Auditory anatomy and sound reception in the beluga whale (*Delphinapterus leucas*) compared to the bottlenose dolphin (*Tursiops truncatus*)

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1. Abstract

Current theories of sound reception in odontocetes are based mostly on one species, the bottlenose dolphin (*Tursiops truncatus*). Generalizations about sound reception pathways should be made with caution because there are large differences in cranial and mandibular anatomy among odontocetes that imply differences in sound reception. In this study, the auditory anatomy and fatty sound reception pathways in the beluga whale (*Delphinapterus leucas*) and the bottlenose dolphin were compared using three-dimensional reconstructions from computerized tomography (CT) data. The beluga was selected for comparison with the bottlenose dolphin because the Monodontidae have a substantially different head structure from the Delphinidae, particularly in terms of rostrum and lower jaw conformation. In addition, comparative data on hearing ranges, sensitivities, and localization are available for both species. The CT images employed were obtained with a maximal resolution of 0.1 mm, allowing features from gross skeletal to inner ear labyrinths to be determined. The reconstructions show that the locations of acoustic fats are similar in the beluga whale and the bottlenose dolphin. However, there are subtle differences that may influence hearing pathways, including the configuration and dimensions of the jaw fats. In particular, the postero-lateral jaw fats that are speculated to serve as an additional acoustic path for lower frequencies in bottlenose dolphins are less evident in the beluga whale. These fats are located ventral to the external auditory meatus (external auditory opening) in both species, a region that has never been tested for acoustic sensitivity in the beluga whale. These comparative data suggest that there are sufficient differences not only in the skull but also in the soft tissues of the heads of cetaceans to warrant additional species-specific studies of auditory anatomy and sound reception pathways. In particular, there may be important differences in key functional anatomical features across families.

2. Introduction

Current theories of odontocete sound reception are based mostly on the bottlenose dolphin, but there are large differences in cranial and mandibular anatomy among odontocetes. For example, the beluga whale has a substantially different head structure compared to the bottlenose dolphin and hearing studies suggest that sound reception pathways may differ between the two species (see below).

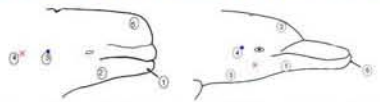


Fig. 1. Areas of beluga (left) and bottlenose (right) heads tested for hearing sensitivities in previous studies (Mohl *et al.*, 1999; Mooney *et al.*, 2008). Jawphones presented acoustic stimuli. Hearing was determined by auditory evoked potentials (AEP). Numbers indicate locations of maximum (1) to minimum (5) sensitivities. The position of minimum latencies of AEP responses is marked by the red 'X'. Location of external auditory opening shown by blue dot. Illustrations modified from Mohl *et al.* (1999) and Mooney *et al.* (2008).

3. Methods

Heads were obtained from strandings and were classified as Code 2 (Fresh Dead) at the time of scanning. Scans were acquired at the Woods Hole Oceanographic Institution CSI facility (whoi.edu/csi) on a Siemens Volume Zoom Spiral CT. Slice thicknesses were 1-3 mm with a maximal resolution of 0.1 mm. 3-D reconstructions were made using AMIRA® Version 5.2.2 by Visage Imaging ®.

- Beluga whale (*D.leucas*-08): 264 cm adult male.
- Beluga whale (*D.leucas*-06): Newborn, whole head in formalin.
- Bottlenose dolphin (*T.truncatus*-59): 191cm female.

4. Results

- Locations of fats along the lower jaw are similar in the beluga whale and the bottlenose dolphin (Fig. 2 & 3). However, there are subtle differences in jaw fats that may influence hearing pathways (see following section).
- The newborn beluga has fat distributions and shapes that closely match those of adults (Fig. 2 & 3). This is consistent with previous studies which showed spatial patterns for lipid class and fatty acid accumulation are established early in fetal development (Koopman *et al.*, 2006; Zahorodny *et al.*, 2009).
- The external auditory opening is located anterior to the ears in the beluga whales, while it is aligned with the ears in the bottlenose dolphin (Fig. 3).

Fig. 2. 3-D reconstructions of (a) adult beluga, (b) newborn beluga, and (c) bottlenose dolphin. Melon & jaw fats = yellow; External auditory opening and ear canal = blue; tympano-periotic complex (ears) = purple. White arrow = lateral fat channel; Black arrows = equivalent location in belugas. White scale bar = 10 cm.

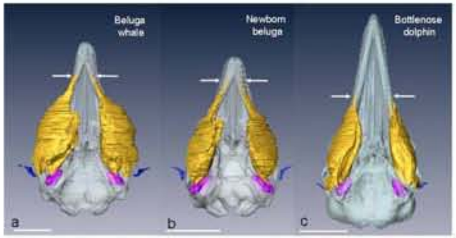


Fig. 3. Ventral view showing distributions and morphology of acoustic fats along the jaws for (a) adult beluga, (b) newborn beluga, and (c) bottlenose dolphin. Color coding as above. White arrows show anterior extent of jaw fats. Scale bar = 10 cm.

Potential functional significance of anatomical differences:

- The jaw fats extend near the mandibular symphisis in the beluga but end much more posteriorly in the bottlenose (Fig. 3 arrows). This may explain why Mooney *et al.* (2008) found that applying sound stimuli at the mandibular symphisis resulted in maximal auditory responses for the beluga, whereas Mohl *et al.* (1999) found no response for the bottlenose dolphin (Fig. 1).
- The lateral fat channels that may act as a second acoustic window in the bottlenose dolphin, particularly for lower frequencies, (Ketten *et al.*, 1999; Popov *et al.*, 2008) is much less prominent in beluga whales (Fig. 2 arrows).
- The beluga melon is dramatically differently shaped than that of the bottlenose and is surrounded by more dense, connective tissues (Fig. 4 & 5). The complex of denser tissues, melon, and jaw fats in the beluga is likely to have significantly different acoustical properties from the melon and jaw fats of the bottlenose dolphin.

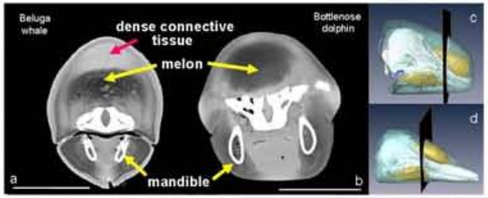
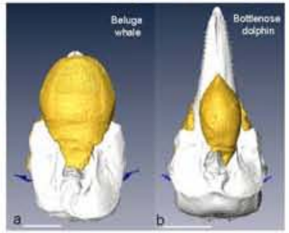


Fig. 4 (above). CT scans through the melon in (a) beluga whale and (b) bottlenose dolphin. Positions where the 2-D cross-section were taken are shown in (c) and (d). Scale bar = 10 cm.

Fig. 5 (right). 3-D reconstructions of (a) beluga whale and (b) bottlenose dolphin melons. Same color scheme as Fig. 2. Scale bar = 10 cm.



5. Conclusions

There are sufficient differences not only in the skull but also in the soft tissues of cetacean heads to warrant additional in-depth, species-specific studies of auditory anatomy and sound reception pathways. In particular, there may be important differences in key functional anatomical features across families.

6. Future Research

- Extend comparative studies to more species from various families.
- Include data from dissections to verify CT findings (see Arruda *et al.*, 2009, this meeting – Poster # 38).

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