forms of treatment, as well as antibiotics and surgical debridement, fail to address the variables that contribute to the onset of pododermatitis. Primarily, facilities housing penguins should address prolonged standing and a lack of swimming, as these are some of the most preventable and crucial aspects of bumblefoot. These behavioral abnormalities indicate that zoos and aquariums are not providing their penguins with the best possible care. Given the progressive nature of bumblefoot and its often-lethal prognosis, it is dire that facilities work to eradicate this infection and provide their penguins with healthier environments, physically and psychologically. Unfortunately, few studies have addressed pododermatitis with such a preventative attitude (e.g. Reidarson et al., 1999; Reisfeld et al., 2013).

Environmental Enrichment

Zoo and aquariums are familiar with and utilize environmental enrichment to improve the welfare of their captive animals, but the true potential of enrichment may be unrealized. Environmental enrichment is the improvement of the biological functioning of captive animals because of environmental modifications that seek to improve desired behaviors, therefore increasing the animal's physiological and psychological wellbeing (Larsson, 2012). This concept revolves around the idea of promoting "species-specific" behaviors that facilities regard as natural and desirable. Enrichment is beneficial in zoos and aquariums because of the way it provides captive animals the opportunity to behave freely, which generates variety in an otherwise highly scheduled lifestyle (Claxton, 2011; Collins et al., 2016; Larsson, 2012). Zoos and aquariums often base their assessment of the wellbeing of an animal on the success of its biological functioning, the amount of "species-specific" behaviors it partakes in, and the number of undesirable or stereotypical behaviors it displays (Claxton, 2011). For captive penguins, behaviors like prolonged standing and a lack of swimming are undesirable and indicate that something is missing from their environment.

Few studies have worked to develop forms of environmental enrichment to increase the amount of time that captive penguins spend in the water, let alone investigated enrichment as a tool for decreasing the prevalence of bumblefoot. Larsson (2012) designed an environmental enrichment structure to encourage penguins living in a Swedish zoo to swim in an area of their pool that they were not using. The structure was modeled after one for sea lions because of the lack of literature specific for penguins. The "whale skeleton" consisted of a sinking ground structure for the penguins to climb up on, and a floating bridge for the penguins to swim through like a tunnel. The penguins changed their use of the pool, but it was unclear as to if the change was the result of the "whale skeleton" or not. Young adults had the greatest interest in the structure but preferred to dive under the floating bridge rather than climb on top of it (Larsson, 2012). The short duration of the study and infancy of the idea warrants the need for future investigation, but structural environmental enrichment has immense potential for increasing the amount of time that penguins spend in the water, which can therefore reduce the occurrence of bumblefoot.

Other forms of environmental enrichment, like changes to the animal's daily routine, may also be successful at altering the abnormal behaviors of captive penguins. Claxton (2011) and Reisfeld et al. (2013) suggested that variations in the timing of feeding and large social groupings can serve as enrichment as they increase the range and diversity of a penguin's behavior. Feeding penguins in the water can encourage them to spend more time swimming and diving as well (Erlacher-Reid et al., 2012; Marshall et al., 2016; Reidarson et al., 1999). Penguins take interest in objects such as sticks, leaves, and toys in their pool. Hoses, when used to create swirling and splashing water, may intrigue the penguins, and keep them in the water for longer periods of time as well (Larsson, 2012). Several studies have recommended the use of objects like rubber balls, plastic rings, bubbles, and flashlights for games of chase to encourage penguins to partake in more active behaviors, in and out of their pools (Erlacher-Reid et al., 2012; Reidarson et al., 1999; Reisfeld et al., 2013). However, few studies show the effectiveness of these strategies. Reidarson et al. (1999) utilized environmental enrichment in addition to traditional treatment to encourage the penguins to spend more time in the water while Reisfeld et al. (2013) showed that environmental enrichment was independently successful at reducing the size of bumblefoot lesions and even healed the wounds of two penguins by increasing their swimming time. Zoos and aquariums with captive penguins have a variety of forms of environmental enrichment to choose from when working to encourage their penguins to spend time in the water, and thus decrease the incidence of bumblefoot in their penguin populations.

Recently, research has proposed that the relationship between penguins and their keepers may serve as environmental enrichment although it is not a physical entity. The human-animal relationship (HAR) exists when both parties can make predictions about the other’s behavior because of previous and frequent interactions. The relationship is positive when the animal is not fearful towards its keeper or trainer and instead displays a sense of confidence in the outcome of the interaction or seeks it out. On the other hand, the HAR is negative if the animal has become fearful of humans and thus avoids them. The numerous benefits that a positive HAR can have on the wellbeing of a captive animal includes a sense of predictability and control. Environmental unpredictability can cause captive animals stress, while a regulated and predictable routine allows the animal to learn how to appropriately respond to the situation and successfully adapt, thus giving them control over the situation. Ten extra minutes of keeper interaction a day can increase activity level in chimpanzees (Claxton, 2011), and zoos and aquariums may apply the same concept to their penguins. Penguins respond well to zoo visitors, whose presence yields an increase in the number of play behaviors, amount of pool use, and overall activity level (Claxton, 2011; Collins et al., 2016). While the relationship between keeper and penguin has potential as an environmental enrichment device for increasing swimming behaviors, interactions between the penguins and facility visitors may also serve this purpose and therefore decrease the number of cases of bumblefoot.

Behavioral Husbandry

In addition to environmental enrichment, behavioral husbandry is a tool that zoos and aquariums may use to ease the process of diagnosing and caring for penguins with pododermatitis. The goal of behavioral husbandry is to achieve the voluntary participation of animals in their routine care through training and positive human-animal relationships. As with environmental enrichment, research on the implications of behavioral husbandry for captive penguins with and without bumblefoot is lacking. However, behavioral husbandry is important for the psychological health of captive animals as it reduces the stress that may be associated with medical procedures and routine exams. This tool may have significant use in the treatment of bumblefoot by assisting with the administration of medications and the development of relationships between staff and penguins. Mystic Aquarium used behavioral husbandry to ease the process of pododermatitis foot examinations in which a keeper cradled the penguins ventral side down on their arm. The facility taught the penguins to fully extend their legs and keep the plantar surface of their foot facing upwards during the exam (Erlacher-Reid et al., 2012). Behavioral husbandry could also be helpful when administering alternative treatments like WBV and PDT in which penguins may become alarmed or stressed. Zoos and aquariums must conduct further research to unveil the full potential of behavioral husbandry in easing the process of diagnosing and treating bumblefoot while they work to implement environmental enrichment devices to prevent further occurrence of pododermatitis.

Conclusion

Bumblefoot, or pododermatitis, is one of the most significant environmental diseases that penguins in human care face. It is a progressive disease and often not diagnosed until its aggressive stages in which the bone, tendons, and joints are infected, and at that point, the disease may even inflict death (Erlacher-Reid et al., 2012; Santos et al., 2016). Given that the contributors to bumblefoot are related to the abnormally sedentary lifestyles of these pelagic birds in captivity (Erlacher-Reid et al., 2012; Marshall et al., 2016; Nascimento et al., 2015;

Osório et al., 2013; Reidarson et al., 1999; Reisfeld et al., 2013), it is important to attack this infection at its source. However, the treatment approach used by veterinarians at zoos and aquariums has long been palliative rather than preventative. Although research has developed new treatment options to counter the issue of antibiotic resistance, such as whole-body vibration and photodynamic therapy, they are still not preventative in approach. To reduce the prevalence of bumblefoot in captive penguins, facilities need to encourage swimming and diving, or "species-specific" behaviors, that are absent from the captive environment. Since environmental enrichment seeks to improve the wellbeing of animals living in human care both physically and mentally through the provision of stimuli, it may be the perfect solution for bumblefoot. Many studies have recommended the use of environmental enrichment to prevent bumblefoot from occurring (Erlacher-Reid et al., 2012; Nascimento et al., 2015; Reidarson et al., 1999), but only one has shown the effectiveness of this tool on bumblefoot lesions independently of other treatments (Reisfeld et al., 1999). Enrichment may take on many forms, including toys, structures, and the relationship that captive penguins have with their keepers and visitors (Claxton, 2011; Erlacher-Reid et al., 2012; Larsson, 2012; Reisfeld et al., 2013). In addition, the use of behavioral husbandry to ease the process of regular foot examinations and administration of treatment can further promote the wellbeing of captive penguins, as well as better the human-animal relationship, while zoos and aquariums introduce their selected form of environmental enrichment. By approaching a chronic, progressive, and potentially deadly infection like bumblefoot with preventative measures such as environmental enrichment and behavioral husbandry, we may one day eradicate pododermatitis from zoo and aquarium-based penguins of all species and improve their quality of life at the same time.

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