5 The Blood Vessels of the Thorax

Chapter Outline

LARGE ARTERIES OF THE THORAX

The Aorta

Ascending Aorta and the Pericardium

The entire ascending aorta lies within the pericardial sac. Consequently, tear or rupture of this part of the aorta results in a massive outpouring of blood into the pericardial cavity, producing cardiac tamponade.

Aneurysm of the Arch of the Aorta

The arch of the aorta lies behind the manubrium sterni. A gross dilatation of the aorta (aneurysm) may show itself as a pulsatile swelling in the suprasternal notch.

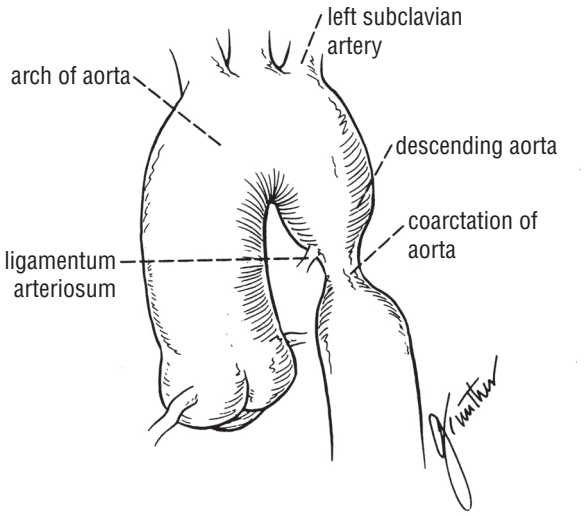
Coarctation of the Aorta

Coarctation of the aorta is a congenital narrowing of the aorta just proximal, opposite, or distal to the site of attachment of the ligamentum arteriosum (CD Fig. 5-1). Clinically, the cardinal sign of aortic coarctation is absent or diminished pulses in the femoral arteries of both lower limbs. To compensate for the diminished volume of blood reaching the lower part of the body, an enormous collateral circulation develops, with dilatation of the internal thoracic, subclavian, and posterior intercostal arteries. The dilated intercostal arteries erode the lower borders of the ribs, producing characteristic notching, which is seen on radiographic examination. The condition should be treated surgically.

Trauma to the Aorta in the Thorax

Deceleration Injuries

The heart is suspended from the aorta much like a weight attached to the end of a curved piece of flexible tubing.



CD Figure 5-1 Coarctation of the aorta.

In **horizontal deceleration injuries** the movement of the body is suddenly stopped and the heart continues to move forward within the pericardial sac. The descending thoracic aorta from the point of origin of the left subclavian artery onward is firmly attached to the vertebral column by connective tissue and pleura. As the heart continues to move forward on body impact, the curve of the arch of the aorta is slightly straightened and the vessel shears just distal to the origin of the left subclavian artery. The aorta may be completely transected and be accompanied by a massive hemorrhage. If the trauma to the aorta is less, a tear may occur in the aortic wall, leaving the more resilient outer connective tissue coat intact. Blood then dissects between the layers of the aortic wall, producing a **false aneurysm.**

In **vertical deceleration injuries**, as in falls from a height, the violent pull of the heart on the end of the aortic arch causes a tear in the inner coat of the aortic wall at the root of the ascending aorta. If rupture of the ascending aorta should ensue, the aortic blood would burst into the pericardial sac, causing immediate cardiac tamponade. The ascending aorta together with the pulmonary trunk is surrounded only by a thin sleeve of serous pericardium and by the fibrous pericardium. Once the sleeve of serous pericardium gives way, the blood enters the pericardial cavity, causing cardiac tamponade. Most of these injuries are fatal.

Penetrating Injuries of the Aorta

Penetrating vascular injuries are likely to occur when the entrance and exit wounds are on opposite sides of the chest, indicating that the bullet has crossed the midline of the chest. Penetrating injuries involving blood vessels and not the heart have the highest mortality when they occur in the superior mediastinum; here the aortic arch gives rise to its major branches, and the superior vena cava and brachiocephalic veins are present.

The Descending Thoracic Aorta and the Esophagus in Posterior Thoracotomy

The relationship of the aorta and the esophagus in the posterior mediastinum is important when distinguishing between these structures when performing an emergency thoracotomy.

The Descending Thoracic Aorta and Left Hemothorax

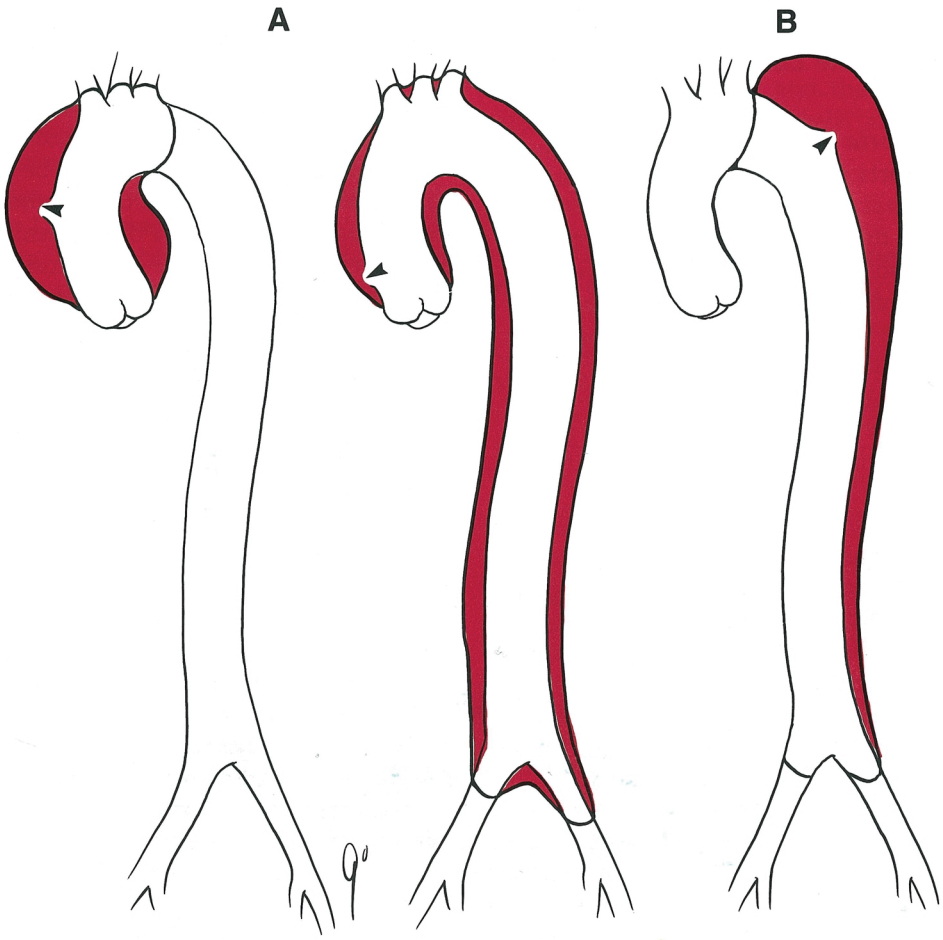
The close relationship of the descending thoracic aorta to the left pleura and lung means that rupture of the aorta may occur into the left pleural cavity, producing a massive hemothorax.

Aortic Dissection

This is the most serious and difficult form of aortic disease to treat (CD Fig. 5-2). Degeneration of the tunica media of the aortic wall is believed to be the basic cause, and the condition is associated with a history of hypertension in the majority of patients. Marfan's disease can also be responsible for the degeneration. Hemorrhage occurs through the tunical intima and extends as an expanding hematoma between the middle and outer thirds of the tunica media. The initial tear may occur anywhere along the thoracic aorta. **Type A (proximal dissection)** involves the ascending aorta or ascending and descending aorta (see CD Fig. 5-2). **Type B (distal dissection)** does not involve the ascending aorta and usually begins distal to the left subclavian artery. The clinical signs and symptoms will depend on the type of aneurysm present and the extent of distal propagation.

The sudden onset of excruciating, sharp, tearing pain localized to the front or the back of the chest and back is a typical presenting symptom. It must be assumed that the pain impulses originate in the aortic wall, ascend to the central nervous system along with the sympathetic nerves, and enter the spinal cord through the posterior roots of the segmental spinal nerves. The pain is then referred along the somatic spinal nerves of the same segments. The number of dermatomes involved will depend on the extent of the dissection. If the dissection continues to spread distally, the pain may be felt segmentally in the abdomen, lower back, and legs.

An aneurysm of the ascending aorta has the highest mortality since it may rupture into the pericardial cavity, producing immediate cardiac tamponade; it may rupture into the mediastinum or pleural cavities; it may extend into the coronary arteries, causing occlusion; or it may extend to the aortic valve, producing acute aortic incompetence. Involvement of the brachiocephalic, left common carotid, or left subclavian arteries at their origin from the aortic arch may give rise to symptoms of cerebral ischemia or upper limb ischemia.



CD Figure 5-2 Aortic dissection. Type A (proximal dissection) involves the ascending aorta or ascending and descending aorta. Type B (distal dissection) does not involve the ascending aorta.

An aneurysm of the descending thoracic aorta can rupture into the pleural cavity on the left side. If the dissection progresses distally to involve the abdominal aorta, occlusion of the mesenteric arteries could result in bowel infarction, and occlusion of the renal arteries could result in renal failure. Ischemic necrosis of the spinal cord resulting in paraplegia could follow blockage of the posterior intercostal arteries arising from the thoracic aorta or the lumbar arteries arising form the abdominal aorta.

Rupture of the aneurysm below the diaphragm may produce catastrophic retroperitoneal hemorrhage.

The Pulmonary Trunk

Penetrating Injuries of the Pulmonary Trunk

Any missile injury with entry or exit wounds close to the manubrium sterni may damage the pulmonary trunk or any other vessel in the superior mediastinum, Remember that the pulmonary trunk and the ascending aorta together are surrounded by a sheath of serous pericardium within the fibrous pericardium (see text Fig. 4-21), so that hemorrhage into the pericardial cavity from either of these vessels could result in cardiac tamponade.

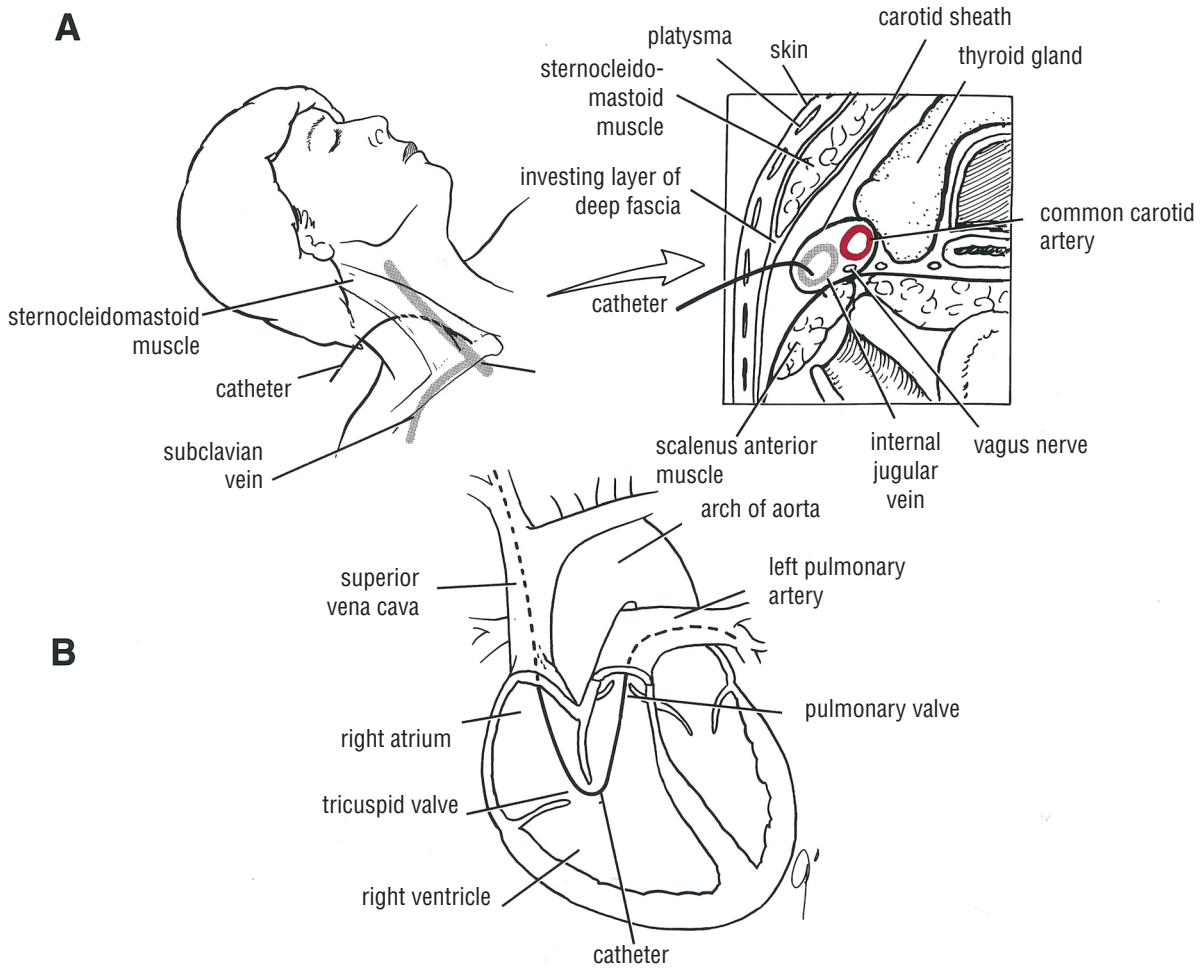
Pulmonary Artery (Swan-Ganz) Catheterization

The pulmonary artery catheter is used to assess left and right ventricular function, measure pulmonary artery and right and left atrial pressures, measure cardiac output, and take samples of right atrial and pulmonary arterial blood.

The catheter is introduced through the right internal jugular vein, right subclavian vein, right basilic vein, or the femoral vein. The catheter is advanced into the right atrium through the tricuspid valve into the right ventricle (CD Fig. 5-3). The balloon is advanced into the pulmonary trunk and then into the left pulmonary artery.

Pulmonary Embolism

In the great majority of patients, the pulmonary emboli arise from a thrombosis in the large deep veins of the lower extremity, especially from the femoral veins, and from the internal iliac veins in the pelvis. Thromboses in the veins of the calf muscles following prolonged immobility, such as



CD Figure 5-3 Pulmonary artery (Swan-Ganz) catheterization. **A.** The catheter has been introduced through the right internal jugular vein (posterior approach). **B.** Diagram showing the course taken by the catheter through the right side of the heart into the pulmonary trunk and the left pulmonary artery.

commonly occurs in long-distance plane flights, may be the origin of pulmonary emboli.

EMBRYOLOGIC NOTE

Detailed Development of the Large Arteries of the Thorax and the Ductus Arteriosus

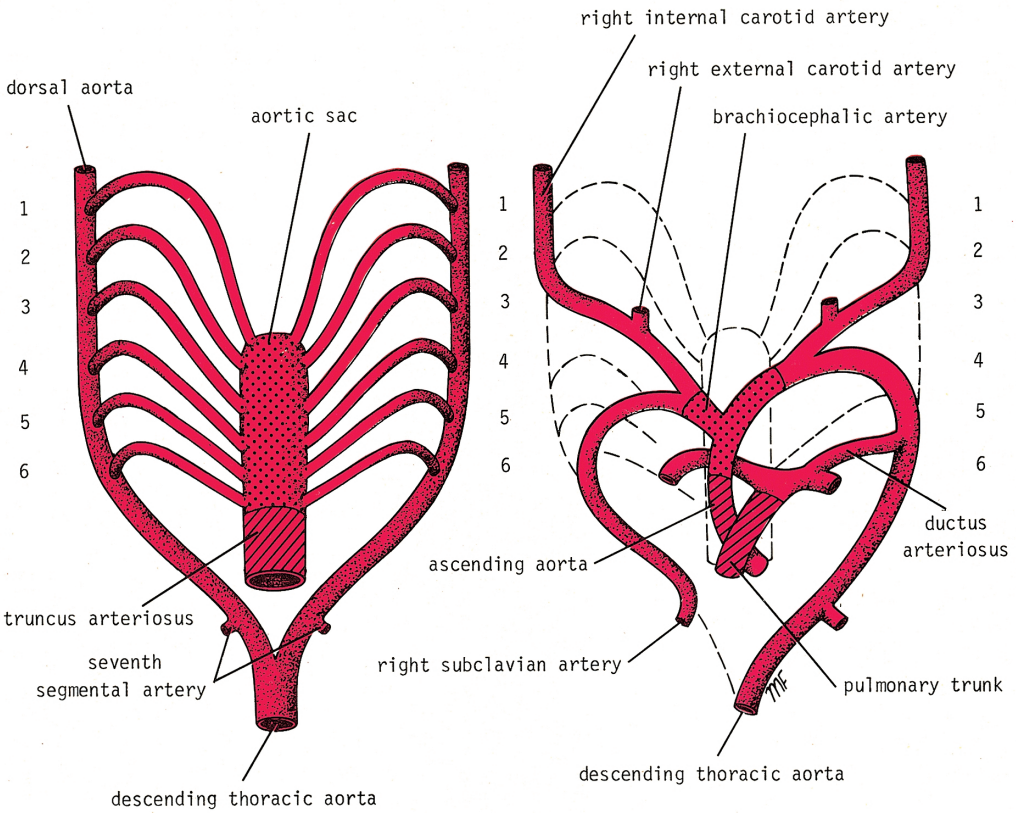
The truncus arteriosus, which is the distal part of the bulbus cordis (CD Fig. 5-4) is continuous beyond the pericardium with a large vessel called the **aortic sac.** This sac gives off two branches, each of which runs dorsally in the first pharyngeal arch on each side in the developing embryo. The branches then pass caudally in the posterior wall of the embryo as the two **dorsal aortae**. Five additional arteries now join the aortic sac to the dorsal aortae (see CD Fig. 5-4). Meanwhile, the two dorsal aortae fuse throughout much of their lengths to form the **descending thoracic aorta** and the **abdominal aorta.**

The **ascending aorta** below the right pulmonary artery and the main pulmonary trunk are derived from the truncus arteriosus (see CD Fig. 5-4). The aorta, from the level of the right pulmonary artery up to the level of the left common carotid artery, is derived from the aortic sac.

The **brachiocephalic artery** also is formed from the aortic sac. The remainder of the **arch of the aorta** is formed from the left fourth aortic arch artery and the left dorsal aorta (see CD Fig. 5-4).

The fourth right aortic arch artery becomes the root of the **right subclavian artery,** which also is derived in sequence from a small part of the right dorsal aorta and the right seventh segmental artery.

The third aortic arch artery on both sides becomes the **common carotid artery;** this sends off a bud of mesenchyme that becomes the **external carotid artery.** The remainder of the third aortic arch artery and part of the dorsal aorta form the **internal carotid artery** on each side.



CD Figure 5-4 The formation and fate of the aortic arch arteries.

The first, second, and fifth aortic arch arteries disappear completely. The **right and left pulmonary arteries** are formed from the sixth aortic arch arteries. The distal part of the right sixth aortic arch artery disappears, while the remainder of the left sixth aortic arch artery becomes the important **ductus arteriosus,** which after birth becomes the **ligamentum arteriosum.**

The **descending thoracic aorta** below the level of the fourth thoracic vertebra is formed from the fusion of the dorsal aortae (see CD Fig. 5-4).

Congenital Anomalies

Patent Ductus Arteriosus

The ductus arteriosus represents the distal portion of the sixth left aortic arch and connects the left pulmonary artery to the beginning of the descending aorta (see CD Fig. 5-4). During fetal life, blood passes through it from the pulmonary artery to the aorta, thus bypassing the lungs. After birth, it normally constricts, later closes, and becomes the **ligamentum arteriosum.**

Failure of the ductus arteriosus to close may occur as an isolated congenital abnormality or may be associated with congenital heart disease. A persistent patent ductus arteriosus results in high-pressure aortic blood passing into the pulmonary artery, which raises the pressure in the pulmonary circulation. A patent ductus arteriosus is life threatening and should be ligated and divided surgically.

Coarctation of the Aorta

Coarctation of the aorta is a congenital narrowing of the aorta just proximal, opposite, or distal to the site of attachment of the ligamentum arteriosum (see CD Fig. 5-1). This condition is believed to result from an unusual quantity of ductus arteriosus muscle tissue in the wall of the aorta. When the ductus arteriosus contracts, the ductal muscle in the aortic wall also contracts, and the aortic lumen becomes narrowed. Later, when fibrosis takes place, the aortic wall also is involved, and permanent narrowing occurs.

Double Aorta and Right Aortic Arch

Anomalies involving double parts of the arterial system are rare conditions that result from the persistence of aortic arch arteries, which normally disappear. In the case of the right aortic arch, the development of the left arch does not take place.

LARGE VEINS OF THE THORAX

Penetrating Injuries

As has been emphasized before with arterial injuries, the highest mortality can occur in penetrating injuries in the region of the superior mediastinum. Behind the manubrium sterni lie not only the aortic arch and its large branches but also the right and left brachiocephalic veins and the superior vena cava. Moreover, the thoracic cage may hide the extent of the bleeding, which may take place entirely within the thoracic cavity. The cage also renders the veins relatively inaccessible to the operating physician.

Migrating Bullets

Bullets entering a large artery or vein may migrate with the blood from their site of entrance. Bullets in the aorta can migrate to the distal branches until they become wedged, causing blockage and ischemia. In the same manner, a bullet entering a pulmonary vein can migrate to the left atrium and left ventricle and enter the systemic circulation. A bullet entering the superior vena cava can migrate into the right atrium and right ventricle and enter the pulmonary circulation. Paradoxic movement of bullets through a patent atrial septum has been reported.

Superior Vena Cava or Brachiocephalic Vein Thrombosis

This condition usually results from compression of the veins by tumors in the superior mediastinum; enlarging lymph node metastases secondary to a bronchial carcinoma is a common cause. Venous blockage results in engorgement of the veins of the head and neck.

Important Connections between the Superior and Inferior Venae Cavae

In obstruction of the superior or inferior venae cavae, the azygos veins provide an alternative pathway for the return of venous blood to the right atrium of the heart. This is possible since these veins and their tributaries connect the superior and inferior venae cavae (CD Fig. 5-5).

EMBRYOLOGIC NOTE

Fetal Circulation and Changes in Fetal Circulation at Birth

Fetal Circulation

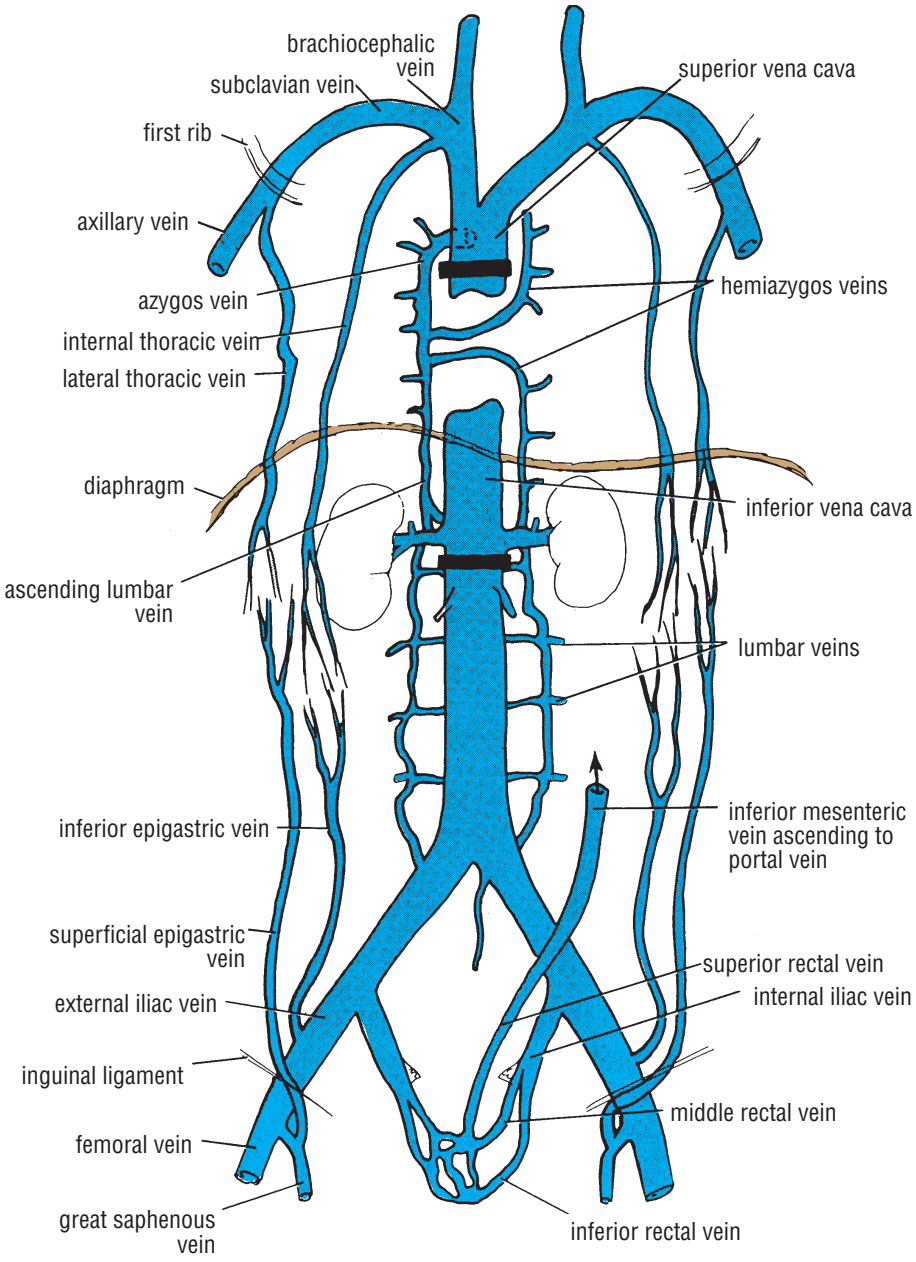
Starting at the placenta, the fetal blood may be traced in the circulation as follows:

Having circulated through the capillaries of the placental villi, the fetal blood returns through the umbilical vein to the fetus about 80% saturated with oxygen and containing many important nutrients, antibodies, and hormones (CD Fig. 5-6). The oxygenated blood then passes toward the liver. However, the greater volume of it bypasses the liver, since this organ is not fully functioning, and travels to the inferior vena cava by way of the **ductus venosus.** The remainder is distributed to the liver sinusoids by offshoots of the umbilical vein, and this in turn passes to the inferior vena cava by the hepatic veins. At the same time, the ductus venosus receives poorly oxygenated blood from the gut by way of the left branch of the portal vein. In addition, the inferior vena cava already contains venous blood from the lower part of the trunk and the lower limbs of the fetus. As a consequence of this admixture of blood from these various sources, the inferior vena cava contains blood about 67% saturated with oxygen.

Before considering the further passage of the fetal blood, it is necessary to examine the anatomic arrangement of the inferior vena cava and its relationship with the right and left atria in the fetal heart (CD Fig. 5-7). In the fetus, the opening of the inferior vena cava into the right atrium lies directly opposite the **foramen ovale.** Thus, blood entering the heart through the inferior vena cava is directed through the foramen ovale and enters the left atrium. This process is assisted by the presence of the **valve of the inferior vena cava.**

The nutritious oxygenated fetal blood, on reaching the foramen ovale, is divided into two streams by the **crista dividens,** which is the lower margin of the **septum secundum.** The greater volume of blood enters the left atrium, and the remainder, joined by venous blood from the superior vena cava and coronary sinus, passes from the right atrium into the right ventricle.

The oxygenated blood in the left atrium is joined by a relatively small volume of blood from the nonaerated fetal lungs. The left atrial blood then passes into the left ventricle and out into the aorta. The oxygen saturation of this blood is about 62%. This is distributed chiefly to the arteries of the head, neck, and upper extremities. Thus, it is apparent that blood that is richer in oxygen and nutrients is transported to the cephalic region rather than the caudal regions of the fetus.



CD Figure 5-5 The possible collateral circulations of the superior and inferior venae cavae. Note the alternative pathways that exist for blood to return to the right atrium of the heart if the superior vena cava becomes blocked below the entrance of the azygos vein (*upper black bar*). Similar pathways exist if the inferior vena cava becomes blocked below the renal veins (*lower black bar*). Note also the connections that exist between the portal circulation and systemic veins in the anal canal.

Meanwhile, the right ventricular blood passes into the pulmonary trunk. Only a small portion of this passes into the unexpanded lungs, since the vascular resistance is high. Most of the blood bypasses the lungs by being directed through the wide channel, the **ductus arteriosus,** into the descending thoracic aorta (see CD Fig. 5-6).

The now relatively poor oxygenated blood passes down the descending thoracic and abdominal aortae and supplies the thoracic and abdominal viscera and lower limbs. The fetal blood, which by this time is loaded with waste products of metabolism and carbon dioxide, then returns to the placenta through the right and left umbilical arteries, where the waste products and carbon dioxide are eliminated and oxygen is picked up. The circulatory cycle then is repeated.

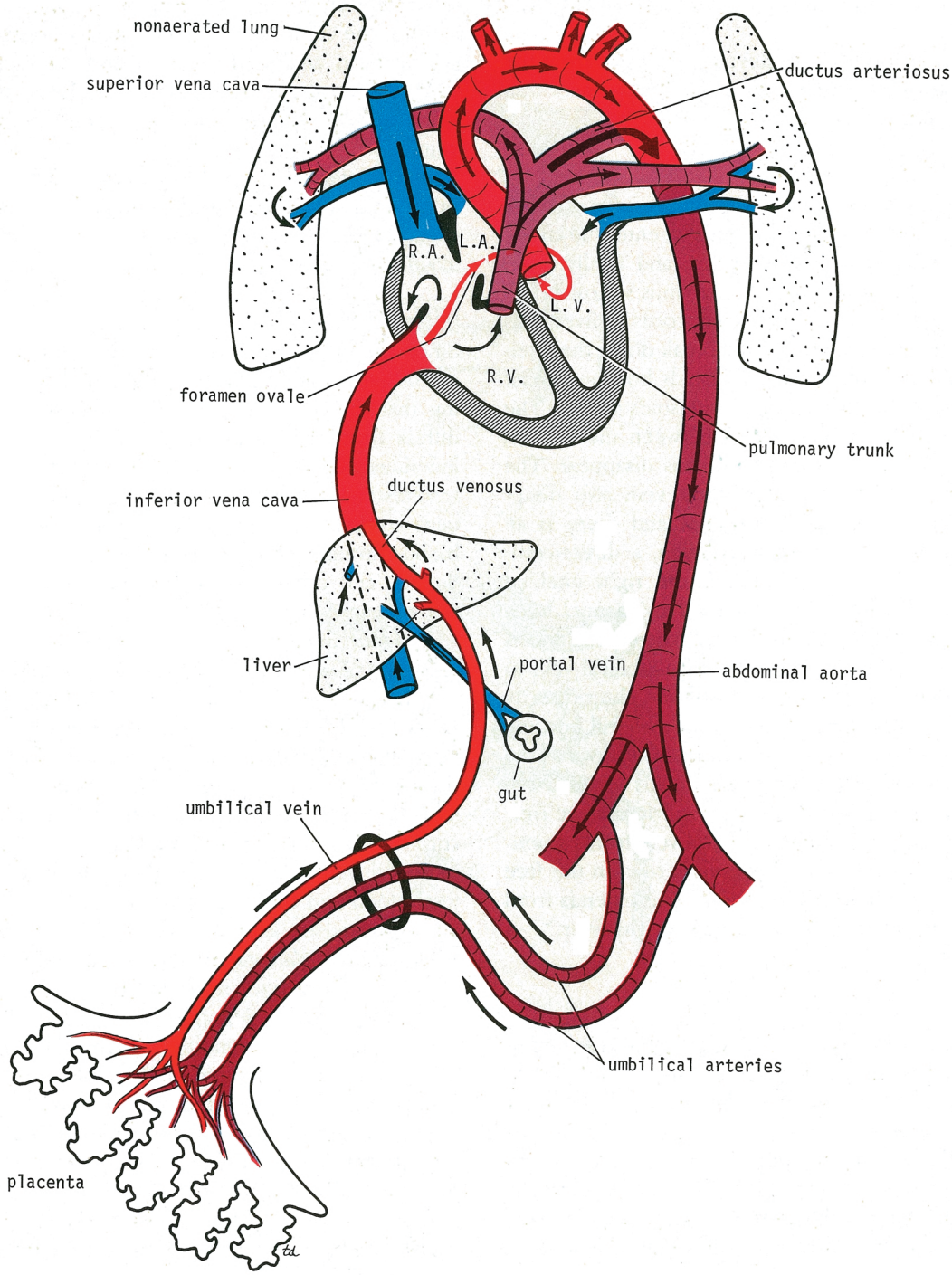
Changes in Fetal Circulation at Birth

Immediately after birth the umbilical cord is tied, thus severing the placental extension of the fetal circulation.

PHYSIOLOGIC NOTE

Blood Flow in the Umbilical Cord after Delivery

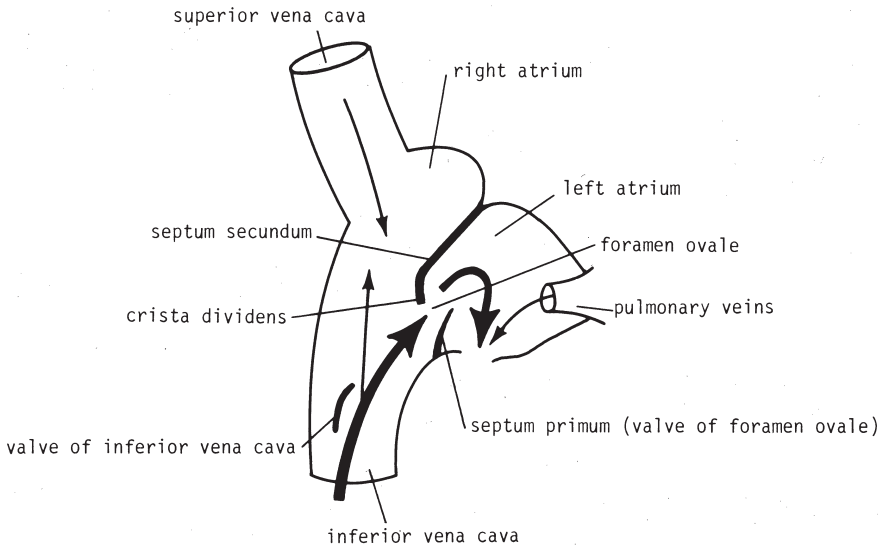
In cases in which the umbilical cord is not tied, the blood flow may continue for several minutes after delivery, although at a rapidly decreasing rate. A number of factors may contribute to this diminishing flow, including (1)



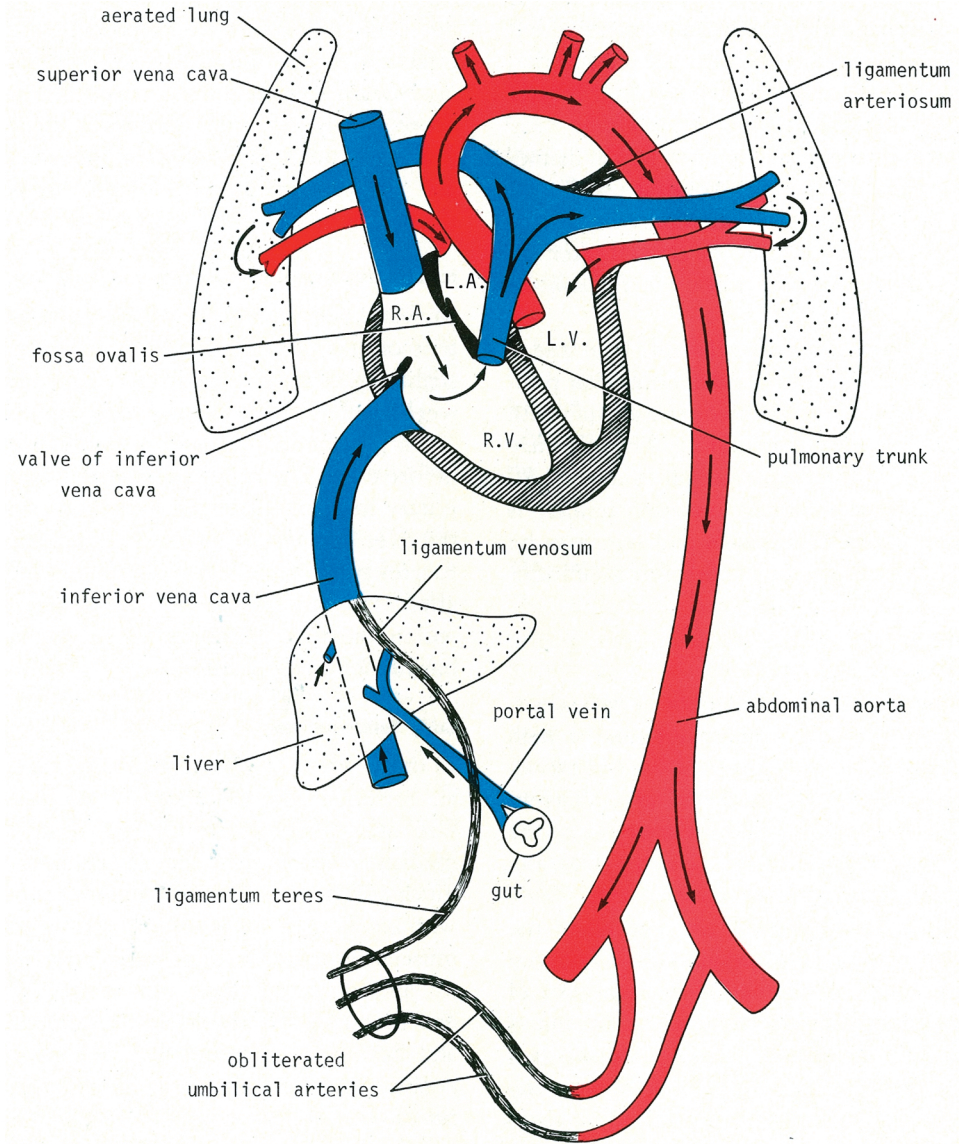
CD Figure 5-6 Fetal circulation. R.A. = right atrium, R.V. = right ventricle, L.A. = left atrium, L.V. = left ventricle.

the contraction of the uterus and the effect of this on the placental attachment and (2) constriction of the umbilical vessels as the result of mechanical stimulation or the presence in the fetal circulation of catecholamines. The fetal blood volume may be increased by as much as 100 mL if the tying of the cord is delayed. However, it generally is agreed that there is no advantage in delaying the tying beyond a minute after delivery.

The interruption of umbilical flow when the cord is tied results in an immediate fall in blood pressure in the inferior vena cava. This fact, coupled with the increased left atrial pressure from the increased pulmonary blood flow, causes the foramen ovale to close (CD Fig. 5-8). From that moment onward the valve of the foramen ovale is kept closed by the hemodynamic changes, and within a few days of birth the valve becomes attached to the edge of the foramen ovale.



CD Figure 5-7 Relationship between the opening of the inferior vena cava and the foramen ovale.



CD Figure 5-8 The circulatory system after birth. Compare this with the circulation in the fetus (CD Fig. 5-6). R.A. = right atrium, R.V. = right ventricle, L.A. = left atrium, L.V. = left ventricle.

The diminished pulmonary vascular resistance associated with inflation of the lungs cause the direction of flow (**from right to left**) through the ductus arteriosus to be changed to the neonatal route of **left to right.** The **ductus arteriosus** constricts as a reaction of its muscle to the raised oxygen tension. It later closes and becomes the **ligamentum arteriosum.** One week after birth its lumen is 2 mm or less in diameter, and by the end of the first month it usually has closed (see CD Fig. 5-8). In addition, the wall of the ductus venosus contracts and the lumen is closed. Later the ductus becomes fibrosed to form the **ligamentum venosum.**

PHYSIOLOGIC NOTE

The Heart in the Newborn

The heart in the newborn is relatively large and is higher in the thorax and in a more horizontal position than it is in later life. The pulse rate is rapid, with an average of 130 beats per minute. The rate may rise considerably with crying and fall to around 80 during sleep. The peripheral circulation initially is slow in the newborn. The hands and feet may be cold and slightly cyanotic for the first few hours after birth.

Clinical Problem Solving Questions

Read the following case histories/questions and give the best answer for each.

1. A 16-year-old girl, on examination in the doctor's office, was found to have absent pulses in both femoral arteries. In addition, her blood pressure was higher in both upper limbs than in both lower limbs. An anteroposterior radiograph of the chest showed notching of the necks of the upper ribs on both sides. What is your diagnosis? Why is there notching of the ribs?
2. Name the common sites on the thoracic aorta where damage occurs in blunt trauma. Between 80% and 90% of such injuries result in immediate death. Explain in anatomic terms the path commonly taken by the escaping blood in cases of traumatic rupture of the thoracic aorta. Name the tissues that can sometimes temporarily control the leak, thus permitting the patients to be taken to the emergency department alive.
3. A 56-year-old man was seen in the emergency department complaining of swelling of both arms. On questioning, he said that he first noticed that his hands were swollen 3 weeks earlier. He admitted being a heavy smoker and had on several occasions coughed up blood-stained sputum. On examination, his face looked puffy, especially around the eyes. Pitting edema was present in both the upper limbs, the face, and the neck. With the patient in the recumbent position, numerous dilated superficial veins were seen over the chest wall and abdomen. Later a chest radiograph revealed a large opacity in the upper lobe of the right lung. A diagnosis of advanced bronchogenic carcinoma of the right upper lobe was made. Can you explain the presence of edema in both the upper limbs, the face, and the neck? What is the cause of the dilated superficial veins of the chest and abdominal walls? Is there normally communication between the main veins draining the upper part of the body and those draining the lower half of the body?
4. A fourth-year medical student was asked by a pediatrician what factors are responsible for the closure of the foramen ovale in the atrial septum at birth. The student also was asked if oxygenated or deoxygenated blood normally passes through the foramen ovale during fetal life. How would you answer these questions?

Answers and Explanations

1. Coarctation of the aorta is a narrowing of the aorta just proximal, opposite, or distal to the site of attachment of the ligamentum arteriosum. It is believed to result from the presence of an unusual quantity of ductus arteriosus muscle tissue incorporated in the wall of the aorta. When the ductus arteriosus contracts after birth, the ductus muscle in the aortic wall also contracts and the aortic lumen becomes narrowed. Later, fibrosis occurs and permanent narrowing takes place. The notching of the lower borders of the ribs is caused by the opening up of the collateral circulation through the subclavian, internal thoracic, and posterior intercostal arteries to carry

blood from above the coarctation to the distal part of the aorta ; it is the dilated posterior intercostal arteries that notch the ribs.

2. Blunt traumatic injury to the thoracic aorta involving horizontal deceleration occurs most commonly just distal to the origin of the left subclavian artery. This site is vulnerable since the heart and the aortic arch are mobile and the descending aorta is fixed. Sudden vertical deceleration, as in a fall, may result in an intimal tear at the root of the ascending aorta; the momentum of the heart filled with blood is sufficient to produce the tear.

   Rupture of the ascending aorta occurs into the pericardial cavity, producing immediate cardiac tamponade and death. Rupture of the descending thoracic aorta frequently occurs into the left pleural cavity. The tear initially occurs in the tunica intima; the tunica media and adventitia and the surrounding connective tissue and the pleura may delay the complete rupture or temporarily control the leak. If untreated, delayed rupture and death usually occur in these cases within 2 weeks.

3. The swelling of both upper extremities and the head and neck, caused by edema, and the engorgement of the superficial veins of the chest and abdominal walls clearly indicate the presence of a superior vena caval obstruction. This obstruction was caused by the expanding metastases in the mediastinal lymph nodes secondary to the bronchogenic carcinoma. The dilated superficial veins included the lateral thoracic vein, a tributary of the axillary vein; lumbar veins, tributaries of the inferior vena cava; and the superficial epigastric vein, a tributary of the great saphenous vein of the leg that drains into the femoral vein. These venous channels provide an alternative pathway in superior vena caval obstruction, permitting superior vena caval blood to return to the heart via the inferior vena cava. The superior vena cava normally communicates with the inferior vena cava through the azygos veins. However, in this case the tumor was pressing on the superior vena cava proximal to the entrance of the azygos vein.

4. The foramen ovale is closed after birth by the valve-like flap formed by the lower part of the septum primum pressing against the septum secundum and fusing with it. This takes place as a result of a rise in blood pressure in the left atrium, which occurs once the child takes a deep breath and the pulmonary circulation is established. During fetal life, oxygenated blood passes through the foramen ovale from the right atrium to the left atrium..