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BIOMECHANICAL AND STRUCTURAL MODELING OF HEARING IN BALEEN WHALES

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Introduction

Anthropogenic noise may be a major source of habitat degradation for cetaceans. To assess and mitigate the effects of noise pollution on marine mammals, we need information on how and what they hear. Although hearing in odontocetes, or toothed whales, is well studied, few data are available for mysticetes, or baleen whales. Behavioural and electrophysiological hearing tests are presently impractical for mysticetes, but biomechanical, structural modelling provides hearing estimates based on auditory system anatomy. In this research, three101 dimensional models were produced for minke Balaenoptera acutorostrata, blue Balaenoptera musculus, and humpback Balaenoptera novaeangliae whale inner ears from CT scans and histology to measure key features for estimating hearing ranges, e.g., basilar membrane thickness-towidth ratios. Full head reconstructions were also produced for minke whales based on head CT images and dissections.

Methods

Intact heads were studied to search for potential pathways of sound into the inner ear. Computerized tomography (CT and MRI) is an effective method of studying odontocete heads (Ketten & Wartzok, 1990) that allows examination of internal anatomy in situ without cutting into the specimen, avoiding distortion or destruction of structures and their relative orientations. For example, Ketten (1994) determined the morphology of odontocete jaw fats using CT and MRI data. Computerized tomography has been underutilized for mysticetes because most mysticete heads do not fit into scanner gantries. Yet, it is possible to scan smaller species such as the minke whale. Therefore, the application of computerized tomography for mysticetes may provide novel data on acoustic pathways inside mysticete heads. Once the complete heads were examined via CT, dissections provided a closer look at both macroscopic and microscopic structures. Dissections carry the advantage of not being in gray scale, and the researcher can physically examine head tissue details in comparison to the scan images. However, there is a limit to visual observations during dissections. Histology is useful for both qualitative and quantitative microscopic evaluations. For histology, periotic bones were decalcified, sectioned, stained, and mounted onto microscope slides. The basilar membrane is a particular focus for histologic study in the inner ear. The basilar membrane vibrates in response to sound energy entering the cochlea, which stimulates hair cells, producing auditory signals through the auditory nerve. The thickness-to-width ratios (T:W) along the basilar membrane are analogues of stiffness and mass changes, which in turn relate to frequency response differences (Ketten & Wartzok, 1990; Liberman 1982). By measuring the T:W of the basilar membrane throughout the length of the cochlea, one can estimate the hearing range of each ear. Thus, computerized tomography and dissection can uncover gross aspects of mysticete hearing and histology can tell us what whale ears fundamentally hear.

Results

This work provides the first analysis of head tissues related to baleen whale sound conduction pathways incorporating CT and dissection as well as new data on inner ears. Scan analyses suggest important parallels exist between odontocetes and mysticetes in head fats that likely act in sound reception. Preliminary calculations of both fats and cochleae indicate baleen whales have wide hearing ranges, with some species capable of detecting infrasonic-to-ultrasonic frequencies. International collaboration is an important component for advancement of anatomical studies that can provide essential data for effective conservation policies.

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