Personal Communication

Orca (*Orcinus orca*) captivity and vulnerability to mosquito-transmitted viruses

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Abstract

Although unreported in wild orca populations, mosquito-transmitted diseases have killed at least two captive orcas (*Orcinus orca*) in U.S. theme parks. St. Louis Encephalitis Virus (SLEV) was implicated in the 1990 death of the male orca Kanduke, held at SeaWorld of Florida. In the second case, West Nile Virus (WNV) killed male orca Taku at SeaWorld of Texas in 2007. Captive environments increase vulnerability to mosquito-transmitted diseases in a variety of ways. Unlike their wild counter-parts who are rarely stationary, captive orcas typically spend hours each day (mostly at night) floating motionless (logging) during which time biting mosquitoes access their exposed dorsal surfaces. Mosquitoes are attracted to exhaled carbon dioxide, heat and dark surfaces, all of which are present during logging behavior. Further, captive orcas are often housed in geographic locations receiving high ultraviolet radiation, which acts as an immunosuppressant. Unfortunately, many of these facilities offer the animals little shade protection. Additionally, many captive orcas have broken, ground and bored teeth through which bacteria may enter the bloodstream, thus further compromising their ability to fight various pathogens. Given the often compromised health of captive orcas, and given that mosquito-transmitted viral outbreaks are likely to occur in the future, mosquito-transmitted diseases such as SLEV and WNV remain persistent health risks for captive orcas held in the U.S. [JMATE. 2012;5(2):9-16]

Keywords: Orca, mosquito-transmitted virus, captivity, logging behavior

Introduction

Since orcas (*Orcinus orca*) were first placed into captivity for entertainment purposes serious health issues related to their captivity have become apparent. Among these, mosquito-transmitted diseases have killed at least two captive orcas in marine parks in the United States. Kanduke, a 25- year-old male orca, died suddenly in the summer of 1990 at SeaWorld of Florida in Orlando. Necropsy results identified St. Louis encephalitis virus (SLEV) as the cause of death (7). Subsequently, Taku, a 14-year-old male orca, died suddenly and without notable premonitory signs of illness in 2007 at SeaWorld of Texas in San Antonio. The necropsy results also confirmed the presence of West Nile Virus (WNV) in brain tissue, with observed lesions consistent with those caused by WNV in other animals (42). An extensive record of mosquitoes feeding on zoo animals exists (1), and mosquitoes may exhibit altered host preferences within zoo settings (44).

Based on prior experience and observations working directly with captive orcas at a marine park in Florida (U.S.), we identify several factors that could place orcas held in U.S. theme parks at increased risk of exposure to mosquito-transmitted viruses, as well as an increased risk of developing the manifested diseases from these viral pathogens. Our animal trainer experience includes thousands of cumulative hours conducting "night watch" observations of captive orcas held in Orlando, Florida. Night watch duties at this park included recurrently documenting killer whale respirations for five minute intervals, and simultaneously noting the orcas' behavioral patterns from night until morning (typically 10:00 p.m. until 6:00 a.m.). We routinely observed long periods of logging behavior during night watch duties at the park, which coincided with the presence of biting mosquitoes.

WNV and SLEV

WNV and SLEV are single-stranded RNA viruses of the *Flaviviridae* subgroup of arthropod-transmitted viruses (17). Since its introduction into North America in 1999, WNV has been reported in nearly all U.S. states (8). WNV is primarily transmitted to avian hosts via mosquitoes of the genus *Culex,* where the virus can then be further dispersed to mammals, including humans (23). Among humans, those most likely to die from WNV exposure are immunocompromised or otherwise unhealthy (5).

Like WNV, SLEV is perpetuated through a mosquito-bird-mosquito cycle and can be transmitted to various mammals (12), including humans (11). SLEV has been reported in most U.S. states since it was first identified in 1933, although most cases of manifested

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SLEV disease have occurred in central and eastern states (8). Among human cases, morbidity and mortality from SLEV is associated with immune deficiency; age (older); hypertension; and perhaps, vascular disease (28). Further, over half of humans who manifest and survive neuroinvasive diseases such as WNV and SLEV continue to exhibit neurologic abnormalities over the course of their lives (30).

With respect to human exposure, most WNV infections are subclinical, although a minority of patients experience neuro-invasive disease, which includes West Nile meningitis (WNM), West Nile encephalitis (WNE), and West Nile poliomyelitis (WNP) (39). While human patients recovering from WNM routinely complain of persistent memory, concentration, weakness and fatigue, outcomes are generally favorable (24). WNE, however, is associated with longer hospital stays and medical complications such as bronchopneumonia and cardiac arrhythmias (5), and like WNE, WNP can manifest as respiratory depression and failure (40). Along these lines, Pepperell *et al*. (34) found that among human patients admitted to the hospital for WNV infection, 25% required mechanical ventilation; 23% of patients developed pneumonia; and 13% eventually developed bacterial infections.

In response to WNV, SLEV and other mosquito-borne illness risks, some municipalities have adopted ground-based spraying programs in an attempt to reduce the population of biting adult female mosquitoes. However, modern, ground-based insecticide spraying in Texas, Florida and other states have been shown to be mostly ineffective in controlling adult mosquito populations, and may pose an environmental and public health risk (35). Due to the aforementioned deaths of the two captive orcas, it is reported that within SeaWorld parks, "Mosquito management practices are similar in both facilities [Texas and Florida] and have been expanded since this diagnosis [of WNV as the cause of Taku's death]" (42). Although we never directly observed mosquito eradication measures at SeaWorld, we interpret the statement above to mean that the two parks have expanded ground-based insecticide application, and/or have attempted to reduce man-made micro-habitats such as standing water that may be found in planters and gutters, as the latter has been suggested as one of most

effective forms of mosquito control in zoos (13). Regardless of the efficacy (or lack thereof) of localized mosquito eradication approaches, managing natural mosquito populations and breeding habitat in areas like Florida and Texas is exceedingly difficult (Figure 1). Additionally, while synthetic skin-applied repellants such as DEET may be effective against biting mosquitoes, their prophylactic use on captive orcas is infeasible as they are readily removed by water immersion.

Figure 1: Aerial view of lakes that can be mosquito breeding habitat (circled in white) adjacent to the orca tanks at a popular marine park in Florida. Image also depicts the absence of shade structure in all but one of the pools during most times of the day. Image adapted from Google Earth.

MOSQUITO-TRANSMITTED VIRUSES IN WILD CETACEANS

Mosquito-transmitted viruses in *wild* orcas has not been reported; however, blood samples extracted from bottlenose dolphins (*Tursiops truncatus*) within shallow inland marshes and mangroves in the Indian River Lagoon, Florida and Charleston, South Carolina suggested possible exposure to Eastern, Western and Venezuelan Equine Encephalitis, and WNV (37). In their study, Schaefer *et al*. (37) found no outwardly manifested disease in any of the dolphins evaluated, and to our knowledge, no other literature exists describing wild cetacean exposure to WNV or SLEV. Therefore, based on our collective experience observing and working directly with captive orcas, we conclude that the captive environment represents unique exposure

risks to orcas living within WNV and SLEV-prone geographic regions.

CAPTIVITY AND MOSQUITO-TRANSMITTED VIRUS EXPOSURE RISKS

As orca trainers in the 1980s and 1990s we commonly witnessed mosquitoes accessing the dorsal surfaces of captive orcas in Florida, especially during evening hours. Compared to wild orcas who are rarely stationary (32), orcas in captivity spend much of their daily cycle logging (floating motionless) due to the spatial constraints imposed by living in shallow pools. This size limitation is evidenced by the fact that Kanduke lived in a pool system where only one pool was deeper (10.9m) than he was long (6.7m). Logging behavior is especially prevalent among captive male orcas, which we estimate to comprise >50% of their total daily behavioral repertoire, on average. Evidence of the inordinate time spent surface resting is thought by some to manifest in the many collapsed dorsal fins of adult captive males. In contrast, less than one percent of wild adult males exhibit this physical abnormality, as wild orcas spend too little time with dorsal fins unsupported by the water column to affect collapse [a]. Logging behavior therefore increases the likelihood of mosquito bites among captive orcas (42), as biting mosquitoes are attracted to exhaled CO_2 (14); body heat (47); dark surfaces (6) and other cues presented by stationary orcas and other cetaceans with dorsal surfaces exposed.

Whereas natural orca habitat in North America is mostly located at higher latitudes where ultraviolet radiation (UVR) exposure is diminished, captive orcas in the U.S. are generally housed at low latitudes where UVR exposure is substantially higher (15). It is known that among various species of wild cetaceans, those who spend relatively more time at water's surface exhibit greater sun damage as manifested by epidermal lesions consistent with sunburn (29). Although dark pigmentation might confer protection against UVR among some mammals (49), we commonly observed sunburnt dorsal surfaces of the captive orcas we worked with, especially among those animals prone to sustained logging. Sunburns we observed presented as discolored, peeling epidermis sometimes accompanied by small blisters similar to those more recently described (29). Further evidence of the potentially damaging effects of

UVR among captive marine mammals has been reported as corneal and eye injury in sea lions (3) and beluga whales (2).

Compounding the challenges of living in high UV areas, facilities housing orcas often provide little shade protection (Figure 1). From a mosquito-transmitted virus risk perspective, UVR exposure is important as it suppresses immunity to pathogens (25), which may increase likelihood of complications and even death from mosquito-borne illnesses (5). It may also depend on the wavelength of this radiation. For example, in human studies, UVB (290-315 nm) radiation acts as a strong immunosuppressant even at doses below that which cause mild sunburn; while UVA (315-400 nm) radiation acts as an even stronger immunosuppressant at dosing as low as that obtained from normal daily activity (10). Further, there is little evidence that photoadaptation in human skin occurs, and therefore it is thought that repeated UVR exposure results in a sustained suppression of the immune response (32). Along these lines, rodent studies demonstrate evidence that UVR increases both the severity of disease and microbial loads (41). Although topical sunscreens may be somewhat effective for preventing sun-induced epidermal lesions among terrestrial animals, they do little to mitigate the immunosuppressant effects of UV radiation (36), and their wholesale use on large marine mammals is infeasible.

Finally, many orcas in U.S. marine parks are burdened with poor dentition (Figure 2) which could compound susceptibility to mosquito borne diseases. We commonly observed captive orcas break or grind their teeth when demonstrating aggression through steel segregation gates or when they mouth/bite concrete or metal pool structures. Additionally, many captive orcas have undergone modified pulpotomy procedures in which a variable-speed drill is used to bore a hole vertically, through the tooth column, and into the pulp below the tooth. These bore holes are typically never filled (such as with amalgam in humans and other mammals) and thus could serve as a conduit for debris and pathogens to enter the bloodstream. It is known that periodontal caries result in bacteremia in humans (16), and given the large diameter bore holes in the teeth of many captive orcas (>4mm dia.) it is likely that these bore holes are associated with chronic bacteremia and

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Figure 2: Image of a captive orca's bored (1), missing (2), and ground (3) teeth. Poor dentition is common among captive orcas, causing chronic infections which are treated with antibiotics. Photo by Jeffrey Ventre reproduced with permission.

other negative health effects.

Consequently, it is common for orcas whose teeth have been drilled, or are otherwise in poor condition, to receive prophylactic antibiotics to control the risk of systemic proliferation of bacteria. In the medical field it known that long-term antibiotic use results in deleterious health effects including, antibiotic-resistant bacteria (45); increased susceptibility to certain cancers (22); and disruption of intestinal flora (38), leading to phytochemical malnourishment (21). Various antibiotics can also cause photosensitization and phototoxicity among those exposed to UVR (18), which has been shown to increase skin cancer risk (20).

Further, the immunosuppressive effects of antibiotic use in mammals are well established (27), which may be tied, in part, to the disruption of the endogenous microflora normally residing in the gut (48). Along these lines, it is known that both the production and activity of lymphocytes can be negatively affected by their administration (8). For example, quinolones, a family of broad-spectrum antibacterials, has been shown to impede macrophage activity by blocking their ability to identify specific target molecules of various pathogens (4).

MARINE MAMMAL INVENTORY AND CAUSES OF CAPTIVE ORCA DEATHS

The Marine Mammal Protection Act, passed by Congress in 1972, mandates that the National Oceanic Oceanic and Atmospheric Administration (NOAA) maintain an inventory of all marine mammals held captive in the United States. Among the data contained within the Marine Mammal Inventory (MMI) is the date a marine mammal enters captivity, and the date and brief description of the cause of death. To comply with NOAA, necropsies of dead orcas are performed by in-house staff at the marine park in which a death occurs. Based on MMI data, we evaluated the causes of death among captive orcas who died in 1990 or later. Of the 22 animals who have died in U.S. marine parks between 1990 and 2010, eight reportedly died of pneumonia; three of encephalitis; three of bacteremia; one of heart failure; and one of leptomeningitis. Notably, Taku is listed in the MMI as having died from "severe multifocal interstitial pneumonia," without mention of the underlying WNV infection. Kanduke's cause of death was described generally as "viral leptomenigitis," without mention of SLEV. While technically not inaccurate, these omissions and generalizations reflected in the MMI, secondary to "in house" necropsies, raise the possibility that underlying viral causes of captive cetacean mortality may be more common than suspected and therefore underreported.

Discussion

Logging behavior and mosquitoes

The constrained pool surface areas and pool depths inherent to the captive environment results in captive orcas consistently spending a greater proportion of their day logging than do their wild counterparts. Logging behavior, in which animals float motionless at the surface of the water, is especially common among large males who are often longer than the depths of the pools they inhabit. Among captive orcas this behavior results in dorsal surfaces exposed to biting mosquitoes, and it is acknowledged that logging increases the probability that cetaceans will be exposed to WNV (42). Mosquitos were commonly seen accessing the backs, heads and dorsal fins of the captive orcas we worked with, especially during warm summer evenings. Therefore, logging behavior, more than any other single factor, increases the likelihood that captive orcas will be exposed to mosquito-transmitted diseases.

Logging behavior and ultraviolet radiation

Orcas housed in low latitude facilities in North America are exposed to the immunosuppressive effects of high UVR dosing, especially among animals prone to excessive logging and who reside in pools lacking shade structure. Sunburn among wild orcas is not described in the literature as most wild orca populations live in low UVR environments. However, we commonly observed blistered and peeling skin on the dorsal surfaces of the captive orcas we worked with, especially among those who commonly exhibited logging behavior. It is accepted that excessive UVR exposure suppresses immunity to various pathogens, including a number of viruses (31), which may make organisms more likely to die from mosquito-borne illnesses (5). As a corollary, among humans possessing suppressed immune systems, there is a 40% risk of developing meningoencephalitis in patients having acquired WNV, compared to less than 1% risk in immunocompetent persons also with WNV (24). While more research is needed to better understand the effects of UVR on specific immunity to the *Flaviviridae* subgroup of viruses generally, it is probable that excessive UVR exposure among logging orcas living at low latitudes in North America serves to decrease resistance to manifested disease from mosquito-transmitted viruses and other pathogens.

Poor dentition and antibiotic use

Finally, the teeth of captive orcas are often in exceedingly poor condition. Ground, broken, missing and bored teeth allow bacteria and other pathogens to continuously enter the bloodstream. As a result of this bacteria loading, whales are often given daily prophylactic antibiotics, which are stuffed into the gills of their food (such as herring). Bacterial pathogens as secondary infections are problematic among humans hospitalized for WNV exposure (34), and it is reasonable to believe that sustained bacterial exposure as a result of poor dentition combined with the immunosuppressive effects of long-term antibiotic use (27) results in an unnaturally high vulnerability to *Flaviviridae* virus disease, especially for captive orcas living in mosquito-prone areas.

Conclusion

Based upon our analysis of the MMI, and because the causes of death of Taku and Kanduke are incomplete or misleading in the MMI, it is possible that other captive cetaceans have died as a result of mosquito-transmitted diseases. As there is little or no oversight by governmental regulatory agencies on necropsies performed by marine park personnel, there may be inadequate in-house expertise and little incentive to incur the expense required to perform the tertiary analyses necessary to determine exact causes of captive cetacean deaths.

Our unique experience working with captive orcas leads us to conclude that mitigating the risks associated with this unique set of circumstances is exceedingly difficult as exposure is primarily a function of the spatial constraints imposed by the captive environment. At a minimum, facilities housing orcas should provide adequate shade structure, strive to control mosquito breeding habitat, and improve surveillance of vector mosquito species.

Finally, we are unaware of any published studies examining the long-term health effects of excessive logging, poor dentition, chronic antibiotic use, high UVR dosing, and other consequences of orca/cetacean captivity as presented in this paper. More research is clearly needed to better understand how these issues fit into the current orca husbandry paradigm. However, based on published studies relying on human and animal models, it is likely that the singular or cumulative negative effects of the issues outlined in this paper conspire to predispose captive cetaceans to biting mosquitoes and manifested mosquito-transmitted diseases. Predispositions aside, perhaps the greatest threat to captive cetaceans succumbing to mosquito-transmitted viruses is virus circulation in a particular area. If so, husbandry measures alone are likely to be inadequate when future mosquito-transmitted viral epidemics occur.

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