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Sharks and Medicine

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Sharks are common and popular display animals in zoos and aquaria. There are more than 440 known species of shark, with variations in lifestyle and environment. Most species are marine, with few exceptions that are not typically maintained in aquaria.

Among the most common sharks maintained in human care are nurse sharks *(Ginglymostoma cirratum),* sand tiger sharks *(Carcharias taurus),* sandbar sharks *(Carcharhinus plumbeus),* blacktip reef sharks *(Carcharhinus melanopterus),* bonnethead sharks *(Sphyrna tiburo),* leopard sharks *(Triakis semifasciata),* zebra sharks *(Stegostoma fasciatum),* and whitespotted bamboo sharks *(Chiloscyllium plagiosum).* Larger species, such as whale sharks *(Rhincodon typus)* and hammerhead sharks (*Sphyrnidae* spp.), are less frequently maintained but are found at some institutions.[1]

Sharks are in the same class as rays, both of which are characterized by their cartilaginous skeletons. However, there are differences in the approach to medical management between these elasmobranchs. This chapter will focus on the management of shark species commonly housed in aquatic and zoological institutions.

Biology, Anatomy, and Physiology

The basic body plan and anatomy are similar among all shark species. Their skeleton is composed of cartilage instead of bone, and they have small placoid scales covering their bodies. Sharks have a two-chambered heart consisting of an atrium and a ventricle. Blood is carried from the heart to the capillaries in the gills, where oxygen exchange occurs. The branchial arteries distribute the blood throughout the body, and deoxygenated blood returns to the heart.[2]

Most species have five pairs of gill slits. Ventilation is dependent on the lifestyle of the shark. Open water pelagic sharks primarily use ram ventilation in which water is forced over their gills while constantly swimming. Few obligate ram ventilators are kept in aquaria due to the challenge of providing adequate space for continuous swimming in a captive setting. In contrast, benthic species can move water over their gills through buccal pumping. This allows them to rest comfortably on the bottom and tolerate hypoxic environments. Many species are intermediate ventilators and use some combination of ram ventilation and buccal pumping.[2]

Sharks have large livers that comprise up to 25% of an individual's body weight. They have a simple stomach and a short small intestinal tract that empties into the spiral colon (also known as the spiral valve). The large surface area of the spiral colon compensates for the overall shortness of the digestive tract and allows for more efficient nutrient absorption. Sharks have a rectal gland that is located proximal to the cloacal opening and is thought to play a role in sodium balance.[2]

Sharks lack bone marrow and lymph nodes and use alternative hematopoietic organs such as the thymus, spleen, epigonal organ, and Leydig cells. The ability of the epigonal organ and Leydig organ to produce lymphomyeloid tissues is unique to elasmobranchs.[2]

Husbandry and Management

As with all aquatic animals, water quality is of paramount importance to maintaining good health. Parameters such as temperature, pH, salinity, nitrates, nitrite, ammonia, alkalinity, and heavy metal levels may vary between shark taxa and should be thoroughly researched prior to bringing a new species to an institution.

Exhibits need to be designed with both animal and human safety in mind. Ideally an exhibit should be set up so that the animal is accessible and may safely be manipulated or restrained. This allows for management of the individual in case of illness or injury. Mixed species exhibits are possible when size and demeanor of the species to be housed together is taken into consideration.

Restraint

Manual Restraint

Many small- to medium-sized sharks can be manually restrained with adequate facilities and experienced handlers. The goal of any restraint is to minimize stress and ensure the safety of both the animal and the handlers. The handler should wear gloves to protect from the abrasive nature of their skin. Many sharks respond well to operant conditioning and may be trained to target and voluntarily move into a sling. Small sharks can be held safely. Many sharks go into tonic immobility when placed in dorsal recumbency. This reflex, documented in multiple species, including blacktip reef sharks and leopard sharks, causes the individual to become immobile and allows for safer handling.[3] Although this restraint technique may be useful for nonpainful procedures, it has not been documented to have analgesic effects and in some instances has been linked to hyperesthesia, so additional analgesia should be used when performing painful or invasive procedures.[4]

Because this method of restraint requires that the shark must be physically turned upside down, it is applicable only to individuals and species that are small enough to do so safely.

Larger sharks may be restrained using a shark box by using a sling to remove them from the water and place them in the box. The restrainers then apply firm pressure along the body with one person holding the jaw shut. The box is small enough to restrict movement and allow safe sample collection. It is important for all restraint that there is not a prolonged pursuit because this may lead to elevated lactate and acidemia.[5]

Chemical Restraint

There are many species of shark that are too large or dangerous to manually restrain, and sedation or anesthesia are required. Anesthetics may be administered through immersion bath, injection, or orally, and numerous protocols have been described.[6,7] Equipment may vary depending on species and environment, but a list of commonly used materials is presented in Box 49.1. There is wide variability in species-specific physiology. As a result, the efficacy of any anesthetic may depend on a number of factors, including temperature, metabolism, drug receptors and distribution, and hepatic transformation.[7] A complete review of shark anesthesia is beyond the scope of this chapter, and the reader should consult additional source material for specific protocols.[7]

• BOX 49.1 Common Equipment Needed for Shark Anesthesia

Appropriately sized container: tub, shark box
Stretcher
Tank water for anesthesia and recovery
Methods of ventilation: red rubber tubes, air pumps, catheter tip syringes
Thermometer
pH meter
Dissolved oxygen meter
Air stone
Protective gloves

Physical Examination

A physical examination on a shark should begin from afar by obtaining a thorough history and observing how the animal interacts with its environment and conspecifics. Appetite, attitude, swimming pattern, and evaluation of any external lesions may all be assessed without needing to restrain the individual.

When performing a physical examination, the handler should evaluate the shark from nose to tail. The integument should be assessed for any lesions, cuts, or abrasions. Overall body condition should be evaluated, and if possible a weight should be obtained. Ocular examination may be performed with the use of a light source, slit lamp, or ophthalmoscope. A safe evaluation of the oral cavity may be done by inserting a polyvinyl chloride (PVC) pipe into the oral cavity and using a light source to evaluate the mucosa and teeth. Respiratory rate and effort should be noted by monitoring opercular movement. Auscultation has little utility for monitoring of cardiac parameters, but a Doppler, electrocardiogram (ECG), or ultrasound may be used to obtain heart rate and rhythm. Because ECG clips may be difficult to place on the skin of sharks, leads should be connected to needles and placed in the appropriate locations. Evaluation of the cloaca for any swelling, lesions, discharge, or discoloration should be included in the examination. Measurements are often taken to track growth and condition.

Diagnostics

Blood may be collected from several locations in a shark, depending on the species and the method of restraint. The dorsal sinus and the ventral coccygeal vein are the two most commonly used sites. The ventral coccygeal vein is preferred because blood in the dorsal sinus pools, whereas the blood in the ventral tail vein is actively circulating.[8] When accessing the ventral coccygeal vein, it is important to ensure that the needle is inserted at a 90-degree angle on midline (Fig. 49.1). In many cases the needle needs to be advanced through cartilage prior to reaching the vessel. In larger species a spinal needle may be used. When obtaining blood from the dorsal sinus the needle should be inserted on midline caudal to the dorsal fin at a 45-degree angle (Fig. 49.2).

Blood should always be placed immediately into anticoagulant tubes. In sharks, dry heparin or ethylenediaminetetraacetic acid (EDTA) can both be used; however, EDTA can cause rapid hemolysis in stingray species, so if both species are maintained in a collection it is preferable to use heparin tubes in all cases. If possible, a hemocytometer count should be performed immediately after collection to prevent thrombocyte and white blood cell aggregation. If this is not possible, an aliquot can be preserved in 10% formalin for later evaluation; this maintains cell morphology and prevents thrombocyte aggregation.[9]

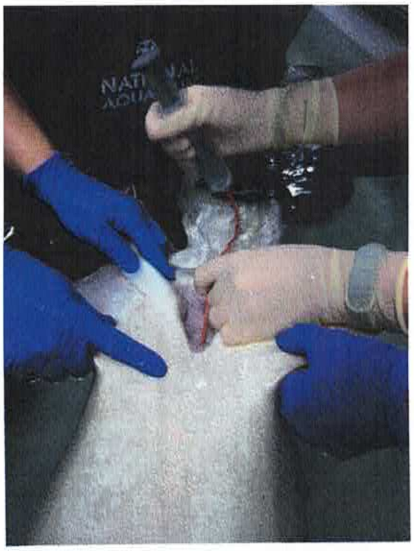
The unique physiologic characteristics of sharks must be taken into account when interpreting blood work results.

• **Figure 49.1** Image of blood collection from the ventral coccygeal vein in a blacktip reef shark *(Carcharhinus melanopterus).*

• **Figure 49.2** Image of blood collection from the dorsal sinus in a sandbar shark *(Carcharhinus plumbeus).*

Marine elasmobranchs retain and reabsorb urea and other solutes, thereby ensuring that plasma remains hyperosmotic to their saline environment.[10] Normal blood urea nitrogen (BUN) should range from 1000 to 1300 mg/dL, and low values may indicate loss from renal disease or decreased production due to hepatic disease. Marine elasmobranchs have efficient salt excretion mechanisms in the kidney and specialized rectal gland that compensate for the influx of sodium (Na) and chloride (Cl) from the environment. However, serum concentrations of these electrolytes are higher than seen in mammals. Differential counts vary by species, but generally there should be 50%–75% lymphocytes, 10%–30% heterophils, 0%–10% eosinophils, 0%–1% basophils, and 0%–3% monocytes.[11] Basophils are rare or absent in many shark species studied. The use of acute phase proteins as markers of inflammation is being explored but has only been investigated in limited species.[12] Reference ranges have not been established in many sharks but Tables 49.1 and 49.2 provide values for some commonly kept species.

Skin scrapes and biopsies may be taken if lesions are detected on examination. It may be difficult to obtain a fecal sample from sharks, but a cloacal wash can be done to obtain a sample. This procedure involves gentle insertion of a lubricated red rubber tube cranially into the cloaca, saline infusion, and gentle suction (Fig. 49.3). This allows for parasite evaluation, as well as provides material to culture if enteritis is suspected.



• **Figure 49.3** Image of cloacal wash being performed to obtain a fecal sample on a blacktip reef shark *(Carcharhinus melanopterus).*

Imaging

The shark skeletal system is composed of calcified cartilage, resulting in excellent radiographic detail, making radiographs a useful tool in evaluating skeletal structures.[11] However, it is often difficult to evaluate soft tissue and organs.[11] When possible, both a dorsoventral and a lateral image should be obtained. The use of contrast medium may be useful in evaluating the gastrointestinal tract but often requires multiple images.[11] Because obtaining radiographs requires removing the shark from the water, there may be increased risk to the animal as well as potential damage to the equipment.

Ultrasound is very useful in assessing organ shape, location, and consistency and is a complement to radiology.[13] It may also be used to monitor gilling and heart rates as well as diagnose pregnancy. It is important to note that sharks have a large, lipid-filled liver, which will appear more hyperechoic compared with mammals.

Advanced imaging, such as computed tomography (CT) or magnetic resonance imaging (MRI), is not typically used in sharks due to their limited availability and complicated logistics. Studies on preserved specimens have revealed that it may be a useful modality to characterize internal structures.[14] Due to logistic challenges, advanced imaging is more often used to evaluate specific lesions of interest and is not generally performed as part of routine scanning.

TABLE 49.1 Hematologic Reference Ranges for Select Shark Species

Parameters	Smooth Dogfish *(Mustelus canis)*[*]	Spiny Dogfish *(Squalus acanthias)*[†]	Atlantic Sharpnose *(Rhizoprionodon terraenovae)*[†]	Bonnethead *(Sphyrna tiburo)*[†]
PCV (%)	20.1–32.1[*]	21.4–55.9	18.9–30.8	22–35
WBC (per µL)	11,438–25,580	21,400–55,900	34,600–119,600	35,300–83,100
Neutrophils (%)	11.2–21.2	5.17–39.2	0–2.3	1.5–16
Neutrophils (per µL)	2,488–5,035	1,300–18,200	0–2,600	6,700–8,500
Lymphocytes (%)	16.2–39	20–49	20.2–57.1	22.7–55
Lymphocytes (per µL)	3,268–11,162	7,600–23,600	10,400–47,400	10,400–37,500
Monocytes (%)	2.4–8.4	1–8.3	0–8.3	1–7
Monocytes (per µL)	550–1,794	410–3,300	0–6,500	470–4,600
Fine eosinophilic granulocytes (%)	8.1–31.7	5.45–26.8	13.5–38.3	9.75–40.5
Fine eosinophilic granulocytes (per µL)	1,190–7,544	2,000–11,200	5,700–26,800	4,700–19,100
Coarse eosinophilic granulocytes (%)	1.6–5.7	4–24.3	4–26.2	0.75–17
Coarse eosinophilic granulocytes (per µL)	334–1,287	1,100–11,400	2,200–22,700	340–12,100
Granulated thrombocytes (%)	19–36.6	10.7–26	6.5–36	7–39
Granulated thrombocytes (per µL)	3,814–8,836	3,500–12,600	3,700–29,000	3,400–27,500

[*] Range (took low mean − SD and high mean + SD).

[†] Persky ME, Williams J, Burks RE, et al: Hematologic, plasma biochemistry, and select nutrient values in captive smooth dogfish *(Mustelus canis)*. *J Zoo Wildl Med* 43:842–851, 2016.

[‡] Haman K, Norton T, Thomas A, et al: Baseline health parameters and species comparisons among free-ranging Atlantic sharpnose *(Rhizoprionodon terraenovae)*, bonnethead *(Sphyrna tiburo)*, and spiny dogfish *(Squalus acanthias)* sharks in Georgia, Florida, and Washington, USA. *J Wildl Dis* 48:295–306, 2012.

Diseases

A variety of bacterial pathogens have been reported in shark species. The bacteria *Tenacibaculum maritimum* has been documented to cause necrotic skin lesions in sand tiger sharks.[15] A Chlamydia-like bacterium was isolated in association with epitheliocystis lesions in a leopard shark.[11] Vibrio, specifically *Vibrio carchariae* and *V. damsela*, have been associated with disease and mortality in multiple shark species, although some, like the lemon shark *(Negaprion brevirostris)*, appear to have resistance.[16,17] *Aeromonas salmonicida* has caused hemorrhagic septicemia in blacktip reef sharks.[11] *Flavobacterium* sp. have been isolated from bonnethead sharks in association with neurologic disease.[11] A pyogranulomatous meningoencephalitis of presumed bacterial etiology was found in a basking shark *(Cetorhinus maximus)*, but the exact organism was not identified.[11]

Viral diseases are less commonly reported in sharks. Viral erythrocytic necrosis has been noted in dusky smooth-hound *(Mustelus canis)* and leopard sharks. The causative agent is an iridovirus that affects the red blood cells, leading to hemolysis and potentially death. Young animals with no immunity to the virus are most often affected. A viral skin disease, associated with a herpesvirus, has also been reported in dusky smooth-hounds and is characterized by white to gray discoloration of the skin. This often occurs after the animal has undergone a stressful event, but there is no associated systemic disease, and lesions often resolve without intervention.[11]

There are several reported incidences of pathogenic fungal disease in sharks. *Paecilomyces lilacinus* fungal infection was seen in a hammerhead shark, leading to systemic and terminal disease.[18] *Fusarium solani* has been documented in several captive hammerhead sharks, causing mycotic dermatitis and affecting the head and lateral line system, and has also caused fatal disease in juvenile bonnethead sharks.[19,20] Coinfection with *Exophiala pisciphila* and *Mucor circinelloides* in a zebra shark also caused fatal systemic fungal infection.[18] *Exophiala* sp. was detected in a swell shark *(Cephaloscyllium ventriosum)* that displayed abnormal circular swimming patterns and mineralization of the cartilage of the skull and cervical vertebrae.[21]

Numerous parasites have been reported in shark species. The monogenean parasite *Dermophthirius nigrellii* has been found in wild lemon sharks.[22] Another monogenean, *Dionchus penneri*, can cause chronic skin lesions in blacktip reef sharks (see also Chapter 47).[23]

Several cestode species have been documented, including: *Paraorygmatobothrium* spp. tapeworm in lemon sharks, *Pedibothrium* spp. in nurse sharks, *Crossobothrium* spp. in

TABLE 49.2 **Biochemical Reference Ranges for Select Shark Species**

Parameters	Smooth Dogfish *(Mustelus canis)*[*]	Spiny Dogfish *(Squalus acanthias)*[†]	Atlantic Sharpnose *(Rhizoprionodon terraenovae)*[†]	Bonnethead Sharks *(Sphyrna tiburo)*[†]
Glucose (mg/dL)	91.6–117	28.2–58.0	129–222	165–191
Urea nitrogen (mg/dL)	968–1017			986–1028
Phosphorus (mg/dL)	4.1–6.3	2.8–5.7	5.5–9.6	7.5–10
Calcium (mg/dL)	16.2–17.5	9.3–15.6	15.9–21.7	16.2–17.2
Total protein (g/dL)	2.1–3.4			2.7–3.4
Albumin (g/dL)	0.4–0.6			0.4
Globulin (g/dL)	1.7–2.9			2.3–3
Albumin/globulin ratio	0.2–0.4			0.13–0.17
Aspartate aminotransferase (IU/L)	3.8–17.5	1.7–19	8.2–51.6	33–66
Creatinine kinase (IU/L)	2.2–8.5	BDL	107–626	47–233
Sodium (nmol/L)	251.5–257.4			279–285
Potassium (mmol/L)	3.5–4.8	3.2–4.8	4.9–7.6	6.4–7.9
Chloride (mmol/L)	249.5–260.7			285–296
Bicarbonate (mmol/L)	5.4–13.6			2–4
Anion gap (mmol/L))	0–1.2			−7.6–0.1
Osmolality (mOsm/kg)	833–855.8	699–1,210		1,078–1,111
Creatinine (mg/dL)	<2[*]	0.1–0.13	0.2–1.1	0.1–0.7
Lactate dehydrogenase (IU/L)	<10[*]			<5
ALT (U/L)		5.9–21.6	3.5–16.0	BDL
Amylase (U/L)		BDL	584–2,030	812–1,800
Lipase (U/L)		2.7–152	1.5–19.7	8.0–68.3
Cholesterol (mg/dL)		56.5–145	6.8–165.2	75–149
Triglycerides (mg/dL)		20–82.3	BDL	20.2–45.3

[*] Values too low to measure; out of range. *BDL*, Below detectable range.

[†] Persky ME, Williams J, Burks RE, et al: Hematologic, plasma biochemistry, and select nutrient values in captive smooth dogfish *(Mustelus canis)*. *J Zoo Wildl Med* 43:842–851, 2016.

[$] Haman K, Norton T, Thomas A, et al: Baseline health parameters and species comparisons among free-ranging Atlantic sharpnose *(Rhizoprionodon terraenovae)*, bonnethead *(Sphyrna tiburo)*, and spiny dogfish *(Squalus acanthias)* sharks in Georgia, Florida, and Washington, USA. *J Wildl Dis* 48:295–306, 2012.

wild seven gill sharks *(Notorynchus cepedianus)*, *Tetraphyllidean* spp. in the spadenose shark *(Scoliodon laticaudus)*, and *Calliobothrium schneiderae* in smooth-hound sharks *(Mustelus lenticulatus)*.[24–27] Nematodes have been shown to cause a parasitic meningoencephalitis in nurse sharks.[28]

Noninfectious diseases of sharks include trauma, foreign body ingestion, neoplasia, and deleterious environmental impacts. Sharks may potentially ingest foreign objects that end up in their enclosures. This is a particular consideration in aquaria where the public has access to the tank. Documentation of neoplastic disease is uncommon in sharks, but oral fibropapillomas, hepatic adenomas, intrahepatic cholangiocarcinoma, testicular mesothelioma, melanoma, and lymphosarcomas have been reported.[11]

Spinal deformities are commonly reported in captive sharks. It has been postulated that some of these deformities could be capture related, particularly when pound nets are used.[29] There have also been correlations with nutritional deficiencies, particularly potassium, zinc, and vitamin C, which play a critical role in cartilage development.[29] In addition, congenital abnormalities of the vertebrae and skeletal system have been documented in several species.[30]

Goiter in association with the addition of ozone to a system has been reported in multiple species. When aquarium water is ozonated, it reduces the amount of environmental iodine available, which is critical for thyroid hormone synthesis.[31] Urogenital sinus calculi have been reported in a sand tiger shark.[32]

Treatment and Therapies

Pharmacokinetic and pharmacodynamic studies of therapeutics in sharks are limited. Treatment dosages are typically extrapolated from other species. Cefovecin, a third-generation cephalosporin, maintains therapeutic serum concentrations for 4 days in white-spotted bamboo sharks *(Chiloscyllium plagiosum)* at a dose of 8 mg/kg subcutaneously.[33] A single 40 mg/kg intramuscular dose of florfenicol in this species was shown to maintain therapeutic concentrations for 120 hours in serum and 72 hours in cerebrospinal fluid.[34]

In cases of acute trauma and/or severe blood loss, blood transfusions may be performed. Cross-matching should be done prior to any transfusion to ensure that the donor is compatible.[35]

Nutritional support is important in anorectic animals, and patients may be assist fed. In some animals this is done by inserting whole fish into their oral cavity using tongs to encourage eating. If the shark does not respond to this, a fish gruel using their diet and vitamins may be made and tube fed. Gruel is administered by inserting a small piece of PVC into the oral cavity to pass a tube, then advancing the tube past the esophageal sphincter into the stomach. A total of 2%–5% of body weight should be given.

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