THE CIRCULATORY SYSTEM

The circulatory system is involved in transporting substances to and from the body cells. It consists of the heart, the arteries, veins, sinuses, capillaries, and the blood.

This extensive system will be studied in several phases. The first is the heart.

THE PERICARDIAL CAVITY

The *pericardial cavity* is the upper portion of the *coelom*, the body cavity. It is much smaller than the lower coelom, the pleuroperitoneal cavity, which we studied earlier. It is located anterior to the transverse septum and contains the heart and the major blood vessels leading to and from the heart.

The Dissection

Place the shark ventral surface upward. Locate the *pectoral girdle*. If not done in a previous dissection, remove the skin anterior to the coracoid bar, till the edge of the lower jaw (Meckel's cartilage). Remove the ventral hypobranchial musculature in this area. A membrane will be found covering a triangular cavity, the *pericardial cavity*. Remove the membrane to expose the heart and some of its major blood vessels. Locate and identify all of the parts listed below.

PERICARDIUM — This is the membrane lining the inner walls of the pericardial cavity. It is known as the *parietal pericardium*. The layer of membrane covering the heart is the *visceral pericardium*. It is fused with the heart and cannot be peeled off. At the upper and lower borders of the heart, observe where the parietal and visceral pericardia join and are continuous with one another.

THE HEART

The shark heart is composed of four distinct continuous tube-like chambers. Blood is passed from the more posterior end anteriorly in sequence, from one chamber to the next. The four chambers are:

1. **sinus venosus**
2. **atrium**
3. **ventricle**
4. **conus anteriosus**

SINUS VENOSUS — This is the most posterior of the four chambers. Deoxynaged blood from the entire body returns first to this chamber of the heart. Lift the main portion of the heart and observe a broad, thin-walled, flattened, almost horizontal, sac-like structure extending the width of the pericardial cavity. Its base lies upon the transverse septum.

ATRIUM — This chamber is anterior and dorsal to the sinus venosus. It is also thin-walled with two lateral bulging lobes. It receives blood from the sinus venosus.

VENTRICLE — This most ventral part of the heart is first seen upon exposing the pericardial cavity. It is an oval-shaped, thick-walled, muscular sac, lying ventral to the atrium. Paired *coronary arteries* may be seen on its ventral surface as well as on the conus arteriosus.

CONUS ARTERIOSUS — A thick, muscular, tubular structure which originates from the anterior surface of the ventricle. It extends anteriorly to the upper end of the paricardial cavity.

Note: Unlike the heart of higher vertebrates, the heart of the shark transports *deoxygenated blood* only. The process of oxygenation takes place at the gills, from where blood passes to the entire body without first returning to the heart.

The Dissection

As you open the heart chambers you will find coagulated blood and, in injected specimens, you will also find rubber-like colored latex. Remove these materials with blunt probes and wash out the heart chambers under gently running water.

SINUS VENOSUS — Probe the inner walls of this chamber and locate the lateral openings for the *common cardinal veins* bringing blood from the entire body and posteriorly the *hepatic sinuses* from the liver which enter medially. Other veins enter anteriolaterally bringing blood from the head.

SINOATRIAL APERTURE — Find this opening between the sinus venosus and the atrium. It is regulated by a pair of *sinoatrial valves*.

ATRIOVENTRICULAR APERTURE — This opening between the atrium and the ventricle is guarded by a pair of *atrioventricular valves*. They prevent blood from returning from the ventricle to the atrium.

VENTRICLE — Note the thick muscular walls of the ventricle and the comparatively small inner ventricular cavity. The inner muscular surface is irregularly folded.

CONUS ARTERIOSUS — Along the walls of the conus arteriosis count a series of *semilunar valves*. The two proximal sets of valves are smaller than the more anterior distal one.

THE VENTRAL AORTA AND AFFERENT BRANCHIAL ARTERIES

The Dissection

Continue the dissection from the pericardial cavity anteriorly. Remove the ventral *hypobranchial muscles* and connective tissues until you reach the lower jaw, Meckel's cartilage. Trace the *conus arteriosus* anteriorly. Follow the major branching blood vessels.

THE VENTRAL AORTA — After the conus arteriosus exits the anterior end of the pericardial cavity, it continues as the *ventral aorta*. Trace it anteriorly. Be careful since it is generally not injected. It gives off five pairs of *afferent branchial arteries* which carry *deoxygenated blood* from the heart to the gills.

AFFERENT BRANCHIAL ARTERIES — These arteries pass laterally from the medial ventral aorta carrying deoxygenated blood to the gills. The *fourth and fifth afferent branchial arteries* arise together from a common branch of the ventral aorta just anterior to the pericardial cavity. Shortly beyond that the ventral aorta gives off the *third afferent branchial* artery. At the level of the hyoid arch the ventral aorta bifurcates, passes laterally, gives off two branches on each side, the *first and second afferent branchial arteries*. Trace these afferent vessels to the gill arches. Note that the second, third, fourth, and fifth afferent branchial arteries enter the interbranchial bars and serve the holobranchs of similarly numbered gill arches. The first afferent interbranchial artery supplies only a demibranch on the anterior surface of the first gill pouch.

THE EFFERENT BRANCHIAL ARTERIES

The *efferent branchial arteries* serve to return oxygenated blood from the gills. This blood is then distributed to all parts of the body.

The Dissection

You have already examined and studied the oral cavity and the pharynx (see page 47 and photo page 54). If you have not already done so, with the shark lying ventral side up, insert the blunt blade of a strong pair of scissors into the right corner of the shark's mouth. Begin cutting posteriorly through the angle of the jaws, across the gill slits as far back as the pectoral girdle. Cut across the ventral musculature to lay the entire preparation flat on your dissection pan. Secure the specimen with large dissection pins.

Remove the mucous membrane from the roof of the mouth and pharynx. Find and identify the large arteries and their branches in the area of the gill arches.

Also remove the mucous membrane covering the floor of the mouth and pharynx. This will expose the dorsal aspect of the heart and the afferent branchial arteries already studied. Your dissection should now appear as the one in the photo on page 68.

EFFERENT BRANCHIAL ARTERIES — Four pairs of arteries may be seen arising from the gills and uniting in the midline to form the median *dorsal aorta*. Careful dissection will reveal the source of each efferent branchial artery; the gill lamallae of the gill pouches.

EFFERENT COLLECTOR LOOPS — They encircle each of the first four gill pouches. The fifth gill pouch has no demibranch on its posterior surface, thus there is no fifth collector loop, only four and a half. Each loop consists of a *pretrematic* branch on the anterior side of each gill pouch and a *post-trematic* branch on the posterior side. Adjacent collector loops are connected to one another by *intertrematic branches* which pass through the interbranchial septa.

Other Branches of the Efferent Branchial Arteries

The efferent branchial arteries give off many branches. These carry oxygenated blood to the more anterior parts of the shark's body.

EXTERNAL CAROTID ARTERY — Arises from the ventral end of *first collector loop*. This small vessel runs anteriorly along the lower jaw. Trace it as far as you can.

HYOIDEAN EPIBRANCHIAL ARTERY (EFFERENT HYOIDEAN ARTERY) — This artery arises from the dorsal end of the first collector loop. It runs anteriorly across the roof of the mouth, then divides in two, the *stapedial* and the *internal carotid* arteries.

The *stapedial artery* passes to the eye to supply some of its outer muscles. The *internal carotid artery* passes sharply to the midline along the ventral surface of the skull. The right and left branches unite temporarily, enter the cranial cavity, then separate and pass laterally to the brain. Soon after entering the chondrocranium, it is joined by the *efferent spiracular artery*.

AFFERENT SPIRACULAR ARTERY — This short vessel arises from the middle of the pretrematic artery of the first collector loop. It passes to the spiracle where it branches to supply blood to the lamellae of the pseudobranch. *Note:* the afferent spiracular artery carries *oxygenated* blood to the pseudobranch. Thus, the spiracular pseudobranch has no role in respiration.

EFFERENT SPIRACULAR ARTERY — This artery exits the spiracle, runs anteromedially into the chondrocranium where it joins the *internal carotid* artery. It turns ventrally past the *stapedial artery* to give rise to the *ophthalmic artery*.

OPHTHALMIC ARTERY — After arising on the *efferent spiracular artery* it passes anteriorly to supply blood to the eye.

PAIRED DORSAL AORTAE (RADIX AORTA) — They are anterior extensions of the unpaired *dorsal aorta*. These paired slender vessels originate from the first efferent branchial arteries near the mid-line. They pass anteriorly and near the level of the spiracles they turn laterally to join the *hyoidean epibranchial arteries*.

COMMISSURAL ARTERY (HYPOBRANCHIAL ARTERY) — This artery arises from the ventral end of the *second collector loop*, passes posteriorly to receive branches from the third collector loop. It continues ventral to the afferent branchial arteries to join and anastomase with its partner from the opposite side.

PERICARDIAL AND CORONARY ARTERIES — Upon entering the pericardial cavity, the commisural artery forms the *pericardial arteries* to the walls of the cavity, and the *coronary arteries* to the ventral surfaces of the conus arteriosus and the ventricle.

ESOPHAGEAL ARTERY (PHARYNGOESOPHOGEAL ARTERY) — Although most lower body parts are supplied by branches of the dorsal aorta, the roof of the pharynx and esophagus are supplied by the *esophageal artery* which originates from the second efferent branchial artery near its origin at the dorsal end of the collector loop. It extends posteriorly to the roof of the pharynx and esophagus.

THE DORSAL AORTA AND ITS BRANCHES

Oxygenated blood passes to most of the body by a branch of the *dorsal aorta*. It supplies both the body wall (epaxial and hypaxial muscles) and the visceral organs.

The Dissection

It will be necessary to view the origins of the aorta in the pharynx and its passage posteriorly to the tail. The dissection of the *pharynx* and the efferent branchial vessels has already been done. The *pleuroperitoneal cavity* has also been opened and the viscera examined. Organs will need to be moved and arterial branches followed with probes and dissecting needles.

Locate and identify the branches of the aorta which are named below. Trace each as far as you can.

DORSAL AORTA — Examine the previously dissected roof of the pharynx. Find the four pairs of *efferent branchial arteries*. They join at the dorsal midline to form the large arterial trunk, the *dorsal aorta*, which passes posteriorly bringing oxygenated blood from the gills to virtually every part of the shark's body, both its musculature and visceral organs. It passes through the *transverse septum* to enter the *pleuroperitoneal cavity*. There it continues posteriorly, giving off branches along its path, toward the tail. Some of the branches are paired, some are unpaired.

Subclavian Artery — This paired artery, the first major branch of the aorta, originates in the posterior pharynx. It supplies blood primarily to the pectoral fins and the muculature of the body wall. The *subclavian artery* originates from the dorsal aorta between the third and fourth efferent branchial arteries. Follow it as it curves ventrally toward the body wall where it gives off several branches.

Lateral Artery — This is the first of the branches of the subclavian artery. It runs parallel and follows the lateral canal posteriorly.

Ventrolateral Artery — This is a second branch, which also passes posteriorly to supply blood to the body musculature. It lies midway between the lateral line and the mid-ventral line.

Brachial Artery — This is the continuation of the subclavian artery passing into the pectoral fins.

The *dorsal aorta* continues posteriorly into the pleuroperitoneal cavity. Expose this cavity. In the mid-dorsal line, between the two kidneys, locate the dorsal aorta. Locate and identify all of the branches of the aorta named below. Study the accompanying photos to help you learn them.

The dorsal aorta gives off four unpaired arteries to the viscera:

1. **Celiac Artery**
2. **Anterior Mesenteric**
3. **Lienogastric**
4. **Posterior Mesenteric**

Celiac Artery — This is the most anterior branch of the dorsal aorta in the pleuroperitoneal cavity. It is also the most extensive; with repeated branches extending to almost all of the visceral organs. The artery passes ventrally to give off small branches to the gonads, the *genital arteries (ovarian arteries* in females, *spermatic arteries* in males). At times these may come directly from the aorta. Other small branches pass to the *esophagus* and the cardiac end of the *stomach*. It then continues posteriorly to give off two main branches: the *gastrohepatic artery* and the *pancreaticomesenteric artery*.

Gastrohepatic Artery — This extremely short artery branches almost at its origin to form the *gastric artery* and the *hepatic artery*.

The Gastric Artery — This artery, as the name implies, supplies the stomach. It divides into *dorsal* and *ventral* branches which supply the dorsal and ventral sides of the stomach.

The Hepatic Artery — This narrower branch turns sharply anteriorly running parallel to the bile duct to supply the liver.

The Pancreaticomesenteric Artery — This last branch is a continuation of the celiac artery posteriorly. It first runs behind the pylorus of the stomach to give off three branches, then continues posteriorly as the *anterior intestinal artery*. The first three branches are the *duodenal artery* to the duodenum, the *pyloric artery* to the pylorus of the stomach, and the *intraintestinal artery* which passes into the valvular intestine.

Anterior Intestinal Artery — This continuation of the pancreaticomesenteric artery runs down the right side of the valvular intestine.

Anterior Mesenteric Artery (Posterior Intestinal Artery) — This next branch of the aorta supplies the left side of the valvular intestine.

Lienogastric Artery (Gastrosplenic Artery) — This next branch of the dorsal aorta passes to the dorsal lobe of the pancreas, to the spleen and stomach.

Posterior Mesenteric Artery — The most posterior of the unpaired visceral branches of the aorta passes along the margin of the mesorectum to supply the rectal gland.

The dorsal aorta also gives off numerous paired somatic branches, the *parietal arteries*, to the body wall.

Renal Arteries are also given off to the kidneys. Beyond the point where the posterior mesenteric artery is given off, the dorsal aorta passes dorsal to the kidneys and is not seen without further dissection.

Iliac Arteries — In the vicinity of the cloaca the dorsal aorta gives off paired *iliac arteries*, which supply blood to the cloaca and the pelvic fins.

The Caudal Artery — This is the most posterior portion of the dorsal aorta; the continuation to the end of the tail. It can be seen in a cross-sectional view of the tail lying in the hemal arches of the vertebrae.

VENOUS SYSTEM

The Hepatic Portal System

The venous system is involved in the return of blood to the heart. In the shark, besides *veins* and smaller *venules*, one finds *venous sinuses* which are large, thin-walled spaces for the collection of venous blood. These are usually injected with *blue latex*.

A *portal system* is a venous system which begins as capillaries in an organ and ends as capillaries in another organ.

The *hepatic portal system* begins as capillaries in the organs of the digestive system. These join together to form the large vein, the *hepatic portal vein*. This vein then enters the liver where it subdivides again to form capillary-like tubes and venous sinuses. Within the liver the products of the digestive organs undergo metabolic processing. The blood from the liver is collected into the hepatic veins (sinuses) to empty into the *sinus venosus* of the *heart*.

In triply injected specimens the hepatic portal system has been injected with yellow latex.

We are choosing this venous system first because we have just examined the arteries leading to organs of the digestive system, and veins of the hepatic portal generally travel together with those arteries. Thus, no further dissection need be made to view this system.

THE HEPATIC PORTAL VEIN — This thick vein may be found in the *lesser omentum*, a mesenteric membrane also known as the *gastro-hepato-duodenal ligament*. It lies alongside and somewhat dorsal to the *bile duct*. It receives small *choledochal veins* from the bile duct. It is, however, formed more posteriorly by the joining of three large visceral veins:

1. **Gastric Vein**
2. **Lienomesenteric Vein**
3. **Pancreaticomesenteric Vein**

Gastric Vein — This is the most anterior of the three branches. Trace this vein to the stomach. Note that it is formed in the middle of the stomach from two *dorsal* and two *ventral gastric veins*. Also note that the *gastric vein* and *artery* travel together.

Lienomesenteric Vein — Posteriorly this vein originates from two others: the *posterior intestinal vein* and the *posterior lienogastric vein*.

> **Posterior Intestinal Vein** — This vessel can be seen coming from the left posterior surface of the valvular intestine. Note the transverse *annular veins* which indicate the lines of attachment of the spiral valve.
>
> **Posterior Lienogastric** — This vein comes from the spleen and the posterior end of the stomach.
>
> The unified *lienomesenteric vein* passes anteriorly from the spleen toward the duodenum along the dorsal surface of the pancreas.

Pancreaticomesenteric Vein — This is the right branch of the hepatic portal vein. It may be seen near the ventral lobe of the pancreas at the duodenum. There it is joined by a small vein, the pyloric vein, which comes from the pylorus of the stomach. It also receives the *intraintestinal vein* from within the spiral valve. Note that these veins travel together with the arteries of the same name. Near the pyloric vein it also receives the *anterior lienogastric vein (anterior splenic vein)* from the spleen. It lies along the pyloric region of the stomach.

Anterior Intestinal Vein — The most posterior portion of the pancreaticomesenteric vein ascends along the right side of the valvular intestine collecting blood from *annular veins* along its way.

The Renal Portal System

The renal portal system is the second venous portal system in the shark. It begins as capillaries in the tail and ends as capillaries in the *kidneys*. Systemic veins (not part of the renal portal system) then return the blood from the kidneys to the heart. The veins of this system have not been injected with a uniquely colored dye and it may be difficult to trace the smaller vessels.

KIDNEYS — You will recall from your examination of the pleuroperitoneal cavity that the kidneys are located along the dorsal body wall, on either side of the mid-line, as two elongate, ribbon-like structures.

CAUDAL VEIN — Recall this vein from our study of the muscular system when we viewed a cross-section of the tail; see photo on page 41. In the ventral portion of the vertebra, below the centrum, locate the hemal arch, carrying blood anteriorly from the tail. By making several more cross-sectional cuts every half inch and proceeding anteriorly you will find that the *caudal vein* bifurcates and proceeds anteriorly as two veins.

RENAL PORTAL VEINS — These are the two veins which result from the bifurcation of the caudal vein. They proceed anteriorly, lying dorsal to and in the lateral border of the kidneys. Lift up the dark ribbon-like kidney at its lateral border. Examine it dorsally with a hand lens.

AFFERENT RENAL VEINS — Lift the dark ribbon-like kidney at its lateral border. Examine its dorsal surface with a hand lens. The numerous small side branches that empty into the kidney are the *afferent renal veins*.

EFFERENT RENAL VEINS — Blood from the kidneys passes through other small and numerous vessels located dorso-medially, the *efferent renal veins*. It enters into elongated *posterior cardinal veins* which pass on either side of the mid-dorsal line. They return the blood from the kidneys to the heart.

The Systemic Veins

The systemic veins of the shark are all those returning blood to the heart that are not a part of the venous portal systems. They are generally paired.

The veins are, in most cases, dilated tissue spaces, without clearly defined walls. They are more properly called *sinuses*. This lack of definite structure makes identification more difficult. It will be helpful if your specimen is injected. Generally the systemic veins are injected with *blue latex*. The latex will conform to the original shape of the vein permitting one to follow even the narrower veins.

We shall begin our study of the systemic veins with the *sinus venosus* of the heart.

SINUS VENOSUS — Eventually all of the systemic veins return blood to the most posterior chamber of the heart, the *sinus venosus*. This chamber was already studied when the heart was discussed; see page 59. Two pairs of veins enter the sinus venosus:

1. **Hepatic Veins**
2. **Common Cardinal Veins (Ducts of Cuvier)**

HEPATIC VEINS (SINUSES) — Probe the posterior wall of the sinus venosus. Find two slits just lateral to the midline. Follow the *hepatic veins* through the transverse septum into the hepatic sinuses of the liver.

COMMON CARDINAL VEINS (DUCTS OF CUVIER) — These vessels enter the lateral corners of the sinus venosus, one on each side. They collect blood from four major branches: the *anterior cardinal veins*, the *inferior jugular veins*, the *posterior cardinal sinuses*, and the *subclavian veins*.

Anterior Cardinal Veins — These veins drain the brain and all of the head except the floor of the branchial region. Anteriorly the *anterior cardinal veins* dilate to form the *anterior cardinal sinuses*. These may have been viewed when studying the branchial musculature. They lie laterally, dorsal to the gill arches, beneath the cucullaris muscles, which must first be removed. The anterior cardinal sinuses originate in the brain.

Orbital Sinuses — In the region of the eye the anterior cardinal sinuses communicate with the *orbital sinuses* which surround the eye. Below the orbits, the *interorbital sinus* connects the right and left anterior cardinal sinuses. Probe this passageway with a flexible probe.

Inferior Jugular Veins — Another set of veins draining the head area are the *inferior jugular veins*. They drain the floor of the mouth and the ventral gill area. In their passage posteriorly they are joined to the anterior cardinal sinuses by a short *hyoidean sinus*, one on each side of the head. It lies posterior to the hyoid arch. Trace the inferior jugular veins posteriorly until they enter the anterior surfaces of the *common cardinal veins*.

Posterior Cardinal Sinuses — From the posterior parts of the body the common cardinal veins receive the paired *posterior cardinal sinus*. It is a large, bluish, thin-walled chamber at the anterior end of the pleuroperitoneal cavity toward the mid-dorsal line. The right and left posterior cardinal sinuses join mid-dorsally at the level of the gonads.

Genital Sinuses — At the level of the gonads the posterior cardinal sinuses receive genital blood vessels (ovarian or testicular veins) from *genital sinuses* that lie beside the gonads. They also receive vessels from the *esophagus*.

Posterior Cardinal Veins — Caudally, the posterior cardinal sinuses continue às two narrow veins, the *posterior cardinal veins*. These run along the dorso-medial line of the pleuroperitoneal cavity. They lie dorsal and medial to the kidneys, and lateral to the dorsal aorta. The right posterior cardinal vein extends further caudally than the left one. They receive blood from the kidneys by way of the tiny numerous *efferent renal veins*.

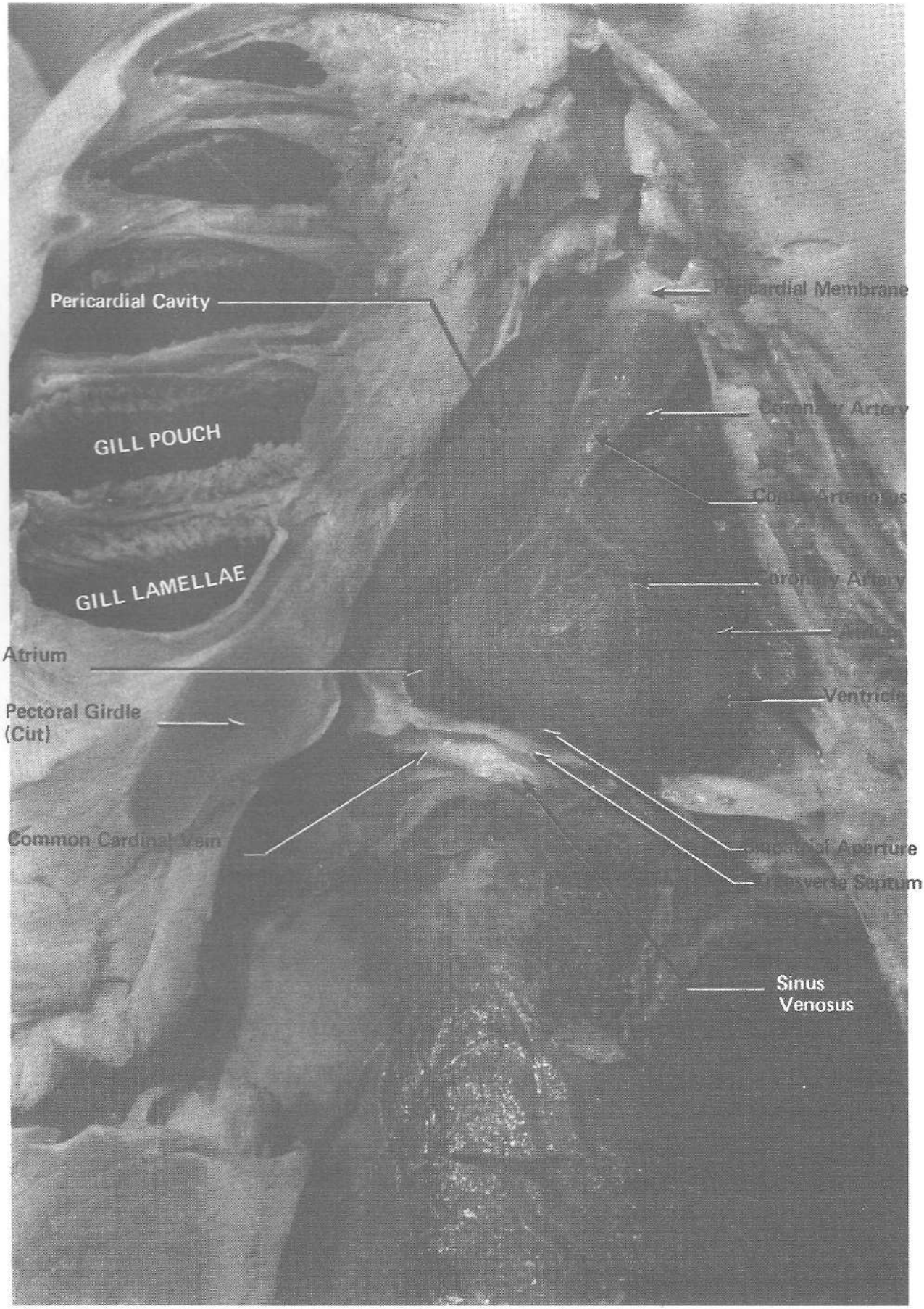
Subclavian Veins — These short veins enter the *common cardinal veins* just lateral to the entrance of the *inferior jugular veins*. They are formed by the union of three veins: the *brachial veins*, the *subscapular veins*, and the *lateral abdominal vein*.

Lateral Abdominal Veins — These veins are readily seen as dark longitudinal lines when inspecting the lateral walls of the pleuroperitoneal cavity, right beneath the parietal peritoneum. They drain the fins and the lateroventral trunk musculature. They also drain the *cloacal veins* which come from the lateral wall of the cloaca. In addition, blood from the pelvic fins, drained by way of the *femoral veins*, continues anteriorly into the *iliac veins* before emptying into the *lateral abdominal veins*. Anteriorly, at the level of the pectoral girdle they receive the *brachial veins* which drain the pectoral fins.

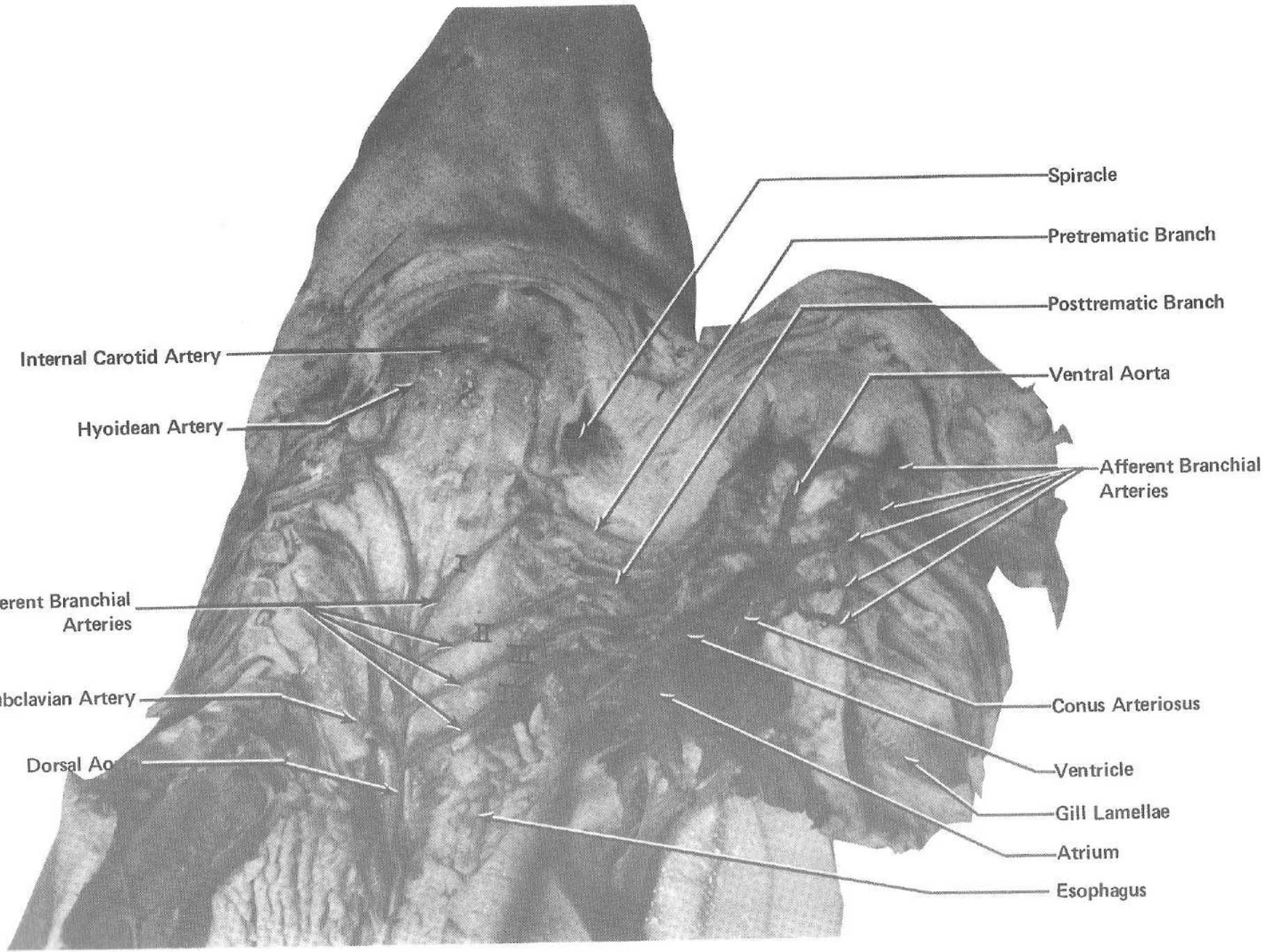
Brachial Veins — Anteriorly, at the level of the pectoral girdle, the *brachial veins* which drain the pectoral fins join the lateral abdominal veins, near their entry into the subclavian veins.

Subscapular Veins — From their dorsal origins in the area of the pelvic girdle, the *subscapular veins* pass ventrally to join the subclavian veins.

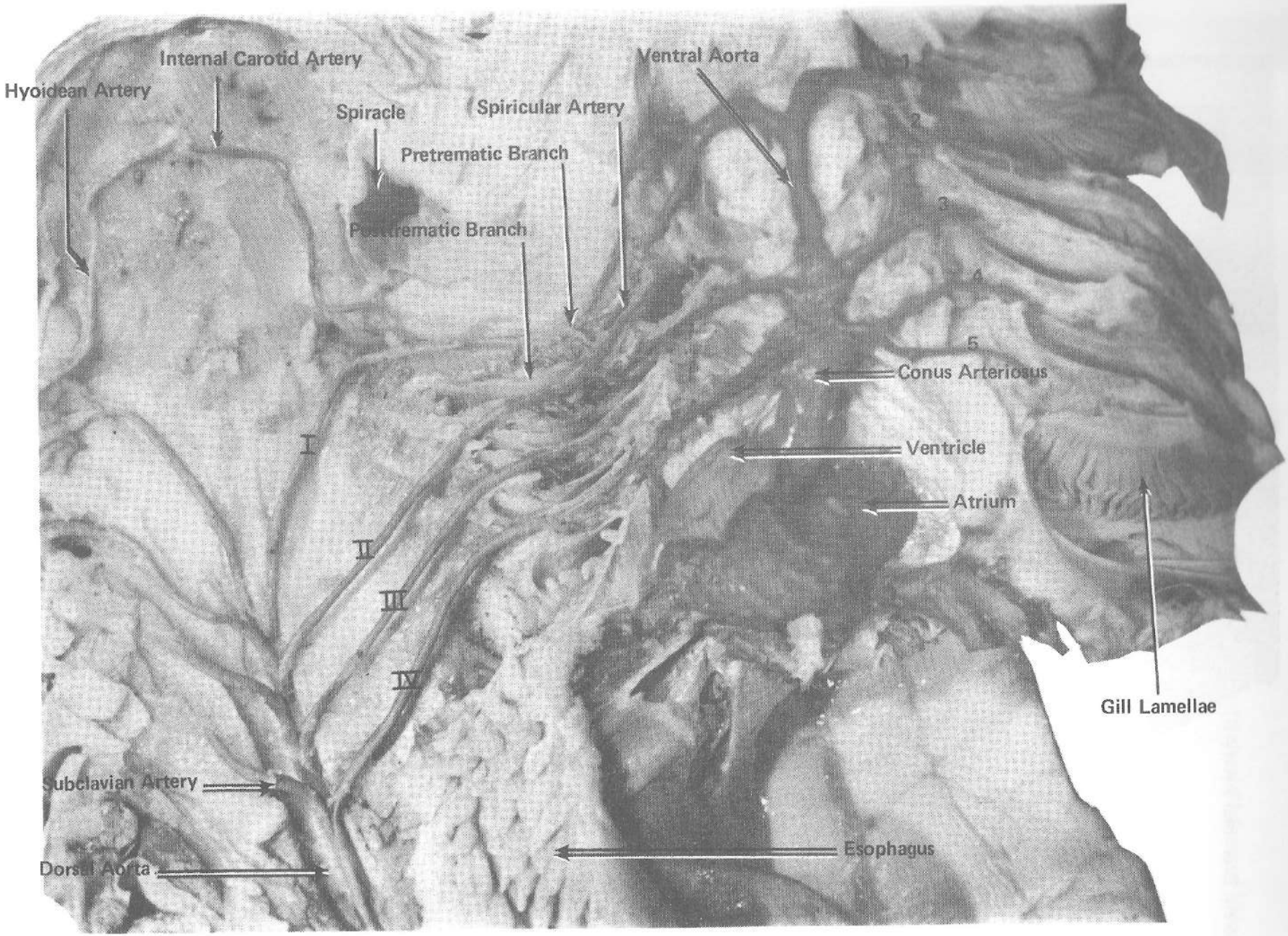
Coronary Veins — These may be seen on the surface of the ventricle of the heart. They enter the sinus venosus by a common aperture.



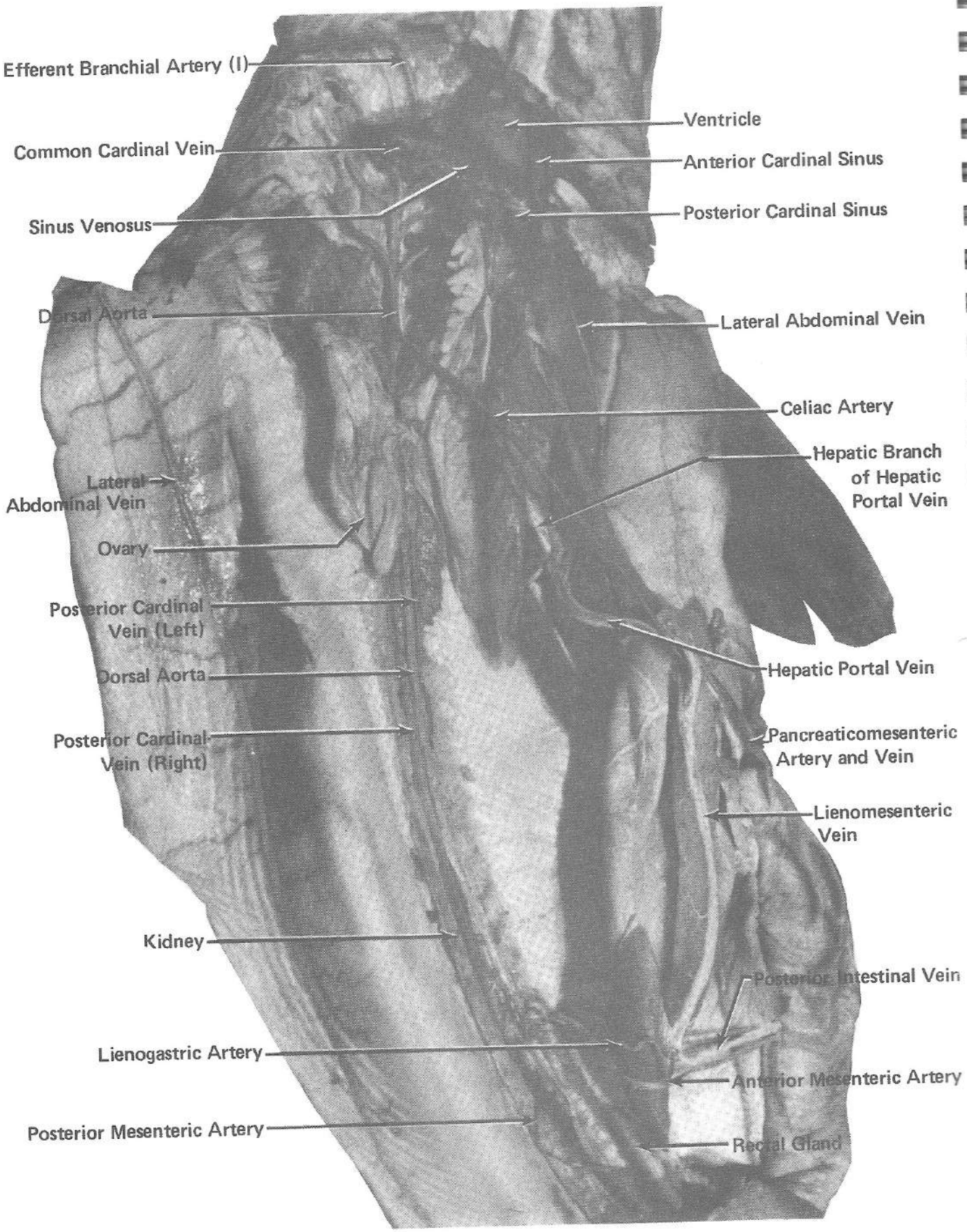
THE HEART – VENTRAL VIEW



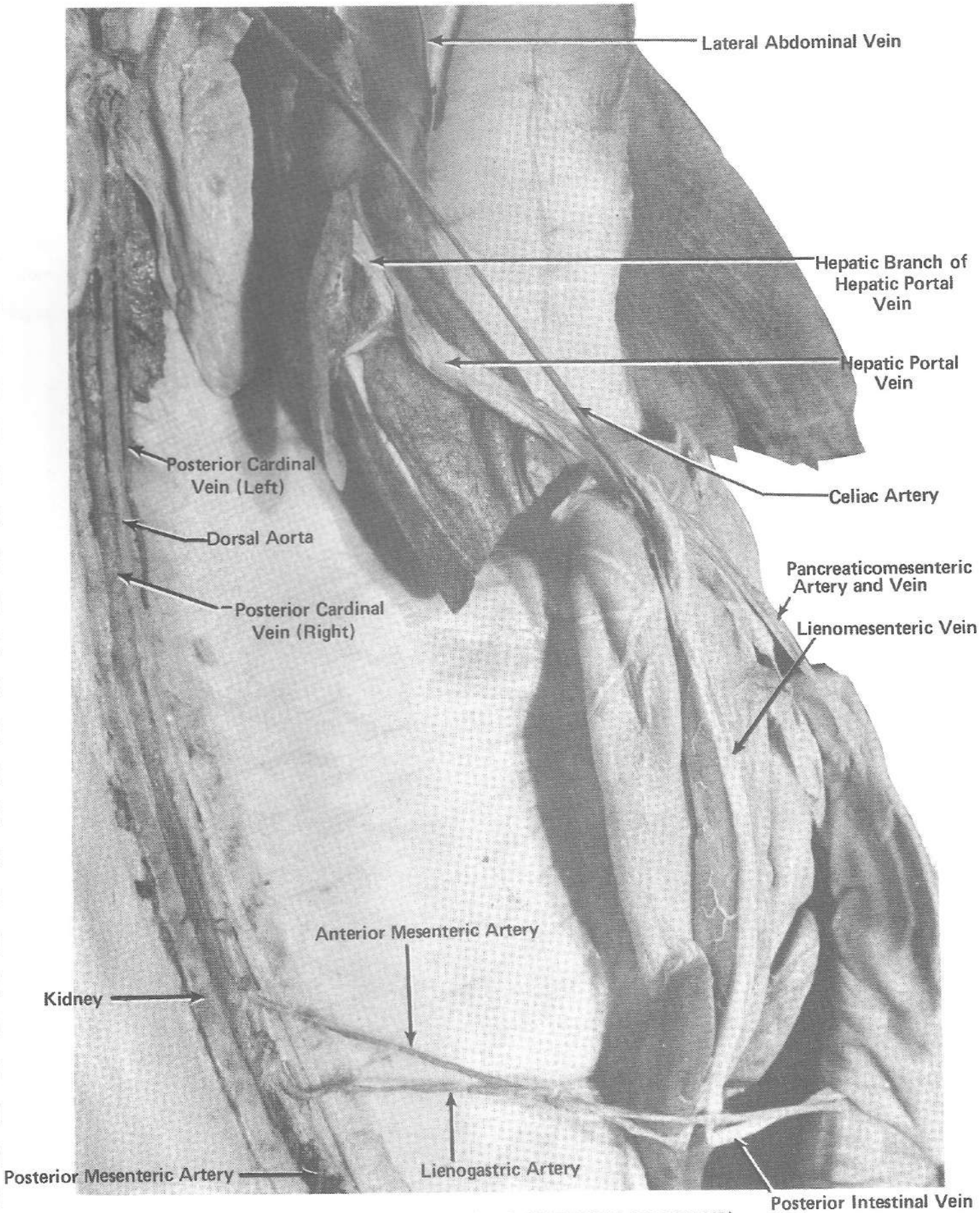
THE BRANCHIAL ARTERIES



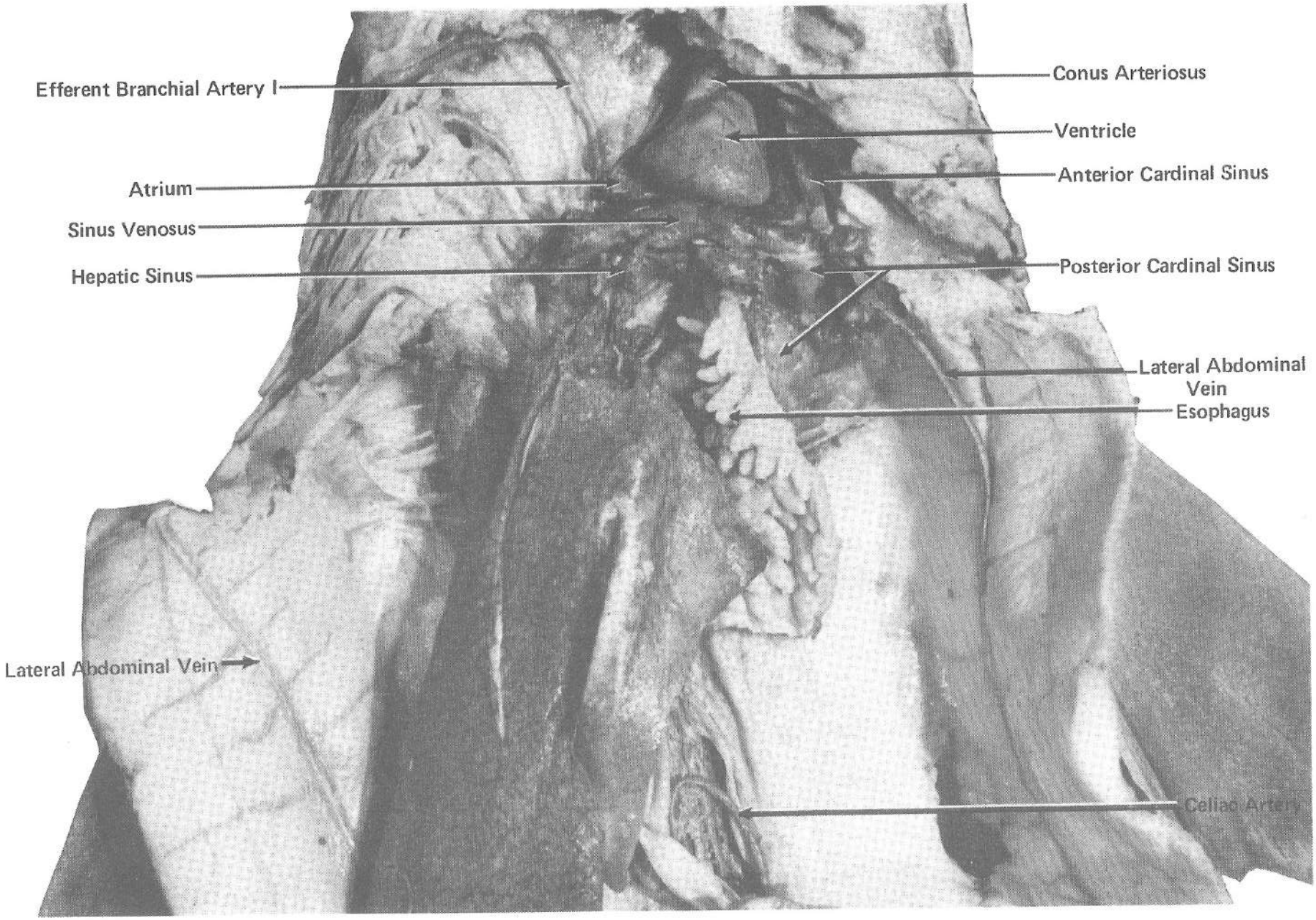
THE BRACHIAL ARTERIES (CLOSE-UP)



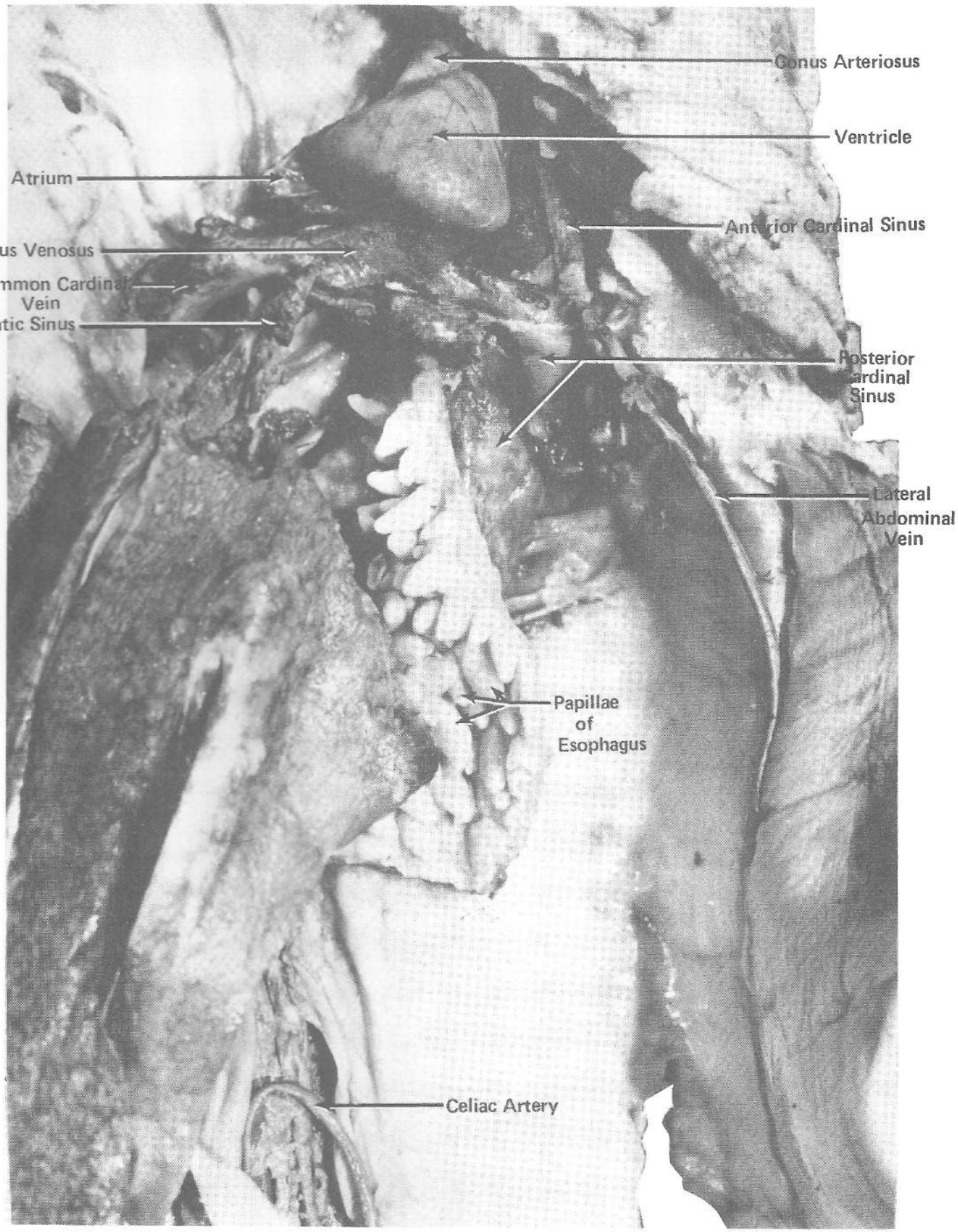
MAJOR BLOOD VESSELS OF TRUNK



MAJOR BLOOD VESSELS OF TRUNK (CLOSE-UP)



SYSTEMIC VEINS



SYSTEMIC VEINS (CLOSE-UP)