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Pugnose eels, *Simenchelys parasiticus* (Synaphobranchidae) from the heart of a shortfin mako, *Isurus oxyrinchus* (Lamnidae)

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Synopsis

A 395 kg shortfin mako, *Isurus oxyrinchus* (Lamnidae) landed at Montauk, New York in June of 1992 was found to contain two dead, but otherwise healthy appearing pugnose eels, *Simenchelys parasiticus* (Synaphobranchidae) within the lumen of its heart. The path along which the eels made their way into the shark's heart was not found. Histological examination of the shark's heart revealed the presence of medial hyperplasia and hypertrophy of small arterioles, multifocal arteriosclerosis, and relatively high numbers of capillaries per unit area. These phenomena were not observed in similar sections taken from hearts of six uninfected mako sharks. The stomachs of both eels were filled with blood, suggesting that they had been within the shark at least long enough to feed. Consideration of this new record along with the literature supports a trophic designation of facultative endoparasite for the species *Simenchelys parasiticus*.

Introduction

On 26 June 1992 two of us (J.N.C. and N.E.K.) were astonished to find two anguilliform fish in the lumen of the heart of a shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, landed at Montauk, New York. Details of this unusual finding are given herein.

Materials and methods

The male shortfin mako was foul-hooked by a longline set in the western North Atlantic 32 km east of Block Canyon in water 1000 m deep, and was brought aboard dead. The shark probably was on a muddy ocean floor around the time of its death, as suggested by a brown discoloration of the ventral surface of its head and mud on its gills. When the mako was boated, the long-line had been deployed for approximately 16 h. The shark was stored in a cold room overnight, and was weighed (395 kg) and necropsied the next day. During the necropsy the general external body surface and internal organs were examined for ecto- and endoparasites. After discovering two dead but otherwise healthy looking eels within the shark's heart, the entire shark was re-examined in an attempt to locate the portal into the shark used by the eels, as well as the avenue of access into the heart itself.

The mako heart and both eels were subsequently placed on ice for the short transport to the laboratory where they were photographed, then fixed in 10% buffered formalin for 7 days, and subsequently preserved in 70% ethanol. Tissue samples (each 1 cm^3) were removed from four regions of the heart: the auricle, the ventricle, the auricular-ventricular junction, and the junction of the ventricle and the conus arteriosus. Equivalent tissue samples served as controls and were prepared from similarly collected, fixed, and preserved hearts of six uninhabited shortfin makos weighing 56-252 kg captured by fishermen off Montauk, New York in July of 1992 and June of 1993. Using standard histological techniques, tissue samples were embedded in paraffin wax, sectioned (15 μm) using a rotary microtome, and stained with hematoxylin and eosin. Four fields of view were microscopically examined (400x) for each of the tissue region samples, and the number of blood vessels observed in each field was recorded. The mean number of blood vessels (± 1 standard error) for each of the four sampled heart regions was calculated for the inhabited heart and for the pooled control hearts.

The body cavity and stomach of each eel were opened via midventral incisions, and stomach contents were removed, stained with geimsa, and examined individually as wet mounts under a compound microscope. Intestinal contents were sampled by probing with a thin glass curette. To determine the sex of each eel, small samples of gonad tissue were removed and microscopically examined. Both eels, the remainder of their stomachs' contents, and representative slides of the histological sections of the infected and control hearts were deposited in the Museum of Comparative Zoology at Harvard University (Coll. No. 100188).

Results

The two eels collected from the shortfin mako heart were identified as *Simenchelys parasiticus* Gill, 1879. The smaller eel measured 21 cm total length and 3.9 cm girth at midsection; the larger eel measured 24 cm total length and 4.7 cm girth at midsection. Both eels were immature females. The smaller eel was found coiled in the auricle of the heart. The larger eel was ventrally flexed with its head in the conus arteriosus, its trunk in the ventricle, and its tail in the auricle (Figure 1). Stomach contents of both eels consisted entirely of clotted blood. No intestinal contents (food or parasites) were found in either eel. No signs of scarring or penetration of either the outer body surface of the shark or its heart were located. Unfortunately, trauma caused by a tow rope which had been used to move the heavy shark prior to necropsy confounded the interpretation of some portions of the branchial region, and it is possible that this damaged region contained the invasion area of the two eels.

Gross areas of intense discoloration were observed within the infected heart at the junction of the conus arteriosus and ventricle, as well as at the junction of the ventricle and auricle. Three histological differences were evident between tissue samples taken at these areas of the eel-inhabited and the control hearts. While lack of replication regarding eel-inhabited hearts prevented statistical analysis of histological data, tissue from all four regions of the eel-inhabited heart had greater mean numbers of arterioles per field of view than equivalent tissues from control hearts: 1.25 ± 0.75 versus 0.92 ± 0.17 respectively for the auricle, 1.0 ± 0.57 versus 0.54 ± 0.15 respectively for the ventricle, 3.5 ± 1.55 versus 0.58 ± 0.17 respectively for the junction of the auricle and ventricle, and 3.0 ± 1.22 versus 0.75 ± 0.22 respectively for the junction of the ventricle and the conus arteriosus. Additionally, there was medial hyperplasia and hypertrophy of small arterioles in the eel-inhabited heart (cf. Figure 2a, b), as well as multifocal arteriosclerosis of small capillaries seen as partial mineralization of vessel walls or total occlusion of vessel lumens by granular mineralized material (Figure 2c). Both the eel-inhabited and control hearts had scattered granulocytes with prominent eosinophilic cytoplasmic granules throughout the myocardium, as well as marked subendocardial loose connective tissue which was sparsely cellular and myxomatous, especially at the ventriculo-conical junction. These areas contained a few fibroblasts and numerous Antischkow cells.

Figure 1. Larger specimen of pugnose eel, *Simenchelys parasiticus*, as found in the heart of a shortfin mako, *Isurus oxyrinchus*. Pencil indicates scale.

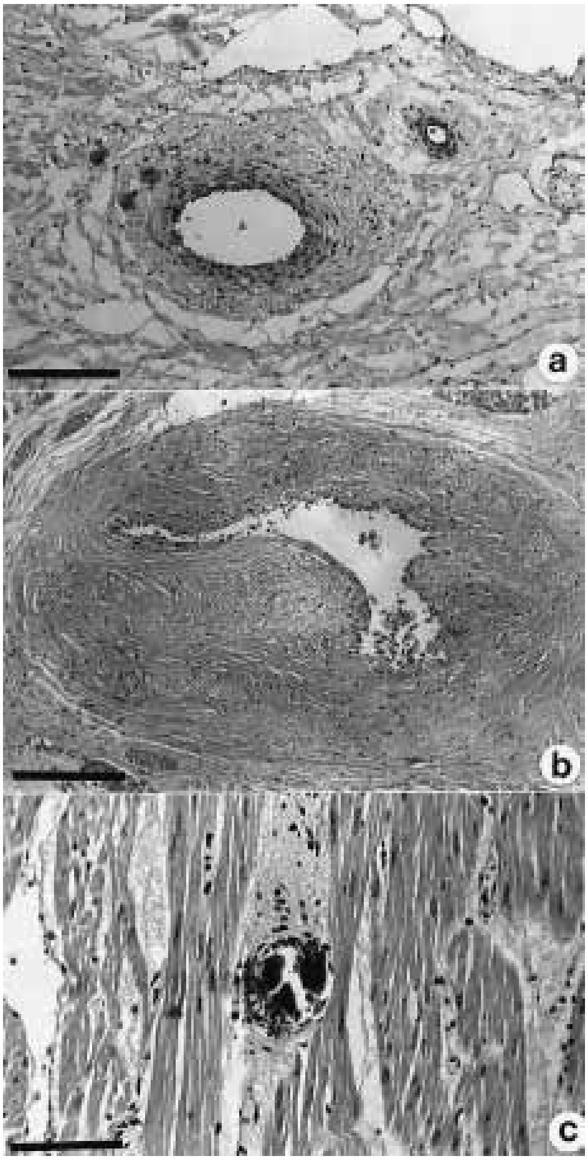

Figure 2. Heart tissue sections of control and eel-inhabited shortfin makos: a - junction between auricle and ventricle of control (uninhabited) heart. Note normal histology of small arteriole. Scale bar = 200 µm. b - junction between auricle and ventricle of eel-inhabited heart showing medial hyperplasia of a small arteriole. Note relative thickness of the arteriole wall and narrowness of lumen (cf. Figure 2a, b) caused by apparent proliferation of myointimal cells. Scale bar = 200 µm. c - junction between auricle and ventricle of eel-inhabited heart showing arteriosclerosis of small capillary. Note mineral deposits within lumen and wall of small vessel. Scale bar = 100 µm.

Discussion

Despite its name, previous natural history data for *Simenchelys parasiticus* do not support an obligatory parasitic life style for this species. The specific epithet refers to the fact that 'individuals have been found burrowing into the flesh of the halibut' (Gill in Goode & Bean 1879, p. 27), these halibut having been trawled at 200-300 fathoms. Goode & Bean (1896, p. 140) provided additional detail of this association in reporting that *S. parasiticus* 'burrows in the muscles of living halibut and other large fishes, after the manner of *Myxine*, and excavates large cavities in the thickest parts of their bodies'. Several sentences later these same authors reiterate that this fish, 'has occasionally been found embedded in the flesh of larger fishes'. Unfortunately, we have been unable to locate reliable records specifically identifying these larger fish hosts. Beyond the aforementioned reports of pugnose eels embedded in fishes, which have been cited or alluded to frequently in secondary literature (e.g. see Nikolsky 1963, Leim & Scott 1966, Marshall 1966, Bond 1979, Scott & Scott 1988), all other reports of *S. parasiticus* have concerned free-swimming juveniles or adults either observed from submersible craft (Herdendorf & Berra 1995) or captured in deep water using a variety of traps (Goode & Bean 1896, Tanaka 1908, Zugmayer 1910, Jordan & Thomson 1914, Roule 1919, Fowler 1936, Bigelow & Schroeder 1953, Castle 1961, Smith 1961, Solomon-Raju & Rosenblatt 1971, Robins & Robins 1989). Castle (1961) and Bigelow & Schroeder (1953) reported the pugnose eel to be locally abundant, and Bigelow & Schroeder (1953) also commented that large numbers of pugnose eels have occasionally been captured in traps over very short periods of time. A schooling behavior or otherwise high local densities of these eels certainly would increase the likelihood of multiple inhabitation of scavenged or parasitized food items, and might help explain how in the present case two pugnose eels became nestled in the same relatively small body organ.

The discovery of blood in the stomachs of both eels reported here indicated that they had been in contact with the circulatory system at least long enough to consume blood. We have no way of knowing whether our inability to find flesh in the digestive tracts of these eels indicated that they had burrowed into this shark some time ago, or whether our inability to find debris in their lower digestive tracts indicated that they had only recently arrived in the mako or that they were intermittent feeders. Likewise, we have no way of knowing whether our inability to find parasites on or within the eels themselves indicated a lengthy endoparasitic existence for these individuals or merely the fact that they had no parasites. Manter (1960) described the trematode *Hypertrema ambovatum* (Fellodistomidae: Digenea) from specimens collected in the intestine of *S. parasiticus*. However, he did not provide details as to whether the pugnose eel host of *H. ambovatum* was captured as a free-swimming individual or embedded in another fish. Manter's report of digenes from the pugnose eel of course suggests that his specimen had been free living at least long enough to expose it to trematode infection.

Based on an age and growth study of shortfin makos (Pratt & Casey 1983), the eel-inhabited shark and largest control shark reported on here could have differed in age by as few as six or as many as nine years, and age differences between the inhabited shark and the remaining control sharks would seemingly be even greater. Furthermore, using data in Pratt & Casey (1983), the eel-inhabited shark would have been mature while the control sharks would either be immature or just mature in the case of the largest control shark. Therefore, the observed increase in myocardial vascularization seen in the eel-inhabited heart could have been related to size, age, maturity, and/or eel infection. Corroboration of any of these associations in sharks would be notable because they are not known in other vertebrates.

The medial hyperplasia of small arterioles, and the multifocal arteriosclerosis of small capillaries (both seen only in the inhabited heart) might be suggestive of some hemodynamic and/or toxic factor acting on the coronary circulation. These lesions could have been caused by obstruction of blood flow and/or metabolic wastes produced by the eels and thus might be evidence that these eels had entered the shark some significant length of time prior to its capture. We are unaware of reports of medial hyperplasia in elasmobranchs. In mammals, however, lesions of the vessels of the heart are often associated with increased blood pressure and nematode infection (Robinson & Maxie 1985). Concerning the arteriosclerosis observed in the inhabited shark heart, we are unaware of this or other lesions (Farrell et al. 1992) in elasmobranchs associated with age or weight. Lastly, regarding the numerous Anitschkow cells seen in both the eel-inhabited and control shark hearts, it is notable that in mammals these cells are associated with regenerative attempts after myofiber injury (Robinson & Maxie 1985). It is unknown what role Anitschkow cells play in elasmobranch myocardial tissue.

Although we have no conclusive evidence and some things remain unexplained, we feel that a likely scenario resulting in our finding pugnose eels in the heart of a mako shark is as follows. Having been compromised by being hooked, the shortfin mako dangled from the capture line on or just above the ocean bottom about the time of its death. Either just prior to or after its death, the two pugnose eels located the shark and burrowed into it in the same general area somewhere about the gills or throat. The eels entered the circulatory system (either via an afferent artery or the ventral aorta) and traveled into the heart. At some time during this process the eels consumed blood. While this scenario suggests the trophic status of scavenger for these two particular eels, information contained in the literature supports the status of facultative parasite for the species *S. parasiticus*. Records of trawl-caught halibut infected with pugnose eels (Gill in Goode & Bean 1879) certainly indicate the pre-capture entry of eels into these benthic fish. The difference between the trophic designations of scavenger and facultative parasite might seem hazy to some in instances such as this. However, we maintain that the latter assignment is proper because the eels reported by Gill (op. cit.) did not consume their entire host and more importantly because they had entered into a close association with another living organism to which they caused some degree of harm. This ability to live even briefly within another organism has important potential evolutionary significance as it provides future opportunity for phylogenetic and ecological changes which could eventually produce obligate parasite lineages and true hosts.

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