Cumulative Sperm Whale Bone Damage and the Bends

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Methods

Sixteen sperm whale calves and adults (Table S1) were examined for bone surface morphology. Age estimated from length (*1*) ranged from 0 to at least 40 years. All were examined as cleaned bone specimens except one (NBWM 2003-95) that was necropsied and the bones then cleaned. Routine histopathological (Armed Forces Institute of Pathology and U. Connecticut Veterinary Diagnostic Laboratory) and microbiological (National Veterinary Services Laboratory, Ames IA) analyses were conducted on NBWM 2003-95. Bone erosion and remodeling was graded for all cases (Table 1). Selected bones were examined with X radiography and computer tomography (Siemens Somatom Emotion).

Extended Discussion

Sheep experimentally exposed to dysbaric conditions (*2*) showed histopathology that included reactive fibrosis, proliferative new bone, osteocyte loss in cortical and cancellous bone, numerous remodeling cavities in cortical bone and eroded periosteal surfaces. This is very comparable to the gross and histological evidence described here and is consistent with the hypothesis that sperm whales exhibit chronic effects of deep prolonged diving. Dysbaric osteonecrosis in humans is limited to weight bearing joints, especially the shoulder and hip. In an essentially weightless sperm whale, the rib and chevron bones are force bearing analogues acting as compression members while the animal flexes and extends the vertebral column to swim. The nasal bone lesions in

sperm whales may be associated with the high energy sonar reflecting off the sinuses adjacent to this bone during echolocation click transmission.

If the chronic effects of nitrogen emboli are apparent in sperm whales, then acute effects may also be a risk. Acute decompression sickness (*3, 4*) is reported in breath holding human divers if they have a low surface to dive time ratio, and re-surface rapidly. Despite human bone lesions being restricted to those that have breathed compressed air, a lack of chronic injury in breath holders may simply be due to less chronic and continuous exposure. If marine mammals are not anatomically and physiologically fully adapted to avoid decompression sickness, a reexamination of marine mammal diving behavior for evidence of decompression sickness avoidance is necessary. Diving behavior could be shaped by this as well as by established determinants of foraging, such as energetic and respiratory limitations. In this regard both sperm and bottlenose whales are reported to intersperse deep dives with shallow subsurface activity which may reflect controlled decompression (*5, 6*). Therefore, the long standing debate over the reality of decompression sickness in diving marine mammals (*7-10*) is relevant to the risks of exposure to loud underwater sound sources (*11-14*). Current studies of such risks should consider not only the direct effect of the sound sources on these animals (*11*), but also the more subtle impacts of stressors that over-ride normal behaviors that minimise the impact of decompression sickness.

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Figure S1. Progressive, erosive and remodelling development of dysbaric osteonecrosis in sperm whale bones. Each panel shows a left to right progression from calf to mature adults. Scale bars 1cm unless indicated below. Dark areas indicate the vascular channels: normal in calves, and increasingly eroded and enlarged in larger animals. Accession numbers left to right from Table S1 for each panel. a. Sub-articular chevron bone surfaces. AMNH 8026, NHA 92.121.1, NBWM 2003.95, AMNH 34872. b. Nasal bone: scale bars 2, 25, and 1 cm. Right image detail of box in center. MCZ 60386, NBWM 2003.95. c. Deltoid crest: scale bars 1 and 2 cm. MCZ 1209, NBWM 2003.95.


A


B

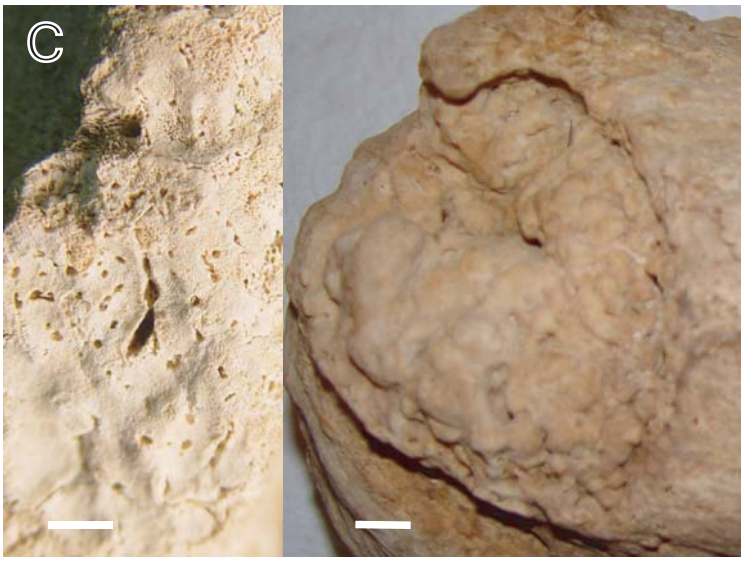
C

Table S1 - Source, sex, length, and bony abnormalities in a size series of sperm whales

State Mo./Y.	Museum Number	Sex	Length (m) Total	Skull	Degree of erosion and remodelling			
					Nasal	Rib head	Rib	Sternum	Chevron
SC 12/1870	MCZ 1209			0.7	-	-	-	-
MA 8/1988	MCZ 60386	F	3.7	0.7	-			
MA 1/1966	MCZ 52289		4.1	0.7	-			
	SIMNH 504311			0.8	-			
MA 8/1897	SIMNH 49488		3.7	0.8	-	-	-	
NY 3/1927	AMNH 80206		6*			-	-/+	-
NY 1/2003	NYSM 14300	M	7.3	1.6	+	+	-	-/+
NJ 12/1891	SIMNH 35315	F		1.7	+			
	MCZ 42088			1.9	++			
VA 4/1969	SIMNH 395398	F		1.9	++			
Japan 4/1928	SIMNH 253051			3.1	+++			
MA 10/1994	MCZ 61406	M	11	3.4	++	+	-	+
MA 12/1997	NHA 92.121.1	M	14	4.2	++	-	+	++
MA 6/2002	NBWM 2003.95	M	14.7	4.2	+++	++	+	+++
NJ 10/1911	SIMNH 301634	M	17.7	5.1	+++	++	+	+
Japan 8/1911	AMNH 34872	M	18.3			++	+	+++

AMNH: American Museum of Natural History; MCZ: Harvard Museum of Comparative Zoology, NBWM: New Bedford Whaling Museum; NHA: Nantucket Historical Association; NYSM: New York State Museum; SIMNH: Smithsonian Institution Museum of Natural History. *Estimated. Blank cell = no specimen or data available. Absent = -, Mild = +, Moderate = ++. Severe = +++