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[Communication]

Protrusion of the Valvular Intestine in Captive Smalltooth Sawfish and Comments on Pristid Gastrointestinal Anatomy and Intestinal Valve Types

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Abstract.—We report on three separate instances of protrusion of the valvular intestine in the smalltooth sawfish *Pristis pectinata,* compare pristid gastrointestinal anatomy and intestinal valve structure with those of other elasmobranchs, and discuss the relevance of anatomy and valve structure to the husbandry of captive specimens. Protrusion of the valvular intestine, or intestinal eversion, has been documented in carcharhinid sharks with scroll-type intestines. All three cases of protrusion in smalltooth sawfish in this report involved specimens in multispecies display facilities and ultimately resulted in mortality. These are the first documented cases of intestinal eversion in any species of elasmobranch with a conicospiral valvular intestine. The valvular intestine of sawfishes (family Pristidae) is of the conicospiral type, which is similar to that described in other batoid species. However, unlike many other sharks and batoids, which possess short, stout pyloric stomachs, the pyloric stomachs in the pristids we examined were long and similar to those of carcharhinid sharks. The ability to protrude the valvular intestine in elasmobranchs may depend upon both valve morphology and the length of the pyloric stomach. The details of the gastrointestinal anatomy may be useful for systematics but also may be relevant to the captive husbandry of carcharhinids and sawfishes.

Sawfishes (Chondrichthyes: Pristidae) comprise four to seven species in two genera, *Pristis* and *Anoxypristis* (Robins et al. 1991; Last and Stevens 1994; Compagno and Cook 1995; Nelson et al. 2004). The biology of most of these species is poorly understood, and the family is in need of taxonomic revision. *Pristis perotteti* and *P. microdon* are considered to be junior synonyms of the largetooth sawfish *P. pristis* by Nelson et al. (2004) and others. In this report, individual species are recognized pending taxonomic revision, as done in recent publications (Deynat 2005; Peverell 2005).

All sawfish species are classified as endangered or critically endangered by the World Conservation Union (IUCN 2000; Cavanagh et al. 2003). The smalltooth sawfish *P. pectinata* is listed as critically endangered in the western Atlantic Ocean (IUCN 2000; Simpfendorfer 2000, 2002) and is the only native marine fish species protected by the U.S. Endangered Species Act (National Marine Fisheries Service 2003). Although smalltooth sawfish still occur along the coast of Florida, they have been extirpated from much of their former range and have suffered significant population declines (Seitz and Poulakis 2002; Simpfendorfer 2002; Poulakis and Seitz 2004). Smalltooth sawfish are born at about 70 cm total length (TL) and grow to a maximum size of 600 cm TL, although some sources cite a maximum length of 760 cm (Bigelow and Schroeder 1953; Last and Stevens 1994). They do well in captivity and have been maintained for several years in public aquaria (Michael 1993), where they are usually housed with other elasmobranchs or in multi-taxa displays containing elasmobranchs and teleosts (Sabalones 1995).

Valvular intestines, or spiral valves, are found in a variety of primitive fish taxa, including dipneustans, brachiopterygians, chondrosteans, holosteans, and chondrichthyans (Crow et al. 1990). Three basic types of valvular intestine have been described in elasmobranchs: scroll, conicospiral, and ring (Meng and Zhu 1985; Compagno 1988; Crow et al. 1990); the latter type is referred to as ''lamellated'' by Meng and Zhu (1985). Gohar and Mazhar (1964) described a fourth type, spiroannular in rhynchobatids, which appears to be a variant of the conicospiral type. In addition, Holmgren and Nilsson (1999) further divided conicospiral into three types based upon the patterns in rajids. The scroll intestine is believed to be derived from the spiral intestine and may allow large food items to pass without obstruction through the intestine while retaining the increased absorptive surface area of the valvular intestine (White 1937, cited in Compagno 1988). In this report, only the

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three major types—ring, conicospiral, and scroll—are considered.

Protrusions of the valvular intestine, some with subsequent mortality, have been reported in carcharhinids, which along with sphyrnids possess the scroll-type valvular intestine (Compagno 1988; Crow et al. 1990, 1991; Crow and Brock 1993). To date, eversions of ring or conicospiral valve types have not been documented. The only published anatomical structure of the valvular intestine in a pristid is that of the conicospiral type for the pointed sawfish *Anoxypristis cuspidata* (Meng and Zhu 1985). This paper describes the protrusion of the intestine in the smalltooth sawfish as well as the gastrointestinal anatomy and morphology in pristids.

Methods

Two smalltooth sawfish, a male and a female, were maintained at the National Aquarium in Baltimore (NAIB) in an oval, racetrack-shaped aquarium system described by Sabalones (1995). Three smalltooth sawfish, one male and two females, were maintained at SeaWorld Orlando in a multispecies exhibit that was described in Murru (1990) and Rasmussen and Murru (1992). The specimens were fed from 2.5% to 4% body weight per week. Water quality parameters of both aquarium systems were maintained within acceptable ranges, and the temperature was maintained at 24.4 ± 0.3°C (mean ± SE). The three specimens reported here were maintained in captivity for up to 16 years without incident.

Necropsy of smalltooth sawfish.—The gross necropsies of the smalltooth sawfish at the NAIB were conducted by systematically examining each organ system. Histopathology samples were collected from each organ system; vertebrae, genetic samples, and other biological samples were also collected from the NAIB specimens. For purposes of this report, particular attention was paid to the gastrointestinal tract.

Observations of the pyloric stomachs in smalltooth sawfish.—The pyloric stomachs of the male and female sawfish at the NAIB were examined. Stomach morphometric data were not collected, but stomachs were categorized as either short and stout or long and slender to allow comparisons to the pyloric stomachs in other species of elasmobranchs.

Observations of the spiral intestines in smalltooth sawfish and other pristids.—Detailed measurements and the number of turns or valves were recorded for the intestine from the female specimen at the NAIB. It was not possible to examine the gastrointestinal tract of the female smalltooth sawfish at SeaWorld. To generalize the information obtained on the gastrointestinal anatomy in the smalltooth sawfish to other pristids, we examined intestines from other pristids within the collection of Dr. Janine Caira, University of Connecticut. The intestines examined were from a 209-cm-TL female pointed sawfish, a 98-cm-TL female dwarf sawfish *P. clavata*, a 101-cm-TL largetooth or freshwater sawfish *P. microdon* of unknown sex, a 230-cm-TL male narrowsnout sawfish *P. zijsron*, and a 541-cm-TL female narrowsnout sawfish.

Results

Observations of Valvular Intestine Protrusion

Protrusion of the valvular intestine in a 309-cm-TL, 86.5-kg male smalltooth sawfish was observed at the NAIB on November 7, 2000, in the process of eversion. The animal was observed with bite marks on tissue protruding from the cloaca, including approximately 10 cm of the intestine. The amount of protruding intestinal tissue increased to about 20 cm; the tissue was observed being bitten by schoolmasters *Lutjanus apodus* and was transected by lemon sharks *Negaprion brevirostris*. The eversion appeared to be a pushing out of the intestine from the inside rather than an unfolding, as described for scroll intestinal protrusions. In addition to bites to the intestine, bite marks on the claspers and pelvic fins were also noted. Bleeding from the cloaca and abdominal pores was noted. The animal was sedated and removed from the system, and staff veterinarians performed an intestinal anastamosis.

Surgery on the smalltooth sawfish confirmed that the valvular intestine was transected and that bite marks on the intestine, claspers, and pelvic fins were characteristic of bites inflicted by lemon sharks and schoolmasters. The fish's condition was continuously monitored, and the animal was humanely euthanatized after the detection of the onset of cardiac arrest at 20 h after the eversion trauma.

The second instance of protrusion of the valvular intestine in this species occurred at the NAIB on June 17, 2002, in a 269-cm, 65.2-kg female. In this case, the eversion was not observed. The protruded intestine was bitten and completely transected by lemon sharks. Bite marks were also present on the pelvic fins. An intestinal anastamosis was performed as described by B. R. Whitaker and colleagues (paper presented at the 2003 Confer-

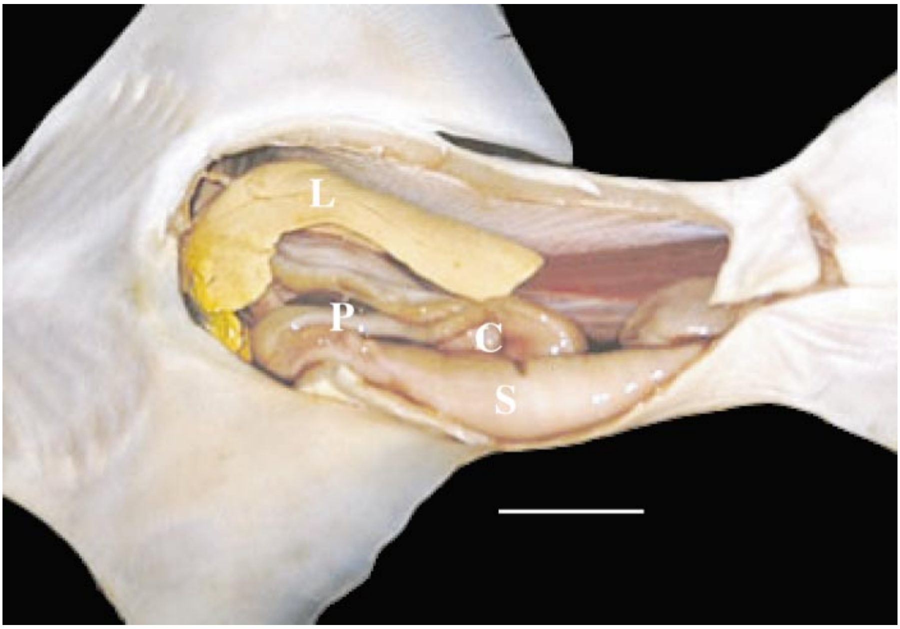

FIGURE 1.—Ventral view of the internal anatomy of a 93.0-cm female largetooth sawfish (L = liver; C = cardiac stomach; P = pyloric stomach; S = spiral valve or valvular intestine). Photograph is by M. McDavitt and is used with permission (scale bar = 10 cm).

ence of the International Association for Aquatic Animal Medicine). The gastrointestinal tract of the female specimen at the NAIB was transected in the distal portion of the valvular intestine, caudal to the valves. The fish died 168 d after the protrusion and traumatic injury. Despite having returned to its former ration for at least 126 d, the animal's weight decreased by 25.3% between the protrusion and death.

A third case of protrusion of the valvular intestine was observed in a 282-cm female smalltooth sawfish at SeaWorld Orlando in 2000. In this instance, the animal was observed to be lying on top of the underwater acrylic tunnel with its intestine protruded. Although other inhabitants of the aquarium system did not bite the protruded intestine, the animal was captured on two occasions and sutures were placed into the tissue in an attempt to prevent the protrusion. In the first instance, the sutures were placed in the cloaca; in the second instance, sutures were placed in the intestine itself. The specimen at Sea World later died from secondary infection despite the attempts to suture the intestine back in place (G. Violetta, SeaWorld Orlando, personal communication).

Necropsy of Smalltooth Sawfish

Ischemia of the distal portion of the male's gastrointestinal tract indicated a loss of vascular supply to that region. The high degree of vascularization in the valvular intestine prevented the successful closure of all blood vessels. At necropsy of the female smalltooth sawfish nearly 6 months after surgery, it was shown that the anastamosis had healed without any compromise to the remainder of the gastrointestinal tract. The histopathology report indicated that the death was caused by acute rhabdomyolysis and was not directly associated with the bite wounds or surgery. Also noted was a loss of fat stores in the hepatocytes in addition to some parasitic granulomas (possibly nematodes) in the intestine. Information from the necropsy of the specimen at SeaWorld was not available to us.

Observations of the Pyloric Stomachs in Smalltooth Sawfish

The pyloric stomachs of the NAIB smalltooth sawfish were long and slender. Although the stomachs are not pictured here, they were similar to that observed in the largetooth sawfish (Figure 1).

Observations of the Spiral Intestine in the Smalltooth Sawfish and Other Pristids

The remaining portion of the intestine in the female sawfish from the NAIB was 19 cm in length from the anterior junction at the duodenum to its

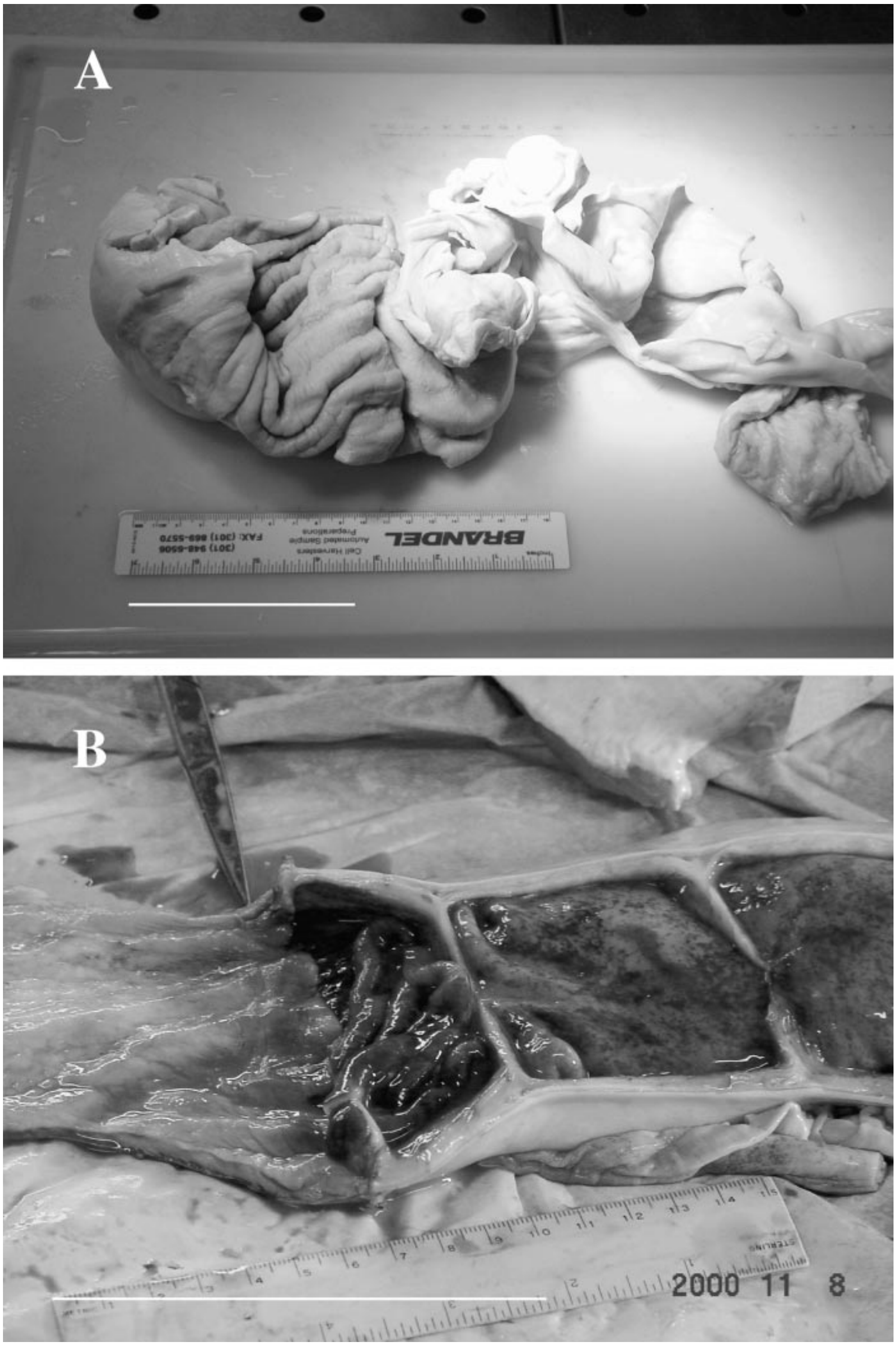

FIGURE 2.—Valvular intestine of a 309-cm male smalltooth sawfish in **(A)** longitudinal view and **(B)** crosswise view. Photographs are by A. Henningsen (A) and B. Whitaker (B) (scale bars = 10 cm).

termination posterior to the valves; the missing segment was approximately 10–15 cm long. The widths of the intestine were 4 cm at the anterior end and 5 cm at the remaining posterior end. The structure of the valvular intestine in the smalltooth sawfish (Figure 2A, B) is of the conicospiral type. The intestines of the other pristids (pointed sawfish, dwarf sawfish, largetooth sawfish, and nar-

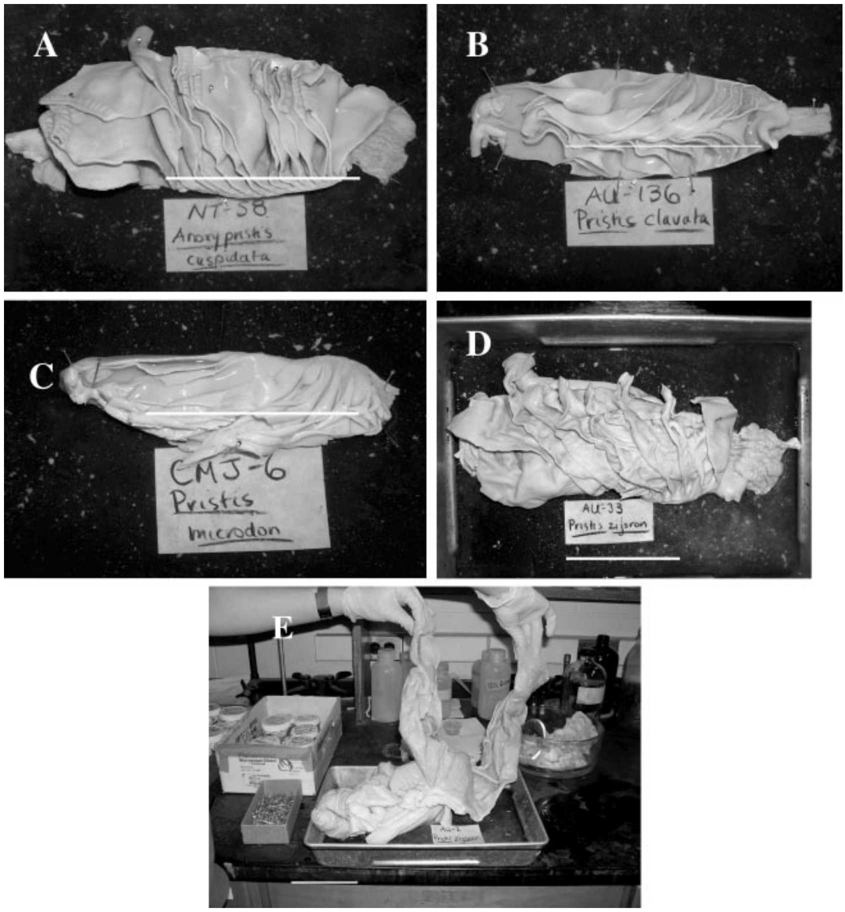

FIGURE 3.—Valvular intestines of **(A)** a 209-cm female pointed sawfish, **(B)** a 98-cm female dwarf sawfish, **(C)** a 101-cm largetooth sawfish of unknown sex, **(D)** a 230-cm male narrowsnout sawfish, and (E) a 541-cm female narrowsnout sawfish with large mucosal folds. Photographs are by J. Caira and are used with permission (scale bars = 10 cm).

rowsnout sawfish) are also classified as conicospiral (Figure 3A–E). Although all are considered to be conicospiral, the intestines from these species exhibit great variation in the length of the turns and all have anterior chambers that are notably long. The length of the anterior chambers and extent of mucosal folds are particularly evident in intestines from large specimens (Figure 3E). The numbers of valves observed for the specimens examined in this report were as follows: 7 for smalltooth sawfish, 15 for pointed sawfish, 7 for dwarf sawfish, 9 for largetooth sawfish, and 8 for narrowtooth sawfish.

Discussion

Protrusion of the valvular intestine is a concern for captive smalltooth sawfish, and it can lead to injury and death when the specimen is maintained with predatory teleosts or other elasmobranchs, as has been shown for captive carcharhinids (Crow et al. 1990, 1991). The long, slender pyloric stomachs observed in the smalltooth sawfish and other pristids examined are similar to those observed in carcharhinid sharks and are in contrast to the short, stout pyloric stomachs found in many batoids and sharks that possess conicospiral or ring valvular intestines (Crow et al. 1990; Holmgren and Nilsson 1999). Given the discussion provided in Crow et al. (1990), we propose that eversion in sawfishes is made possible by a combination of the large anterior intestinal chambers and the long, slender pylorus. Additional evidence for the similarities in the gastrointestinal tract between carcharhinids, sphyrnids, and pristids is that stomach eversion has been observed both in smalltooth sawfish and in some sharks (G.R. Poulakis, Florida Fish and

Wildlife Conservation Commission, personal communication; J.C. Seitz, Florida Museum of Natural History, personal communication).

It has been suggested that the protrusion of the valvular intestine is a natural flushing action to rid the gastrointestinal tract of feces, undigested food, and irritants, and possibly loosely attached parasites such as nematodes (Compagno 1988; Crow et al. 1990, 1991). The effect of food type or quantity on the frequency of intestinal eversion is unknown. The two occurrences at the NAIB showed no obvious trends, as the eversions occurred at 6 d postprandial in the first case and at 4 d postprandial in the second case. Further, the food items and quantities were 1.21-kg spotted seatrout *Cynoscion nebulosus* in the first case and 0.81-kg Spanish mackerel *Scomberomorus maculatus* in the second case; both of these species were common food items in the established weekly rations. No alterations in environmental conditions (e.g., photoperiod, temperature, water quality, and water chemistry) were observed in the three cases reported here. Crow et al. (1991) suggested that in captivity, the density of sharks possessing a scroll valve may predispose these animals to intestinal biting from tankmates. However, Crow et al. (1991) also cited aquarium system design, shark size, water depth, and the mixing of newly acquired specimens with resident sharks as possible factors that may promote such events. Intestinal eversion by carcharhinids has occurred at the NAIB without incident (Crow et al. 1990; A.D.H., personal observation). In addition to intestinal eversions, other conditions related to the gastrointestinal tract in captive elasmobranchs, such as intussusception and intestinal torsion (Morales and Dunker 1999), have been reported.

Although there is a low degree of variability in counts within a species, the number of valves (or turns) in valvular intestines has been useful in elasmobranch systematics (Compagno 1988). The number of valves observed in the specimens in this report agrees with previous observations of about 8 turns in *Pristis* spp. and 15 turns in *Anoxypristis* spp. (Garman 1913; Meng and Zhu 1985). The number of turns of the valvular intestine in fetal largetooth sawfish *P. perotteti* (=*pristis*) increased ontogenetically from three in a 51-mm-TL specimen to the final number of nine in a near-term, 677-mm-TL fetus (Oetinger 1978). This may be relevant to the putative synonymy of *P. perotteti* and *P. microdon* with *P. pristis,* pending taxonomic resolution within the family Pristidae.

Despite the historical abundance of sawfishes worldwide, there is little published biological information except for the contributions by the late Thomas Thorson on the largetooth sawfish (Seitz and Poulakis 2002). Only recently has information been published on the biology and ecology of the smalltooth sawfish (Seitz and Poulakis 2002; Simpfendorfer 2002; Poulakis and Seitz 2004). Detailed examination of the length of the pyloric stomach and intestinal morphology across chondrichthyans may provide insight into other species capable of intestinal protrusion, which may be relevant to both captive husbandry and systematics.

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