Carolina Biological Supply Company
presents

The Anatomy of the Shark

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Abstract. This program facilitates a study of the anatomy of the spiny dogfish as a representative cartilaginous fish. Each individual system can be viewed and discussed separately.

Running Time: 56:25 total minutes (The External Anatomy: 7:25 minutes, The Skeletal System: 8:20 minutes, The Muscular System: 0:40 minutes, The Digestive System: 6:35 minutes, The Respiratory System: 1:45 minutes, The Circulatory System: 9:00 minutes, The Excretory System: 1:40 minutes, The Reproductive System: 3:20 minutes, The Nervous System: 10:00 minutes, The Sense Organs: 5:45 minutes).

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Narration

Sharks are an ancient group of fishes that belong to the class Chondrichthyes, fish whose skeletons are made of cartilage. Relatives of the sharks include the skates and rays. Most cartilaginous fish are marine. Although for many years cartilaginous fish were considered to be primitive, more recent studies have indicated that they are probably specialized fishes actually evolved from bony fish ancestors.

Our subject in this program is the spiny dogfish, a small shark common in the Atlantic Ocean off the east coast of the United States and in the Gulf of Mexico. Mature specimens are usually 3–4 feet in length, and weigh 15–20 pounds. Dogfish have a lifespan of about 25 years.

THE EXTERNAL ANATOMY

As we begin our study of shark anatomy, we need to review some basic anatomical terms. In this program, **cranial** refers to a position toward the head. When speaking specifically about the head, **rostral** means toward the nose. **Caudal** means toward the tail, **dorsal** means toward the back, and **ventral** means toward the belly. **Distal** indicates a relative position away from the center of the body, while **medial** indicates a relative position closer to the center of the body.

The body of the shark is divided into three regions: the **head**, the **trunk**, and the **tail**. The head extends from the tip of the **snout** to the caudal edge of the gill slits. From there, the trunk extends to the ventral openings for the anus and urogenital organs. The tail extends caudally from these openings. The body of the shark is fusiform, or torpedo-shaped.

The skin is grayish on the dorsal surface, and whitish on the ventral surface. This is an example of counter-shading, a defensive adaptation that reduces the chance of the shark being seen by a potential enemy from above or below, and an offensive adaptation that may reduce the chance that potential prey might see the shark in time to escape. The skin is almost entirely covered with small, sharp **placoid scales**, or dermal denticles, each of which extends posteriorly from the body wall. The general structure of the placoid scale is similar to that of a tooth, with a central pulp cavity, an outer covering of dentine, and a small amount of enamel covering the dentine. The base of each scale is embedded in the skin.

Sharks have both paired and unpaired fins. The unpaired fins include two **dorsal fins** and the **caudal fin**. Most sharks other than dogfishes also have an anal fin. As in nearly all other sharks, the

cranial dorsal fin is larger than the caudal dorsal fin. The dorsal fins act as vertical stabilizers in swimming.

A special feature of the spiny dogfish is the presence of two long **spines**, one located immediately anterior to the base of each dorsal fin. These spines can puncture potential predators, as well as inject a poison from glands in their bases. It is wise to remove the spines before dissection.

The third unpaired fin is the caudal fin. This fin is **heterocercal**, with the dorsal lobe conspicuously larger than the ventral lobe. The caudal fin provides the thrust needed to move the animal through the water. The larger dorsal lobe produces more force than the smaller ventral lobe. The result is a downward as well as forward thrust with each movement of the tail.

The shark's paired fins represent a common vertebrate trait, paired appendages. The spiny dogfish has two sets of paired fins. The anterior **pectoral fins** have short bases and semiflexible surfaces. Their angle counters the downward thrust produced by the tail, causing the dogfish to move ahead in a straight line. In this respect, they function like the elevators and horizontal stabilizers of an airplane. The other set of paired fins is the **pelvic fins**, located on either side of the cloacal opening. These also function as stabilizers. The shape of the pelvic fins differs in males and females. In the male, they are modified for the transfer of sperm during copulation. The medial surface of each pelvic fin on the male is elongated to form a rodlike, grooved **clasper**. During copulation, the clasper is inserted into the cloacal opening of the female, and sperm is transferred.

The pointed, anterior end of the snout, the **rostrum**, bears the paired **external nares**. A close examination of an individual naris reveals two openings separated by a flap of skin—an **incurrent aperture**, and an **excurrent aperture**. As shown in this diagram, the nares are really sacs through which water flows. The **olfactory epithelium** provides the shark with a very sensitive set of chemoreceptors.

One of the most obvious features of the head is the ventral **mouth**. The mouth contains dozens of **teeth**. These teeth are actually modified placoid scales. Behind them are several rows of developing teeth that can grow to replace any lost teeth.

On either side of the head are the prominent **eyes**. Immovable upper and lower eyelids provide protection for the eyes. Each eye is covered by a transparent **cornea**. A pigmented **iris** controls the amount of light entering the eye.

Immediately dorsal and posterior to each eye is a **spiracle**. The spiracles are actually modified first gill slits. Through them, water enters the pharynx while the mouth is closed, allowing respiration to continue. A **spiracular valve** regulates the flow of water through the spiracle.

Posterior to each spiracle are five external **gill slits**. Water taken in through the mouth or spiracles leaves the body through the gill slits. Gill slits are a basic vertebrate characteristic; all vertebrates have them at some stage in their development.

On top of the head behind the eyes are two **endolymphatic pores**, the openings of the **endolymphatic ducts**. The endolymphatic ducts connect with the inner ears, which provide the shark with senses of equilibrium and hearing.

On the ventral surface of the rostrum are numerous pores that open into the **ampullae of Lorenzini**, sense organs derived from the lateral line system. They function in the perception of slight changes in electrical fields and are important in the shark's feeding and navigation.

Along each side of the body is a distinct **lateral line**. The lateral line is actually a specialized sense organ that detects vibrations and water currents. The lateral lines aid the shark in avoiding obstacles and in orienting its body in a current.

On the ventral surface between the pelvic fins is the **cloacal opening**, the common external opening for the digestive, excretory, and reproductive systems.

THE SKELETAL SYSTEM

Since the skeleton of the shark is composed of cartilage, it is easily damaged in a dissection. It is best studied by using prepared mounts embedded in plastic or immersed in fluid. As in other vertebrates, the skeleton can be divided into two main divisions: the **axial skeleton**, composed of the skull, gills, and the vertebral column, and the **appendicular skeleton**, composed of the pectoral and pelvic girdles along with their respective fins.

We begin our study of the axial skeleton with the skull or **chondrocranium**. The chondrocranium is made up of the **neurocranium** and the **splanchnocranium**. The neurocranium is the dorsal portion of the skull that protects the brain and certain sense organs. It is comprised of several regions. The **rostrum** is the most anterior portion. The dorsal portion of the rostrum is a hollow structure, the **precerebral cavity**. On the ventral surface is a ridge called the **rostral carina**, and at the caudal end are the **precerebral fenestrae**. On either side of the rostrum are the remains of the **nasal capsules**. In an intact specimen, these contain the olfactory epithelium and open to the outside through the external nares. Caudally, we see the large **optic orbits**. The shelflike dorsal surface of each orbit is the **supraorbital crest**, which protects the eyeball. Inside each orbit are several openings or foramina. The **optic foramen** is the passageway for the optic nerve which connects the eye with the brain. Posterior to the optic foramen is the

trigeminofacial foramen, through which the trigeminal and facial nerves pass. The **posterior orbital process** projects into the eye and articulates with the upper jaw. Above the optic orbit are the numerous **superficial ophthalmic foramina**. Caudal to the orbits on each side are the **otic capsules**, which contain the inner ears. On the medial dorsal surface of the skull between the anterior margins of the supraorbital crests lies the **epiphyseal foramen**, a small opening through which the pineal body, or epiphysis, projects from the brain. Also on the dorsal surface is a large depression, the **endolymphatic fossa**. At its anterior end are the **endolymphatic foramina**, while the **perilymphatic foramina** are at its caudal end. These foramina and their respective ducts connect the tissues over the endolymphatic fossa with the inner ears. At the caudal end of the skull are the paired **occipital condyles**, which articulate with the vertebral column. Between them is a large opening, the **foramen magnum**, through which the spinal cord passes from the braincase into the vertebral column. Two foramina lateral to each occipital condyles are the medial **vagal foramen**, through which the vagus nerve passes, and the lateral **glossopharyngeal foramen**, through which the glossopharyngeal nerve passes.

We now turn our attention to the **splanchnocranium**. The splanchnocranium, also known as the **visceral cranium**, is composed of seven **visceral arches**. The first two visceral arches form and support the jaws. The **mandibular arch** forms the jaws. It is modified into the paired **palatoquadrate cartilages**, which form the upper jaw, and the paired **Meckel's (mandibular) cartilages**, which form the lower jaw. The jaws contain and support the teeth. The second visceral arch is the **hyoid arch**, modified into two portions. The paired, dorsal **hyomandibular cartilages** are attached to the otic region of the cranium and provide support for the jaws. The ventral portion of the hyoid arch is composed of the paired **ceratohyal cartilages** and the unpaired **basihyal cartilage**. These provide support for the tongue and also form the floor of the mouth. The last five visceral arches are the **branchial arches**. Branchial arches three—six support the gills and bear **gill rays** that support the tissues of the gills. The seventh arch bears no gill rays and is not associated with a gill.

The **vertebral column** of the dogfish has only two morphological types of vertebrae—**trunk** or **body vertebrae**, and **tail** or **caudal vertebrae**. The typical trunk vertebra consists of a ventral **centrum** and a dorsal **neural arch**. The centrum is the main body of the vertebra. It is deeply concave, or **amphicoelous**, on both ends. A small canal which contains the **notochord** runs through the middle of the centrum. Short **transverse processes** extend laterally from each side of the neural arch. Attached to these processes are slender **ribs**. The **neural arch** encloses and protects the spinal cord. The neural arch is composed of a

pair of triangular **neural processes** that meet dorsally to form the **neural spine**. Near the base of each neural process is a foramen through which passes the ventral root of a spinal nerve. Between each neural process is an **intercalary plate**, which completes the protective housing for the spinal cord. Each intercalary plate contains a small foramen through which passes the dorsal root of a spinal nerve.

The **tail**, or **caudal**, **vertebrae** are similar to the trunk vertebrae. There are no transverse processes on a tail vertebra. There is, however, a conspicuous ventral **hemal arch** beneath the centrum. Within this arch are two blood vessels: the **caudal artery** and the **caudal vein**.

The **appendicular skeleton** is composed of the pectoral and pelvic girdles and their respective fins. The **pectoral girdle** encircles the ventral side of the trunk. It consists of a midventral **coracoid bar**, and paired **scapular** and **suprascapular cartilages**. Each **pectoral fin** articulates with the pectoral girdle at the **glenoid surface**. The fin itself is composed of a set of three basal cartilages. Extending from these basal cartilages are the **radial cartilages**, which provide some rigidity to the fin. Fibrous, dermal **fin rays**, or **ceratotrichia**, extend from the radial cartilages and support the distal portion of the fin.

The **pelvic girdle** is simpler than the pectoral girdle. A single **ischiopubic bar** lies in the ventral abdominal wall just anterior to the cloaca. At each end is a small **iliac process**. The **pelvic fins** articulate with the pelvic girdle at the **acetabulum**. Each fin consists of two **basal cartilages**, with **radial cartilages** extending from the basal cartilages, and dermal **fin rays** supporting the distal portion of the fin. The pelvic fins differ in males and females. Males have two highly modified radial cartilages, or claspers, that aid in the transfer of sperm to the female during copulation.

THE MUSCULAR SYSTEM

Sharks have a relatively simple muscular system. Except for certain muscles that control the jaws and the individual fins, the bulk of the musculature consists of large, striated, segmented, V-shaped muscle groups called **myotomes**, clearly seen in a skinned shark. Individual myotomes are separated from each other by a **myoseptum** made of connective tissue. They are also separated into dorsal and ventral groups by a **horizontal septum**.

THE DIGESTIVE SYSTEM

Study of the internal organs of the shark requires that a midventral incision be made from the opening of the cloaca to the lower jaw, and transverse incisions be made cranial to the pelvic girdle and caudal to

the pectoral girdle. Folding back the parts of the body wall reveals the **coelom** or body cavity. The coelom is divided into the **pleuroperitoneal cavity**, or the abdominal cavity, which houses the digestive and reproductive structures; and the **pericardial cavity**, which encloses the heart. The **transverse septum** separates the two cavities.

A number of membranes and mesenteries line the coelom and surround and support the organs. The interior of the body wall is lined with the **parietal peritoneum**, while the surface of the organs is covered by the **visceral peritoneum**. The visceral and parietal peritoneums are connected dorsally by the **dorsal mesentery**, a double-walled membrane that supports the organs in the body cavity.

The digestive system begins at the **mouth**, behind which is the oral cavity. On the jaws are many sharp **teeth**. The shark has **homodont** teeth, meaning all are shaped roughly the same. The teeth are actually modified placoid scales, and are replaced regularly. On the floor of the mouth is the immovable **tongue**, supported by two cartilages.

Posterior to the mouth is the **pharynx**, a cavity connecting the mouth cavity and the esophagus. Opening the pharynx reveals six pairs of openings on the lateral walls. The first pair are the internal openings to the spiracles. The next five pairs are the **internal gill slits**. Evident in the gill slits are the **gill rakers**, which prevent food particles from entering the gill chambers.

The largest and most conspicuous organ in the abdominal cavity is the three-lobed **liver**. The right and left lobes are large and elongated, filling much of the cavity. The medial lobe is much smaller. The liver is the largest organ in the body and has numerous functions: 1) it produces bile, which aids in the digestion of fats; 2) it helps regulate blood sugar levels by storing excess energy as oil and releasing it as more energy is needed; 3) it aids in the metabolism and disposal of nitrogenous wastes; 4) it breaks down toxins and old red blood cells; and 5) it produces a factor that aids in blood clotting. Embedded in the right side of the medial lobe of the liver is the **gallbladder**, a small sac that may appear greenish from the presence of bile. The gallbladder stores bile and releases it into the small intestine through the **common bile duct**. The **falciform ligament** attaches the liver to the ventral body wall.

Moving aside the liver reveals the rest of the digestive tract. The posterior end of the pharynx is constricted at its connection with the **esophagus**, a short tube lined by many cone-shaped papillae that leads to the stomach.

The esophagus connects with the **cardiac region** of the **stomach**. Numerous glands in the stomach lining produce acids and enzymes that digest food. The shark does not chew its food, but swallows large chunks, which may remain in the stomach for some time. Opening the stomach reveals a number of longitudinal ridges, the **rugae**. The rugae are folds in the stomach wall that increase the available surface area

for gastric glands and allow the stomach to expand when engorged with food. The caudal section of the stomach is the **pyloric region**. This ends in a muscular **pyloric valve**, which regulates the passage of food into the intestine.

Although there is no clear distinction between the small and large intestines as in tetrapods, the **small intestine** is said to begin at the pyloric valve. The first portion of the intestine is the short **duodenum**. The larger and longer portion is the **ileum**. Opening the ileum reveals the **spiral valve**, a unique adaptation of sharks that greatly increases the surface area available for absorption of nutrients without increasing the overall length of the intestine. The **large intestine** or colon is very short, and connects with the short **rectum**, which leads to the cloaca.

The **cloaca** is the common receptacle or chamber for the digestive, excretory, and reproductive systems. The cloacal opening is the common opening for these systems.

An accessory digestive organ is the whitish, glandular **pancreas**, lying in the bend where the stomach joins the intestine. The pancreas has two lobes, a round, flattened **ventral lobe**, and a long, narrow **dorsal lobe**. The two lobes are connected by a short **isthmus**. The pancreas functions as both an exocrine and an endocrine gland. As an **exocrine gland**, it produces and secretes pancreatic enzymes involved in digestion. These enter the small intestine through the **pancreatic duct**. As an **endocrine gland**, it produces insulin for the regulation of blood sugar.

Although a part of the circulatory system rather than the digestive system, the **spleen** is usually studied at this time because of its position in the abdomen. This dark, triangular organ is loosely attached to the stomach. The spleen produces white blood cells, destroys old red blood cells, and stores blood, thus regulating the volume of circulating blood.

THE RESPIRATORY SYSTEM

As in all fishes, the respiratory system consists of the gills along with their associated support structures and blood vessels. Inside the pharynx are the **internal gill slits**. Water passes through these slits over the **gills**, and then to the outside through the **external gill slits**. As water passes over the highly vascularized gills, oxygen diffuses into the blood, and carbon dioxide diffuses out of the blood.

If we look closely at a diagram of the gills, we can better understand their structure. Each gill is supported primarily by a **visceral arch**. Blood courses through the gills via efferent and afferent arteries. A single **afferent artery** brings deoxygenated blood to each gill, and two **efferent arteries**, one on each side of the afferent artery, carry

oxygenated blood away from the gill. **Gill rays** from each visceral arch extend into a cartilaginous support structure, the **interbranchial septum**. **Gill rakers** project from the visceral arch into the pharynx.

Except for the most anterior hyoid arches, each septum has **gill lamellae** on each side. The hyoid arch has lamellae only on the posterior side. Such a single set of lamellae is termed a **hemibranch**, while a **holobranch** is an entire gill, composed of two hemibranchs with an interbranchial septum.

THE CIRCULATORY SYSTEM

The circulatory system is composed of the heart, blood vessels, and blood. We will limit our discussion to the heart and blood vessels. The **heart** lies in the **pericardial cavity**. Lining the cavity is the **parietal pericardium**. The heart itself is covered by another protective membrane, the **visceral pericardium**. The heart of any fish is composed of four chambers. The two principal chambers, however, are the **atrium** and the **ventricle**. The heart of the fish pumps deoxygenated blood only. Blood enters the heart through the thin-walled **sinus venosus**. Entering on opposite sides of the sinus venosus are the paired **common cardinal veins**. The paired **hepatic veins** bring blood from the liver and enter the sinus venosus just lateral to the midline. Blood passes from the sinus venosus into the long, thin-walled **atrium**. From the atrium, blood passes into the small but muscular **ventricle**. The ventricle propels blood to all parts of the body through a thick, muscular tube, the **conus arteriosus**, which carries blood to the **ventral aorta**. The conus arteriosus expands to receive the ejected ventricular blood, and then contracts during ventricular diastole, somewhat reducing the sudden increase in pressure and preventing damage to the gill capillaries.

In observing the beating heart of a fish embryo, we can see blood moving through the sinus venosus, the atrium, the ventricle, and the conus arteriosus. We can also observe several valves that prevent backflow of the blood. Between the sinus venosus and the atrium is the **sinoatrial valve**. The **atrioventricular valve** is found between the atrium and the ventricle.

The ventral aorta is a relatively short, thick artery that quickly divides into five pairs of **afferent branchial arteries** carrying deoxygenated blood to the gills. The second through the fifth afferent arteries carry blood to both sets of holobranchs, while the first carries blood to the first two hemibranchs. The arteries supply numerous **capillary beds** in the gill filaments. These capillaries drain into several vessels that encircle the gill pouches. On the rostral side of each gill pouch is a **pretrematic artery**, while on the caudal side is a **post-trematic artery**. Between these arteries are large **cross connections**. Each

pair of pretrematic and post-trematic arteries forms a **collector loop** that leads to an efferent branchial artery.

Oxygenated blood returns from the gills through four pairs of **efferent branchial arteries**. These four pairs bend posteriorly and combine to form the **dorsal aorta**. A number of small arteries arise directly from the collecting loops and efferent arteries. From the dorsal end of the first collector loop arises a **hyoidean epibranchial artery**, a large artery that is joined by one of the **paired dorsal aortae** near the spiracle to form the **internal carotid**. The internal carotid continues forward and curves toward the midline, where it unites with the internal carotid from the opposite side as they enter the chondrocranium. The two then split again and are the principal arteries for the brain. A **stapedial artery** branches laterally from the internal carotid where the latter curves toward the midline. The stapedial artery carries blood to certain eye muscles.

The anterior paired dorsal aortae join posteriorly and connect with a single median **dorsal aorta**. This unpaired dorsal aorta extends caudally, eventually becoming the **caudal artery**, which carries blood into the tail. Along the way, the dorsal aorta gives rise to several important branches. First, the paired **subclavian arteries** arise between the third and fourth efferent branchial arteries. The subclavians supply blood to the pectoral fins and the musculature of the body wall. The large, unpaired **coeliac artery** arises a short distance posterior to the subclavians. The coeliac splits into two branches: the **gastrohepatic artery** to the stomach and liver; and the **pancreaticomesenteric artery**, which sends branches to the stomach, pancreas, and intestine. The next major branch of the dorsal aorta, the **anterior mesenteric artery**, supplies the left side of the ileum. The **lienogastric artery** supplies blood to the pancreas, spleen, and stomach. The most posterior single branch is the **posterior mesenteric artery**, which supplies blood to the rectal gland and spiral valve. Other paired arteries are the **renal arteries**, which supply blood to the kidneys, and the **iliac arteries**, which supply the pelvic fins.

Blood returns to the heart through the **systemic veins**. Certain veins in the shark could be more accurately described as sinuses. It is easier to trace the veins moving away from the heart, rather than toward the heart as the blood actually flows. Beginning at the sinus venosus, we can locate the large, paired **hepatic veins**. These drain blood from the hepatic portal system, which we will observe later. Entering either side of the sinus venosus are the **common cardinal veins**. The common cardinal veins are the junctions for four pairs of veins that receive blood from most of the rest of the body. The large **posterior cardinal sinuses** found on each side of the body drain much of the blood from the caudal portion of the body. They enter the common

cardinal veins. A pair of **posterior cardinal veins** lies between the kidneys on either side of the dorsal aorta and receives blood from the veins of the kidneys. The posterior cardinal veins carry blood to the posterior cardinal sinus.

In addition to the systemic veins, the shark also has two **portal systems**—the hepatic portal system that carries blood from the various parts of the digestive tract and spleen through the liver, and the renal portal system that drains blood from the tail through the kidneys. The **hepatic portal system** begins with capillaries in the digestive system. The hepatic portal system receives blood from several larger veins that collect blood from various parts of the digestive tract. These veins join near the cranial end of the dorsal lobe of the pancreas. The **gastric vein** carries blood from the stomach. The **lienomesenteric vein** receives blood from the rectal gland, spleen, pancreas, and the left side of the intestine; and the **gastrointestinal vein** runs along the line of attachment of the mesentery to the dorsal lobe of the pancreas. The **pancreaticomesenteric vein** comes from the ventral lobe of the pancreas. These veins converge to form the **hepatic portal vein**, which enters the liver. In the liver, the blood passes through many small sinusoids, where certain nutrients are absorbed and stored, the blood is filtered, and toxins are removed. Within the liver, the sinusoids converge to form the **hepatic veins**, which enter the sinus venosus.

The **renal portal system** begins with the caudal vein enclosed by the hemal arch of the vertebrae. The caudal vein divides into two **renal portal veins**, proceeding cranially along the dorsal surface of the kidneys, which carry blood to the kidneys for filtering. Blood enters the kidneys through many small **afferent renal veins**, and exits through small **efferent renal veins**, which enter the posterior cardinal veins and return blood to the heart.

THE EXCRETORY SYSTEM

The excretory system is closely associated with the reproductive system. There are several important differences between males and females.

The excretory system consists of a pair of opisthonephric **kidneys**, long, thin, strips of highly vascularized tissue that remove nitrogenous wastes, primarily urea, from the blood. The kidneys are drained by the **archinephric ducts**. In the male the cranial portion of the archinephric duct has chiefly a reproductive function, but the more caudal portion also transports urea formed by the kidneys. The archinephric ducts are shorter and smaller in the female. In males, urine from the archinephric ducts flows into two small **accessory urinary ducts** that empty into the urogenital sinus. The archinephric ducts and the male accessory urinary ducts empty into the **urinary**

papilla, a small projection into the cloaca. The urinary papilla is also known as the **urogenital papilla** in males.

The **cloaca** receives materials from the excretory, digestive, and reproductive systems. Excretory products pass from the cloaca to the exterior.

The **rectal** or **digitiform gland** joins the large intestine through a duct. This tubular organ excretes excess sodium chloride and aids the dogfish in maintaining proper osmotic balance in its body fluids.

THE REPRODUCTIVE SYSTEM

The gonads of the male shark are the **testes**, slender, soft organs located dorsal to the lobes of the liver. The testes produce sperm and are especially active during the breeding season. The testes are supported by a thin mesentary, the **mesorchium**. Various blood vessels and nerves pass through this mesentary to the testes. Also present in the mesorchium are the many small **efferent ductules**, which carry sperm from the testes to the epididymis. The **epididymis**, composed of sperm-conducting tubules, is located in the anterior region of each kidney. This portion of the kidney has very little excretory function. The portion of the kidney directly caudal to the testes and beneath the epididymis is **Leydig's gland**. It produces a thick, milky, seminal fluid. Sperm pass from the epididymis to the large, highly coiled **vas deferens**. The enlarged caudal portion of each vas deferens is the **seminal vesicle**. In each seminal vesicle, sperm and seminal fluid move into the **sperm sac**, at the caudal end of the vesicle. The caudal ends of the seminal vesicles and the sperm sacs on each side join to form a **urogenital sinus**. The two urogenital sinuses extend into the **urogenital papilla**. Male sharks also have a pair of **siphons** just cranial to the cloaca. Flexing of the claspers causes the sacs to fill with sea water. During copulation, contraction of the sacs causes water to be squeezed from the sacs. The water and sperm are then washed through a groove in the clasper to the female oviduct.

Female sharks have a pair of soft, cream-colored **ovaries** dorsal to the liver and supported by thin sheet of connective tissue, the **mesovarium**. The ovaries produce eggs. During ovulation, mature eggs are released into the body cavity and enter the oviducts. The **oviducts** are long tubes that carry the eggs to the uterus. The oviducts join within the falciform ligament and have a common opening, the **ostium**, through which eggs enter. The eggs of the shark are usually fertilized in the oviducts. Near the anterior end of each oviduct is an enlarged area, the **nidamental gland**. The nidamental gland secretes a thin proteinaceous shell around the eggs. The caudal portion of the oviduct is enlarged to form the **uterus**. Dogfish are **ovoviviparous**. Fertilized

eggs develop into embryos in the uterus. Each egg has its own yolk. When the embryos are fully developed, a process which may take close to two years, the young are born through the cloaca.

THE NERVOUS SYSTEM

The two major divisions of the shark nervous system are the **central nervous system**, composed of the brain and spinal cord, and the **peripheral nervous system**, composed of cranial and spinal nerves. The sense organs will be studied separately.

The **brain** of the shark is enclosed and protected by the chondrocranium. The brain is also enclosed and protected by a thin, highly vascular membrane, the **meninx**. The brain of the shark consists of three main parts: the forebrain or **prosencephalon**, the midbrain or **mesencephalon**, and the hindbrain or **rhombencephalon**. We shall study the dorsal aspect of the brain first.

The prosencephalon has two divisions. The more anterior is the **telencephalon**. The rostral portion of the telencephalon contains the **olfactory bulbs** and the **olfactory tracts**. These connect with the cerebral hemispheres of the brain and receive and conduct sensory stimuli from the olfactory epithelium, providing the shark a sense of smell. The paired **cerebral hemispheres** make up the posterior portion of the telencephalon. Posterior to the telencephalon is the second portion of the forebrain, the **diencephalon**, a narrow, depressed area just anterior to the optic lobes. The roof of the diencephalon is covered by a thin membrane, the **tela choroidea**. Vascular folds extend from the tela choroidea into the third ventricle within the cerebral hemispheres to form an anterior choroid plexus, which secretes cerebrospinal fluid into the ventricles. The anterior portion of the tela choroidea forms the **paraphysis**, which is actually a part of the telencephalon. The caudal portion of the diencephalon bears the **pineal gland** or **epiphysis**. The function of this gland in the shark is not known. The roof of the diencephalon caudal to the cerebral hemispheres is the **epithalamus**. The lateral walls of the diencephalon extend ventrally to form the **thalamus**. The floor of the diencephalon that we will see later is the **hypothalamus**.

The midbrain, the **mesencephalon**, is characterized by the two large **optic lobes**. Impulses carried by the optic nerves are interpreted in the optic lobes.

The hindbrain or rhombencephalon is divided into two regions: the **metencephalon** and the **myelencephalon**. The anterior portion of the hindbrain is the metencephalon. The dorsal portion of the metencephalon consists of the **cerebellum**. The cerebellum partly covers the optic lobes. The cerebellum is responsible for the control of muscle

reflexes. The cerebellum is particularly large in animals which are very active and in constant motion. The inner cavity of the cerebellum is the cerebellar ventricle. At the posterior end of the cerebellum is a pair of **auricular lobes**, which function as centers of equilibrium. Immediately posterior to the cerebellum is the posterior portion of the hindbrain, the myelencephalon, or **medulla oblongata**. The elongated medulla tapers into the spinal cord. Within the medulla is a large cavity, the fourth ventricle. The medulla is a pathway for nerves between the brain and the spinal cord. In addition, it contains centers that control circulation.

In a ventral view of the brain, the telencephalon and the olfactory tract are visible. Caudally, the **optic chiasma** is seen. The optic chiasma is the point where the optic nerves cross before entering the brain. Caudal to the optic chiasma are the **hypothalamus**, and the **hypophysis** or **pituitary gland**. The pituitary gland is an endocrine organ involved with the production of numerous hormones.

A major characteristic of all vertebrates is a dorsal hollow nerve cord. Evidence of this characteristic, the **ventricles**, is revealed by a midsagittal section of the brain. The first and second ventricles are in the telencephalon. These connect through a narrow channel, the **foramen of Monro**, with the third ventricle, contained in the diencephalon. The third ventricle connects with the fourth ventricle through the **aqueduct of Sylvius**. The fourth ventricle is the cavity of the medulla. The ventricles are filled with **cerebrospinal fluid**.

The peripheral nervous system includes both the cranial nerves and the spinal nerves. Eleven pairs of **cranial nerves** connect directly with the brain without first passing through the spinal cord. The most anterior, the small **terminal nerve (0)**, is a delicate sensory nerve that arises with the olfactory nerve and extends into the nasal regions. (The terminal nerve was discovered after the numbering system for the other 10 cranial nerves had already become established, hence its designation of 0.) The **olfactory nerve (I)** is composed of many small, separate sensory fibers. The olfactory nerve originates in the nasal epithelium and ends in the olfactory bulb. The **optic nerve (II)** is a large white nerve tract that originates in the retina of the eye. This sensory nerve enters the ventral surface of the diencephalon. In a ventral view of the brain, we see the **optic chiasma**, the point where the two optic nerves cross. Each enters the side of the brain opposite the eye where it began. Also emerging from the ventral surface of the brain is the **oculomotor nerve (III)**, a branching somatic motor nerve that innervates four of the six large muscles of the eye. It emerges from the ventral surface of the mesencephalon and terminates in the four muscles. The **trochlear nerve (IV)** is a motor nerve that emerges from the dorsal surface of the mesencephalon and carries impulses to the superior oblique muscle of

the eye. The **trigeminal nerve (V)** is a large mixed nerve with both sensory and motor functions. It is attached to the lateral side of the medulla with nerves VII and VIII and then divides into four branches. One of these branches, the superficial ophthalmic branch, combines with a branch of the facial nerve to form the **superficial ophthalmic nerve**, a sensory nerve that terminates in the skin of the rostral portion of the head. The **abducens nerve (VI)** is a motor nerve emerging from the ventral surface of the medulla. It carries impulses to the lateral rectus muscle of the eye. The **facial nerve (VII)** is a mixed nerve. The facial nerve emerges from the anterior part of the medulla and combines with the trigeminal nerve at its exit from the brain. The facial nerve innervates the hyoid arch, spiracle, and lateral line organs on the rostrum. The **statoacoustic nerve (VIII)** is a sensory nerve that emerges with nerves V and VII on the medulla and carries impulses from the inner ear. The **glossopharyngeal nerve (IX)** is a mixed nerve emerging from the medulla just posterior to the statoacoustic nerve. The glossopharyngeal nerve both receives from and carries impulses to the first gill arch. The last cranial nerve is the **vagus nerve (X)**, a mixed nerve that emerges from the posterior end of the medulla and sends branches to the lateral line, the remaining gills, the head, and the abdominal organs.

The **spinal cord** is also part of the central nervous system. The spinal cord arises within the medulla and runs the length of the body within the vertebral column. A cross section of the spinal cord reveals much about its structure. An area of **white matter**, consisting of myelinated nerve fibers, surrounds an H-shaped area of **gray matter**, composed of nerve cell bodies and synaptic junctions. The section of gray matter has a dorsal horn and a ventral horn. The central canal runs through the center of the gray matter. The spinal cord gives rise to the numerous **spinal nerves**, which emerge between each pair of vertebrae. The spinal nerves are mixed nerves that carry impulses from the various regions of the body to the brain, and impulses from the brain to the various organs and regions of the body. A diagram of the spinal cord shows that each spinal nerve has two roots, a **dorsal root** and a **ventral root**, which combine outside the vertebrae into a single spinal nerve. The dorsal root contains both sensory and motor neurons, while the ventral root contains only motor neurons. On the dorsal root before it joins with the ventral root is a **dorsal root ganglion**, which contains the sensory nerve cell bodies.

THE SENSE ORGANS

There are five major sense organs in the shark: the ampullae of Lorenzini, the lateral line organ, the olfactory organ, the ear, and the eye.

Over the surface of the head are numerous pores. These represent the openings to the **ampullae of Lorenzini**, which serve to detect weak electrical fields, and are important in locating prey. They also possibly aid in the detection and avoidance of predators. As seen in this diagram, each pore opens into a small tube, which in turn leads to the bulblike ampulla. The ampullae contain sensory cells that detect minute changes in water temperature, salinity, and electrical currents. These cells are innervated by delicate nerve strands from branches of the facial nerve.

Running along the side of the shark from nose to tail is the **lateral line organ**. On the head, numerous branches of the lateral line form interconnected canals. A diagram of the lateral line reveals numerous pores that open to a canal lying beneath the skin. Sensory receptors called **neuromasts** are located at various intervals along the canal. The neuromasts are ciliated cells that are bent by currents and other water movements, thereby aiding in orientation and locomotion.

The **olfactory organ** is responsible for receiving external stimuli that are later interpreted in the brain as smells. The openings to the olfactory organs are the external nares. Each naris has an incurrent and excurrent opening for the passage of water. The openings are divided by a flap of tissue. As seen in this section of the rostrum, the external nares open into the **olfactory sacs**, containing the **olfactory lamellae**. The lamellae are covered with **olfactory epithelium**. The olfactory epithelium is innervated by fibers from the olfactory tract, which leads to the olfactory lobe of the brain.

The **ear** is a delicate structure embedded in the cartilage of the chondrocranium. The ear functions in hearing and in maintaining equilibrium. The openings to the ears are the **endolymphatic pores**, located medially on the dorsal surface of the head. These openings lead via two endolymphatic ducts to the membranous labyrinth. The inner ear is composed of a set of three **semicircular canals** filled with endolymph, a fluid that moves when the head moves. Each semicircular canal has a swollen area, an **ampulla**, in which are located patches of sensory cells, called **cristae**. The cristae detect the movements in the endolymph and pass the impulses to the nerve endings of the statoacoustic nerve. The **sacculus** is a large central chamber of the inner ear. The sacculus contains sensory receptors called **maculae**, that are very similar to the cristae, along with grains of sand and calcareous deposits

known as **otoliths**. The otoliths touch the maculae when the shark moves, leading to counter moves that maintain equilibrium.

The **eye** of the shark is quite similar to the eye of other vertebrates. The eyes are located at the sides of the head in sockets called **orbits**. The shark has immovable eyelids. There are six **oculomotor muscles** that move the eye. Viewed from the back of the eye, they are: the **superior rectus**, the **superior oblique**, the **lateral rectus**, the **inferior oblique**, the **inferior rectus**, and the **medial rectus**. Visible at the rear of the eye is the **optic pedicel**, a cartilaginous rod that supports the eye, and the large **optic nerve**. A diagram of a cross section of the eye reveals several structures. On the outer surface is the **sclera**. The **cornea** is the thin, transparent portion of the sclera in the front of the eye. The black-pigmented, highly vascularized middle layer is the **choroid**. The **iris** is the pigmented anterior portion of the choroid. In the center of the iris is the **pupil**, an apperture that regulates the amount of light entering the eye. Behind the iris is the **lens**. The lens of the shark does not change shape to focus light. Instead it changes position. The lens is attached by the elastic **suspensory ligament**. Between the lens and the iris is a fluid-filled **anterior chamber**. The **retina** is the membrane on the back of the eye that contains the light receptors, (the rods and cone cells). Nerve fibers from the rods and cones converge to form the optic nerve. Between the retina and the lens is another chamber, the **vitreous chamber**, filled with the gelatinous **vitreous humor**. The vitreous humor helps maintain the shape of the eye.

Contrary to popular belief, the shark is not a primitive animal. Rather, it is a highly evolved, specialized vertebrate derived from bony fish ancestors. Its external morphology illustrates some useful adaptations for its life as a marine predator, and its internal anatomy indicates that the shark is a not-to-distant relative of the higher vertebrates.

Abducens nerve (VI). The sixth cranial nerve. A motor nerve emerging from the ventral surface of the medulla that carries impulses to the lateral rectus muscle of the eye.

Accessory urinary duct. One of the small ducts of the male shark that transport urine from the kidneys to the urogenital sinus.

Acetabulum. One of the surfaces of the pelvic girdle that articulate with the pelvic fins.

Amphicoelous vertebra. A vertebra in which the anterior and posterior surfaces of the centrum are concave.

Ampulla. One of the saclike enlargements of the semicircular canals.

Ampullae of Lorenzini. Sensory receptors located on the ventral surface of the head that detect weak electrical charges.

Appendicular skeleton. That portion of the skeleton comprised of the pectoral and pelvic girdles and their associated fins.

Aqueduct of Sylvius. The canal between the third and fourth ventricles of the brain.

Atrioventricular valve. A valve in the heart located between the atrium and the ventricle, which prevents the backflow of blood into the atrium when the ventricule contracts.

Atrium. The chamber in the heart of the shark that receives blood from the sinus venosus.

Axial skeleton. That portion of the skeleton comprised of the skull, vertebral column, and ribs.

Basal cartilage. One of the cartilages that form the primary structure of each appendage.

Basihyal cartilage. The unpaired cartilage which, together with the paired ceratohyal cartilages, forms the ventral portion of the hyoid arch.

Branchial arch. The cartilaginous structures that support the gills.

Capillary. One of the many thin-walled blood vessels that connect an artery and a vein. The capillaries are the sites for exchange of oxygen, carbon dioxide, wastes, nutrients, and chemical messengers between the circulatory system and the body cells.

Caudal. An anatomical term meaning toward the tail.

Central nervous system. That portion of the nervous system comprised of the brain and spinal cord.

Centrum. The thick, round, central portion of a vertebra. The centrum forms around and replaces the embryonic notochord.

Ceratohyal cartilage. One of the paired cartilages which, together with the unpaired basihyal cartilage, form the ventral portion of the hyoid arch.

Cerebellum. The portion of the shark brain on the dorsal surface posterior to the optic lobes. It is associated with the coordination of muscular activity and equilibrium.

Cerebral hemisphere. One of the two halves of the cerebrum; an enlarged portion of the brain just posterior to the olfactory tract.

Cerebrospinal fluid. The fluid enclosed within the ventricles of the brain and spinal cord. This fluid also circulates between the outer covering (meninx) of the brain and the underlying brain tissues.

Chondrocranium. The skull of the shark; it is composed of the dorsal neurocranium and the ventral splanchnocranium.

Choroid. A vascular membrane containing large, branched pigment cells that lies between the retina and the sclera of the vertebrate eye.

Clasper. One of a pair of copulatory organs on the pelvic fins of elasmobranchs.

Cloaca. The common chamber into which the digestive, excretory, and reproductive systems empty.

Coelom. The mesodermally lined space inside the body wall that encloses the internal organs of the shark.

Common bile duct. The duct through which bile passes from the gallbladder to the intestine.

Conus arteriosus. A thick, muscular tube that receives blood from the ventricle and passes it on to the ventral aorta; it expands to receive the ejected ventricular blood and then contracts to force blood along the ventral aorta during ventricular diastole.

Coracoid bar. The midventral, unpaired cartilage of the pectoral girdle.

Cornea. The transparent part of the coat on the anterior surface of the eye that covers the iris and pupil and admits light to the interior.

Cranial. An anatomical term meaning toward the head.

Cranial nerve. One of the nerves that arise directly from the brain.

Diencephalon. The portion of the brain comprised of the thalamus, hypothalamus, pineal body, and pituitary gland.

Distal. An anatomical term meaning away from the midline.

Dorsal. An anatomical term meaning toward the back.

Dorsal aorta. The large, muscular artery that carries blood away from the efferent arteries of the gills of the shark. The dorsal aorta branches into numerous smaller arteries which then supply blood to the various regions of the body.

Dorsal fin. One of the large, unpaired fins located on the dorsal surface of the shark.

Duodenum. The most anterior portion of the small intestine.

Endolymphatic duct. A small, tubelike duct connecting the inner ears with the exterior.

Endolymphatic foramen. One of the pair of small openings located in the endolymphatic fossa which serve as the opening to the exterior for the endolymphatic ducts.

Endolymphatic fossa. The large depression on the dorsal surface of the head containing the endolymphatic foramina and the perilymphatic foramina.

Epididymis. An elongated mass of convoluted tissues in the testes that transport sperm to the vas deferens.

Epiphyseal foramen. A small opening located on the mid-dorsal surface of the chondrocranium through which the epiphysis projects from the brain.

Esophagus. The short, muscular tube connecting the pharynx with the stomach; part of the digestive system.

External naris. One of the paired external openings to the olfactory sacs.

Facial nerve (VII). The seventh cranial nerve. A mixed nerve that emerges from the anterior part of the medulla and combines with the trigeminal nerve at its exit from the brain. The facial nerve innervates the hyoid arch, spiracle, and lateral line organs on the rostrum.

Falciform ligament. A sheet of connective tissue that attaches the liver to the ventral body wall.

Fin ray. One of the many small, cartilaginous support structures located in the distal portion of each fin.

Foramen magnum. The large opening in the back of the skull through which the spinal cord passes.

Gallbladder. A saclike structure located on the medial lobe of the liver that receives and stores bile.

Gill. The respiratory organ of the shark.

Gill lamella. One of the many thin, highly vascular sheets of tissue that serve as the respiratory surface in the gills of the shark.

Gill raker. A toothlike projection from the gill arch that prevents large particles of food and other materials from passing into the gill chambers from the pharynx, and directs the particles toward the esophagus.

Gill ray. A cartilaginous projection from the visceral arch of a gill that helps support the gill lamellae.

Gill slit. One of the external openings between the gill arches through which water passes as it leaves the shark.

Glenoid surface. The posteriolateral surface on each side of the pectoral girdle of the shark that articulates with the pectoral fin.

Glossopharyngeal foramen. One of the paired openings on the back of the skull through which the glossopharyngeal nerves pass.

Glossopharyngeal nerve (IX). The ninth cranial nerve. A mixed nerve that emerges from the medulla just posterior to the statoacoustic nerve (VIII). The glossopharyngeal nerve both receives from and carries impulses to the first gill arch.

Gray matter. Those portions of the brain and spinal cord containing both nerve cell bodies and nerve junctions. Most of the gray matter in the brain is internal and forms distinct nuclei; in the spinal cord it forms a continuous central column.

Hemal arch. An opening in the ventral portion of a caudal vertebra that encloses and protects the caudal aorta and caudal vein.

Hemibranch. One-half of a gill; composed of a visceral arch and one set of gill lamellae.

Hepatic portal system. The system of veins and capillary beds that receives blood from various organs and carries it to the liver. In the liver, the blood is filtered and toxins are removed before it is returned to the heart through the hepatic veins.

Heterocercal tail. A caudal fin in which the dorsal lobe is much larger than the ventral lobe, and in which the vertebral column turns upward into the dorsal lobe.

Holobranch. A complete gill; composed of a visceral arch and two sets of gill lamellae, one on either side of the visceral arch.

Homodont. The condition in which all the teeth are structurally the same; as opposed to heterodont, the condition in which the teeth are differentiated into various types.

Hyoid arch. The second visceral arch; provides support for the jaws, tongue, and the floor of the mouth of the shark.

Hyomandibular cartilage. One of the paired, dorsal cartilages that help form the hyoid arch and support the jaws.

Hypophysis. The pituitary gland; produces a number of important hormones and regulates the production and release of others.

Hypothalamus. A ventral portion of the brain located beneath the thalamus. The hypothalamus helps to regulate the autonomic nervous system.

Ileum. The larger and longer caudal portion of the small intestine; also known as the valvular intestine; contains the spiral valve.

Iliac process. One of the small protuberences on the ischiopubic bar of the pelvic girdle.

Infundibulum. The hollow, conical process of gray matter that connects the pituitary gland with the brain.

Interbranchial septum. A cartilaginous structure that provides the main support for the gill lamellae.

Intercalary plate. One of the cartilaginous structures between adjacent centra in the vertebral column of the shark that help cover and protect the spinal cord.

Iris. The opaque, contractile portion of the eye that surrounds the pupil.

Ischiopubic bar. The median cartilaginous bar located anterior to the cloaca that forms the main portion of the pelvic girdle.

Kidney. One of the paired excretory organs of the shark. The kidneys filter nitrogenous wastes from the blood.

Lateral line system. A unique sensory system of fishes and larval amphibians. The lateral line system helps a shark to detect currents and other water movements, to maintain its position in water currents, and possibly serves also as a receptor for electrical currents. The lateral line system consists of sensory cells located in two longitudinal canals lying under the skin on each side of the trunk and other canals on the head of the shark.

Lens. A highly transparent body in the anterior portion of the eye that focuses light on the retina.

Leydig's gland. That portion of the kidney directly caudal to the testes and beneath the epididymis that produces a thick, milky, seminal fluid.

Liver. The large, trilobed organ in the abdominal cavity that produces bile, helps regulate blood sugar levels, aids in metabolism and the disposal of nitrogenous wastes, breaks downs toxins and old red blood cells, and produces a clotting factor.

Mandibular arch. The first visceral arch; modified into the paired palatoquadrate cartilages and the paired Meckel's cartilages. The mandibular arch forms the jaws.

Meckel's (mandibular) cartilage. One of the paired cartilages that form the ventral portion of the mandibular arch; together the pair forms the lower jaws.

Medial. An anatomical term meaning toward the midline.

Medulla oblongata. The most caudal portion of the brain.

Meninx. One of the membranes that surrounds and protects the brain and spinal cord of the shark.

Mesencephalon. The midbrain; composed mainly of the optic lobes.

Mesorchium. The thin sheet of connective tissue that supports the testes.

Metencephalon. The anterior portion of the hindbrain composed of the cerebellum.

Myelencephalon. The posterior portion of the hindbrain composed of the medulla oblongata.

Myoseptum. The thin connective tissue separating the individual myotomes.

Myotome. One of the V-shaped, voluntary muscle groups in the shark and other fishes.

Nasal capsule. One of the paired cartilaginous structures located on the rostral portion of the skull that contain and support the olfactory sacs.

Neural arch. A cartilaginous structure extending dorsally from the centrum of each vertebra formed by the junction of two neural pro-

cesses; surrounds and protects the spinal cord.

Neural process. A dorsal cartilaginous projection from the neural arch of certain vertebrae of the shark.

Neurocranium. The dorsal portion of the chondrocranium that contains and protects the brain and certain sense organs.

Neuromast. Special sensory cells located along the lateral line canal that detect alterations in water currents.

Notochord. The flexible rodlike structure that provides embryological support for the axis of the body.

Occipital condyle. One of the paired projections at the caudal end of the skull that articulate with the vertebral column.

Oculomotor muscle. One of the six muscles that provide for movement of the eye.

Oculomotor nerve (III). The third cranial nerve. A branching somatic motor nerve that innervates four of the six large muscles of the eye. The oculomotor nerve emerges from the ventral surface of the mesencephalon and terminates in the four muscles.

Olfactory epithelium. The sensory epithelium containing receptor cells lining the olfactory lamella.

Olfactory lamella. Platelike structures in the olfactory sacs lined with olfactory epithelium.

Olfactory lobe. The anterior portion of the brain where sensory impulses for the olfactory nerves are received and interpreted.

Olfactory nerve (I). The first cranial nerve. A cranial nerve composed of many small, separate sensory fibers that originate in the nasal epithelium and end in the olfactory bulb.

Olfactory sac. The saclike structure located in the olfactory capsule that contains the olfactory epithelium.

Optic chiasma. The crossing of the left and right optic nerves on the ventral surface of the brain.

Optic foramen. The opening in the skull through which the optic nerve passes from the orbit to the brain.

Optic lobe. The portion of the brain where sensory impulses from the optic nerves are received and interpreted.

Optic nerve (II). The second cranial nerve. A large, white cranial nerve that originates in the retina of the eye. This sensory nerve enters the ventral surface of the diencephalon.

Optic pedicel. A small, cartilaginous stalk that supports the eye.

Orbit. The large, cuplike cavity of the skull that surrounds and protects the eye.

Otic capsule. That portion of the skull that protects the membranous labyrinth in the nostril.

Otolith. A calcareous concretion in the inner ear.

Ovary. The female gonad. The ovary produces eggs and certain hor-

mones.

Oviduct. The tube that carries eggs from the ovary to the urogenital opening into the cloaca; its distal portion is enlarged to form the uterus.

Ovoviviparous development. A form of development in which the embryo develops from a fertilized egg inside the mother, yet obtains its nourishment from its own yolk sac.

Palatoquadrate cartilage. One of the paired cartilaginous structures that form the upper jaw.

Pancreas. A large compound gland derived from the digestive tract that secretes digestive enzymes and hormones.

Parietal pericardium. The outer mesodermal lining of the pericardial cavity.

Parietal peritoneum. The mesodermal lining of the abdominal cavity.

Pectoral fin. One of the paired fins associated with the pectoral girdle.

Pectoral girdle. The group of cartilaginous skeletal structures that support the paired pectoral fins.

Pelvic fin. One of the paired fins associated with the pelvic girdle.

Pelvic girdle. The group of cartilaginous skeletal structures that support the paired pelvic fins.

Pericardial cavity. The mesodermally lined portion of the coelom containing the heart.

Perilymphatic foramen. One of the paired openings to the perilym phatic ducts that connect the inner ears with the exterior.

Peripheral nervous system. That portion of the nervous system comprised of the spinal cord and those nerves outside the brain.

Pharynx. The portion of the digestive tract between the cavity of the mouth and the esophagus.

Pituitary gland. An endocrine gland located on the ventral surface of the brain. The pituitary gland produces a number of hormones, and regulates the activities of numerous other glands.

Placoid scale. A scale of dermal origin that has an enamel-tipped spine.

Pleuroperitoneal cavity. That portion of the coelom containing the abdominal organs.

Posterior orbital process. A cartilaginous projection from the posterior portion of the neurocranium that articulates with the upper jaw.

Precerebral cavity. A hollow structure located on the dorsal surface of the rostrum.

Prosencephalon. The forebrain; composed of two divisions—an anterior telencephalon and a posterior diencephalon.

Pupil. The variable opening in the iris of the eye that admits light

into the eye.

Pyloric valve. The ring of muscle between the stomach and the small intestine that regulates the passage of materials from the stomach into the small intestine.

Radial cartilage. Small cartilages that articulate with the basal cartilages and help support the appendages.

Rectal gland. A tubular organ located in the posterior portion of the abdominal cavity that excretes excess sodium chloride and aids in maintaining proper osmotic balance.

Rectum. The short, terminal portion of the large intestine.

Renal portal system. A group of veins that collect blood from the posterior region of the body of a shark and carry it to the kidneys for filtering before it passes into the posterior cardinal veins and returns to the heart.

Retina. The lining of the back of the eye that contains sensory cells, or rods and cones, which transforms light waves into nervous impulses and pass these impulses on to the optic nerve.

Rhombencephalon. The hindbrain; composed of the metencephalon and the myelencephalon.

Rostral. An anatomical term meaning toward the nose.

Rostral carina. The keel-like ridge on the ventral surface of the rostrum.

Rostrum. The nose of the shark.

Sacculus. The saclike chamber of the inner ear.

Sclera. The white outer coat enclosing the eyeball except for the anterior portion covered by the cornea.

Semicircular canal. One of the three fluid-filled canals that are a part of the inner ear.

Seminal vesicle. The enlarged, caudal portion of the vas deferens that serves for temporary storage of seminal fluid.

Sinoatrial valve. The valve between the sinus venosus and the atrium that prevents blood from flowing back into the sinus venosus during atrial contraction.

Sinus venosus. A saclike portion of the heart that receives blood from the veins and passes it into the atrium.

Siphon. One of the paired, saclike structures in a male shark located just cranial to the cloaca that is filled with water prior to copulation, which is later released during copulation to wash sperm into the female cloaca.

Small intestine. The long tubelike digestive organ where digestion is completed and nutrients are absorbed into the blood.

Sperm sac. The caudal portion of the seminal vesicle in which sperm

and seminal fluid are stored.

Spinal cord. The elongated cylinder of nervous tissue that extends posteriorly from the brain through the vertebral canal and connects with many pairs of spinal nerves at various intervals. The spinal cord surrounds a tiny central canal.

Spinal nerve. One of the many pairs of nerves that connect with the spinal cord through foramina in the vertebral column and innervate various body organs.

Spiracle. One of the highly modified first gill slits through which water can enter the pharynx to aid in respiration.

Spiracular valve. The flap of tissue in the opening of the spiracle that regulates the passage of water through the spiracle.

Spiral valve. A complex spiral fold in the intestine of sharks and other primitive fishes that slows the passage of food and increases the efficiency of digestion. The spiral valve also increases the surface area for absorption.

Splanchnocranium. That portion of the chondrocranium also known as the visceral cranium; composed of seven cartilaginous arches that form and support the jaws and the gill arches.

Spleen. A highly vascularized organ of the circulatory system that filters and stores blood and produces, stores, and destroys old blood cells.

Statoacoustic nerve (VIII). The eighth cranial nerve. A cranial nerve with sensory functions that emerges with nerves V and VII on the medulla and carries impulses from the inner ear.

Stomach. The muscular chamber of the digestive tract where food is mixed with enzymes and acids, and digestion begins.

Superficial ophthalmic foramen. The opening in the neurocranium through which the superficial ophthalmic nerve passes.

Superficial ophthalmic nerve. A sensory nerve formed by a branch of the trigeminal nerve and a branch of the facial nerve. The superficial ophthalmic nerve terminates in the skin of the rostral portion of the head.

Suprascapular cartilage. One of the paired cartilages that, together with the coracoid bar and the paired scapular cartilages, make up the pectoral girdle.

Systemic vein. One of the many veins that return blood to the heart from the various regions of the body.

Tela choroidea. The membrane covering the roof of the diencephalon; folds extending from the tela choroidea into the third ventricle form the anterior choroid plexus, which secretes the cerebrospinal fluid.

Telencephalon. The anteriormost portion of the brain.

Terminal nerve (0). Cranial nerve 0. A delicate cranial nerve with sensory functions that arises with the olfactory nerve and extends into the nasal regions. The terminal nerve was discovered after the numbering system for the other 10 cranial nerves had already become established, hence its designation of 0.

Testis. One of the paired male gonads. The testes produce sperm and certain hormones.

Transverse septum. The thin sheet of connective tissue separating the abdominal and pericardial cavities of the coelom.

Trigeminal nerve (V). The fifth cranial nerve. A large cranial nerve with both sensory and motor functions. It is attached to the lateral side of the medulla with nerves VII and VIII and then divides into four branches.

Trigeminofacial foramen. The opening on the skull through which the trigeminal and facial nerves pass.

Trochlear nerve (IV). The fourth cranial nerve. A cranial nerve with motor functions that emerges from the dorsal surface of the mesencephalon and carries impulses to the superior oblique muscle of the eye.

Urinary papilla. The small conical projection into the cloaca of male sharks formed by the junction of the archinephric ducts, accessory urinary ducts, and urogential sinuses.

Urogenital sinus. The junction of the seminal vesicles and sperm sacs in the male shark; it extends into the urogenital papilla.

Uterus. The caudal portion of the oviduct in the female shark into which eggs pass from the oviducts and, in dogfish, in which the fertilized eggs develop and hatch.

Vagal foramen. The opening lateral to the foramen magnum through which the vagus nerve passes.

Vagus nerve (X). The tenth cranial nerve. A mixed motor and sensory cranial nerve that emerges from the posterior end of the medulla and sends branches to the lateral line, the remaining gills, the head, and the abdominal organs.

Vas deferens. The highly coiled tube in male sharks through which sperm pass from the epididymis to the vas deferens.

Ventral. An anatomical term meaning toward the underside or belly.

Ventral aorta. The thick, muscular artery that carries blood from the conus arteriosus anteriorly to the afferent arteries in the gills.

Ventricle. The thick, muscular chamber of the heart that pumps blood throughout the body.

Ventricle of the brain. One of the several cavities inside the brain

that are continuous with the hollow portion of the spinal cord.

Vertebral column. The cartilaginous protective covering of the spinal cord, composed of individual vertebrae. The vertebral column also provides support for the body.

Visceral arch. One of the cartilaginous structures that form and support the jaws and the gill arches.

Visceral pericardium. The mesodermal connective tissue covering the heart.

Visceral peritoneum. The mesodermal connective tissue covering the abdominal organs.

Vitreous chamber. The cavity within the eye between the lens and the retina that contains the vitreous humor.

Vitreous humor. The gelatinous substance that fills in the vitreous chamber of the eye and helps maintain the shape of the eye.

White matter. That portion of the spinal cord comprised of myelinated nerve fibers; the white matter usually surrounds the gray

matter.

The Anatomy of the Shark

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