

Short Note

Air Release from the Left Orbit of an Indo-Pacific Bottlenose Dolphin (*Tursiops aduncus*): Symptomatic and Anatomical Aspects

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An unusual release of gas bubbles is described in an adult female Indo-Pacific bottlenose dolphin (*Tursiops aduncus*). We will refer to this gaseous mixture from the respiratory tract as *air*, although we recognize that it is not the exact composition of atmospheric air after respiration has occurred. This air bubble release was observed under water (~10 m depth, 10 to 15 m clarity) in June 2006 outside Chichi-Jima harbor, Ogasawara, Japan, during an eco-tour program involving swimming with a mixed group of spinner (*Stenella longirostris*) and bottlenose (*T. truncatus*) dolphins (Figure 1). Underwater observations of this air release were documented by John Anderson (video) and James Brinck (still frames), both associates of the primary author. The dolphin, which had distinctive

scarring that would facilitate re-identification, swam up from the sea floor to the surface. During the ascent, she released a stream of bubbles from the region of her left orbit. Her ascent, air release, and following respiration at the surface were captured on video and transparency (Figure 2). Field-by-field video motion analysis confirmed that the point of bubble emergence was the medial angle of her left eye. The pathway for this unusual air release likely involves a communication with the respiratory tract.

Video and Still Photo Collection

A standard-definition 3-chip Canon GL1 digital video with high-quality century optics (with a .55

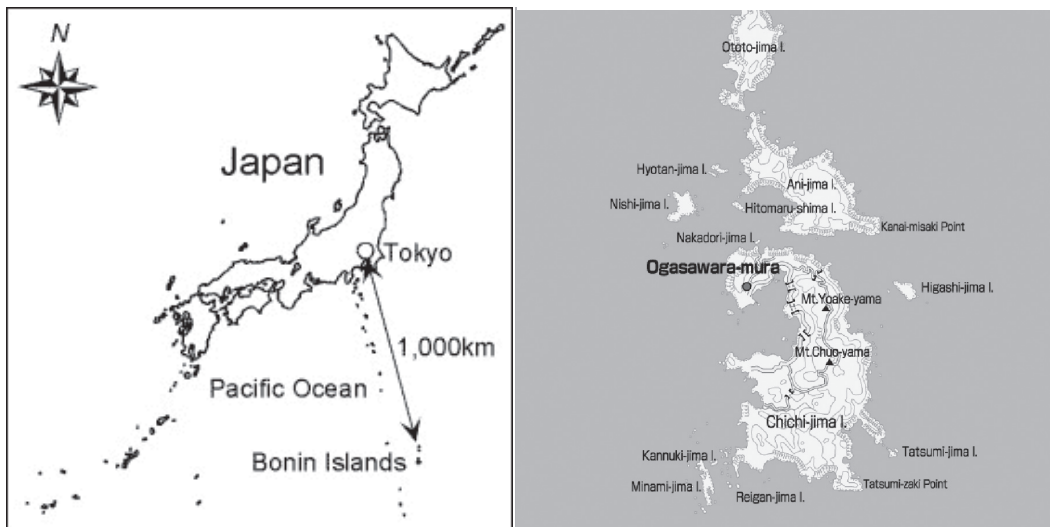


Figure 1. Map of Bonin Islands (Ogasawara) on left and Chichi-Jima on right



Figure 2. Enlarged view of 35-mm slide image of air emission from left orbit on adult female *Tursiops aduncus*; blowhole indicated by *a*, and air release at left orbit identified by *b*.

wide-angle lens adapter) was used inside a custom-built underwater housing with a 15.2-cm dome port to record the dolphins under water. Camera focus was manually set, and the aperture was set to slow automatic. For the 35-mm slide frames, a Nikonos 5 with a 15-mm Nikonos lens was used. No underwater lights or strobe were used to capture video or still frames.

Video Analysis

This air release was analyzed field-by-field at 60 Hz with *Vicon Peak Motus*, Version 9.0, motion analysis software (Centennial, CO, USA), using the approximate dolphin body length (268 cm) as a reference scale (from Kakuda et al., 2002). The tip of the rostrum, eye, cranial edge of the dorsal fin base, and the distal margin of the initial bubble

trail were digitized from the available video. A Fast Fourier filter was applied to all motion data. The angle of the bubble stream was calculated using the eye, tip of rostrum, and center of the far margin of the bubble trail as landmarks. Ascent angle was calculated using the surface of the water, tip of the rostrum, and the eye as landmarks. This video is available for viewing at <http://vimeo.com/30554766>.

Results

Field-by-field motion analysis confirmed that the point of bubble emergence was from the left eye's medial angle (*angulus oculi medialis*) (i.e., the space between the eye globe and eyelids at the rostro-lateral region of the orbit, adjacent to the medial palpebral commissure/fissure). The exhaled bubble trail lasted for 2.33 s and was approximately 534 cm in length (Figure 2). The mean angle of the bubble trail was 5.6° (± 5.67 SD) above the long axis of the dolphin but also fluctuated below the longitudinal axis as the dolphin's ascent angle changed (Figure 2). The dolphin ascended from a depth of approximately 10 m, and its body position was nearly vertical with a mean angle of 154.6° ($\pm 8.76^\circ$ SD) relative to the surface of the water.

Discussion

There are no published reports of any communication between the respiratory tract and the periorbita (globe, conjunctiva, extraocular muscles, nerves, blood vessels, adipose, and connective tissues) in normal, healthy dolphins. Therefore, the emergence of bubbles from the rostral aspect of the orbit is likely due to a defect of the intervening tissues, causing air to escape through an abnormal connection. The most likely source of air is the respiratory tract, due to its close proximity to the orbit near the skull base.

Dolphins possess several out-pouchings of the upper respiratory tract, including a pair of diverticula located largely within and around the pterygoid bones and occupying the medial orbital regions of the skull base. These air-filled, mucosa-lined diverticula have been variously referred to as pterygoid sacs (Fraser & Purves, 1960; Reidenberg & Laitman, 2008) or pterygoid sinuses (Fraser & Purves, 1960; Houser et al., 2004; Cranford et al., 2008; Mead & Fordyce, 2009; Costidis & Rommel, 2012; see also review in same). Although these pterygoid sacs/sinuses have an incomplete encasement in bone (unlike typical cranial respiratory sinuses) (Reidenberg & Laitman, 2008), we will use the more commonly accepted term *sinus* here to be consistent with more recent literature.

The pterygoid sinuses are bounded medially by bone but laterally by a network of veins and venous sinuses (fibro-venous plexus) that separate them from the ocular tissues of the orbits (Costidis & Rommel, 2012). In addition to the fibro-venous plexus, the lateral aspects of the pterygoid sinuses are surrounded by fat, connective tissue, and skeletal muscle. Together, these tissues comprise a flexible lateral wall (compared with bone) whose movements or variable diameter may passively accommodate changing air volumes during diving or ascent, or actively cause pressurizations that drive air flow between the various respiratory diverticula.

The pterygoid sinus abuts the orbit rostrally (ventral to the palatine, maxillary, and frontal bones), medially (within the pterygoid hamulus of sphenoid bone), and caudally (ventral to the basisphenoid, basioccipital, and temporal bones). It surrounds the globe of the eye medially, adjacent to the extrinsic ocular muscles, but allows passage of the optic nerve (Costidis & Rommel, 2012) and presumably other associated oculomotor complex nerves, sensory orbital nerves, and blood vessels of the orbit. The proximity of the pterygoid sinus to the orbit makes it the most likely candidate for the source of an anomalous air leak into the orbit. If a sinus wall were to be breached, it is feasible that differences in pressures could force air to leak through the breach.

One potential cause of sinus wall breach is head trauma with skull fracture. A fracture that traverses the orbit behind the eye and through the pterygoid sinus region could result in an accidental release of air from the respiratory tract to the orbit. Since the dolphin displayed an otherwise normal external appearance and behavior, there was no evidence it had suffered any serious traumatic injury to its head. Although possible, this scenario is considered unlikely.

A second potential route for air leaking is a developmental defect in the region of a persistent naso-lacrimal duct. In terrestrial mammals (including closely related artiodactyls), the naso-lacrimal duct (ductus nasolacrimalis) connects the rostral or medial aspect of the orbital floor (medial angle of the eye) and the lateral wall of the nasal cavity to drain tears to the nose. Adult cetaceans lack a naso-lacrimal duct (Waller & Harrison, 1978). However, it is unclear whether fetal or infant cetaceans develop a vestigial duct that then closes with maturity. If so, then an abnormal patency of the naso-lacrimal duct could occur. Such a developmental defect, especially if abnormally enlarged, could channel air from the nasal passageway to the orbit and out the medial angle of the eye.

A third potential cause for an air leak could be the pathological breakdown of intervening tissues between the orbit and respiratory tract (e.g., occurring secondary to infection). A potential mechanism of such a breakdown of these tissues could result from the activity of nematode parasites (e.g., *Crassicauda* sp.; Mead & Potter, 1995) that are often found in delphinid paranasal sinuses. In this case, nematodes burrowing outward from the pterygoid sinus could penetrate the periorbital tissues, resulting in a lateral defect in which air could escape into the orbit and be released adjacent to the rostral aspect of the globe of the eye, exiting from the medial angle of the eye. Alternatively, it is possible that a lesion resulting from a nonseptic puncture (e.g., from the barb from a ray) may have caused this unusual communication between the air sacs and the periorbita, but no apparent scar or puncture wound was observed.

During diving, air is normally trapped from escape by a closed blowhole in the upper respiratory tract; however, Boyle's Law dictates that expanding air volume (from decreasing ambient pressure) should distend the walls of the respiratory tract. The tissues in the walls of the paranasal diverticula should readily expand due to their relatively high compliance and superior position in the head region of a vertically oriented dolphin on ascent (air rises from the lungs to the head due to its being less dense than the surrounding body tissues or seawater). If these diverticula reach their limit of expansion before ascent is complete, the excess air should flow into other more compliant regions of the respiratory tract until pressures are equal throughout the respiratory tract. The normal path for evacuating excess air from the pterygoid sinus is via the pharyngotympanic tube (auditory or Eustachian tube), which connects medially to the nasopharynx. Upon reaching the surface, air will cease expanding, and it should be equal to the volume inspired during the last breath.

If the above conjecture is correct, then an open tube to the outside would provide a path of least resistance for this expanding air, compared with the effort of expanding respiratory tract tissues. We propose that either a pathological or traumatic perforation of the lateral wall of the pterygoid sinus or a large diameter patency of a naso-lacrimal duct atavism could explain this abnormal air release into the orbit. Since the medial angle of the eye is superior to the globe of the eye during ascent, free air within the orbit likely rose to this point to exit. An air leak is unlikely to be fatal but could compromise fitness if air reserves are depleted or water flows through the breach and floods the respiratory system. Additional anatomical work (e.g., dissection, resin casting, or dye tracing with imaging) should be conducted

to confirm this connection if this individual, or another one with the same symptom, becomes available for research *postmortem*.

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