CHAPTER 5

Abdomen, Pelvis and Perineum

GENERAL TERMINOLOGY

The part of the trunk inferior to the abdominal diaphragm constitutes the abdomen and pelvis. The word "pelvis" has two meanings. In its narrowest sense it refers to the articulated ossa coxae (innominate bones) and sacrum (Fig. 5-1*A*). This is best called the *bony pelvis*. In its broader meaning, "pelvis" designates that *region* of the body enveloped by, and including, the bony pelvis. In this sense, pelvis contrasts with abdomen, which is that region of the body above the pelvis and below the thorax. Due to the shape of the bony pelvis, the pelvic region of the body is considerably taller in back than in front, and the abdomen is longer in front than in back.

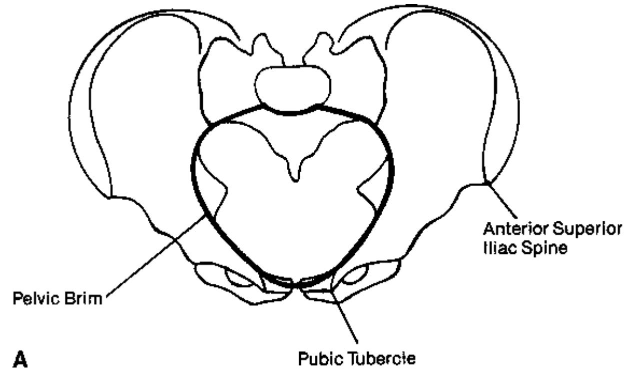
The pelvic region of the body is further subdivided into greater (false) and lesser (true) portions. The boundary between these subdivisions is identified by reference to landmarks on the bony pelvis[13]. On the inner aspect of this structure, the iliac fossa and superior surface of the pubis are demarcated from the lower portions of these bones by a prominent ridge that runs from the auricular surface of the ilium all the way round the front to the pubic tubercle (Fig. 5-1*B*). This is the **iliopectineal (terminal) line**. Along with the pubic crests, ventral rims of the sacral alae, and the sacral promontory, the iliopectineal line contributes to a "circle" of bone (see Fig. 5-1*A*) that lies halfway between a transverse and a coronal plane. It is this circle, called the **pelvic brim**, that divides the pelvis into a greater portion anterosuperiorly and a lesser portion postero-inferiorly.

Like the thorax, the trunk below the abdominal diaphragm consists of a large cavity surrounded by body wall. This is the **abdominopelvic cavity** (Fig. 5-2). It contains a fluid-filled sac and internal organs. The abdominopelvic cavity is bounded superiorly by the abdominal diaphragm, which, as was previously mentioned, has holes in it for passage of structures to and from the thoracic cavity. Inferiorly, the abdominopelvic cavity is bounded by the pelvic diaphragm, another flat muscle with holes that allow structures to pass out of it into a region of the pelvis called the **perineum**, which by definition is that part of the trunk below the pelvic diaphragm.

The part of the abdominopelvic cavity within the abdomen is called the **abdominal cavity (sensu stricto)**. That part within the pelvic region of the trunk is called the **pelvic cavity**, which in turn has greater and lesser portions, according to whether it is above or below the pelvic brim. The demarcation

---

[13] If the reader is unfamiliar with the basic structure of the innominate bone, he or she should refer to Chapter 10.



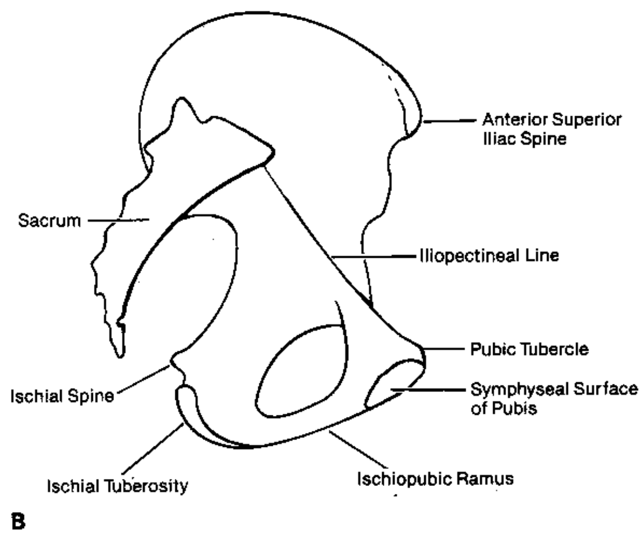


Figure 5-1. *A*, Superior view of bony pelvis. *B*, Medial view of left os coxae and sacrum. The iliopectineal line represents the os coxae's contribution to the pelvic brim.

between the abdominal cavity and the greater pelvic cavity is so arbitrary that most persons consider them to be one space, which they call the **abdominal cavity (sensu lato)**. This is the usage I will follow. On the other hand, the lesser pelvic cavity is easily distinguished by its much smaller diameter and its position below and behind the abdominal cavity (see Fig. 5-2). Thus, the **lesser pelvic cavity** is spoken of as being the true pelvic cavity or, even more frequently, simply as the **pelvic cavity**. It is in this sense that I will use the word.

The abdominopelvic cavity of the embryo is largely filled by one fluid-filled sac whose posterior wall is indented in the midline by the vertebral column, aorta, and gut tube (Fig. 5-3*A*). This sac is the representative of the coelom caudal to the abdominal diaphragm and is called the **peritoneal sac**. Like the pleural and pericardial sacs, it is composed of connective tissue lined internally by serous mesothelium. The mesothelial-lined connective tissue is called **peritoneum**. The cavity of the peritoneal sac is the **peritoneal cavity**, filled only with fluid. In the embryo, only a narrow strip of peritoneum is in direct contact with the gut tube in the posterior midline (see Fig. 5-3*A*). This is called **visceral peritoneum**. The remainder of the peritoneum is called **parietal peritoneum**.

In early embryonic life the dorsal portions of the peritoneal cavity on either side of the midline are continuous with the pleural cavities through gaps in the septum transversum. A bit later,

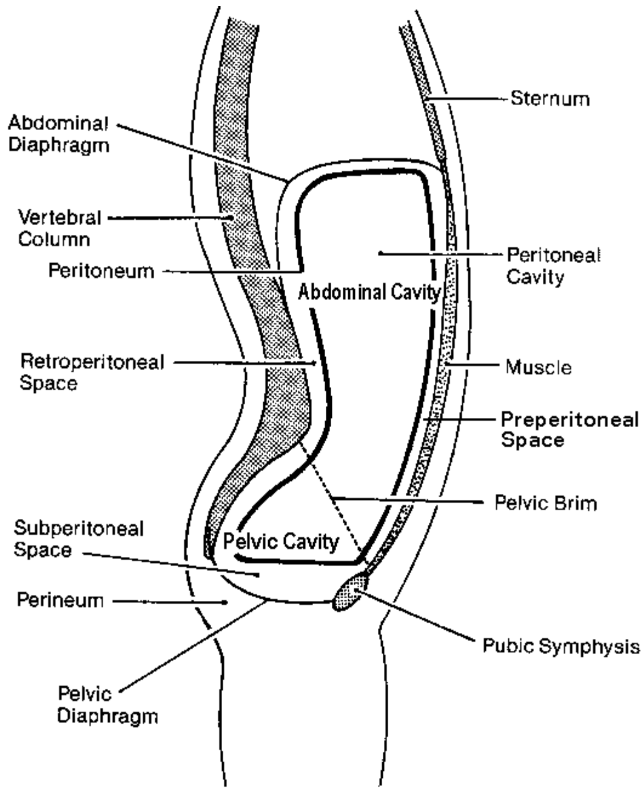


Figure 5-2. Schematic median sagittal section of abdominopelvic cavity. Postero-inferior to the pelvic brim is the lesser (true) pelvis with its cavity. Immediately anterosuperior to the pelvic brim is the greater (false) pelvis, the cavity of which merges without demarcation into that of the abdomen. The peritoneal sac abuts the abdominal diaphragm but stops short of the pelvic diaphragm.

pleuroperitoneal membranes close these gaps, separating the peritoneal cavity from the pleural cavities. These membranes contribute a small portion to the central tendon of the diaphragm, which is derived largely from the septum transversum . In the adult, the superior limit of peritoneal sac abuts the abdominal diaphragm. Inferiorly, the peritoneal sac stops short of the pelvic diaphragm, its lower wall reaching a plane that coincides with a plane between the lower end of the sacrum and the pubic crests (see Fig. 5-2). Nonetheless, part of the peritoneal sac lies in the (true) pelvic cavity.

Whereas the parietal pleura is thin and in direct contact with the endothoracic fascia that lines the muscles and bones of the thoracic wall, the parietal peritoneum is thick and separated from the **transversalis fascia**, which lines the muscles of the abdominal wall, by a loose fatty connective tissue called **extraperitoneal tissue**. This extraperitoneal tissue is said to reside in an **extraperitoneal space**. That portion of the extraperitoneal space behind the peritoneal sac is called the **retroperitoneal space**. One may say that there are two lateral extraperitoneal spaces and one anterior extraperitoneal space[14]. Additionally, below the peritoneal sac and above the pelvic diaphragm is a **subperitoneal space**. Clearly these are arbitrary divisions, since the extraperitoneal space is one continuous region enveloping the peritoneal sac.

At its earliest stage of development, the gut tube may be viewed as lying in the retroperitoneal space (see Fig. 5-3*A*). However, it soon moves further ventrally into the abdominal cavity. As it does so, the gut tube pushes the visceral peritoneum ahead of it, causing a bilayer of parietal peritoneum to be

[14] Much of the anterior extraperitoneal space is very thin by virtue of close approximation of parietal peritoneum to the posterior layer of the rectus sheath (see further on).

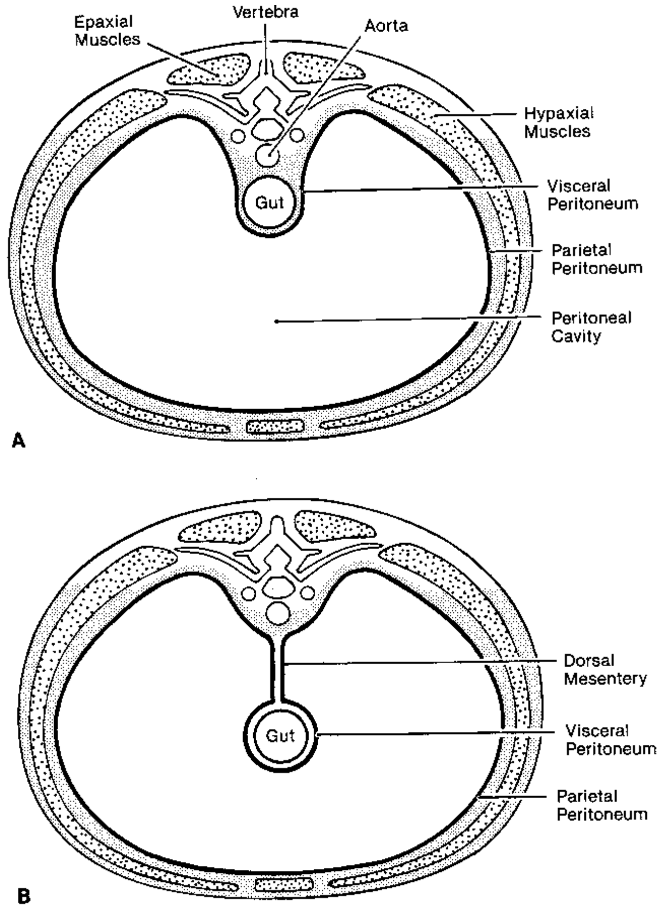


Figure 5-3. Schematic transverse sections through the embryonic abdomen at two sequential stages in development. *A*, A very early stage, in which the gut causes the dorsal wall of the peritoneal sac to deviate around it but in which no actual dorsal mesentery exists. *B*, A slightly later stage, in which further invagination of the gut into the peritoneal sac causes a bilayered dorsal mesentery to be "stretched out" between the parietal peritoneum over the aorta and the visceral peritoneum adherent to the gut itself.

stretched out between the gut and the aorta (Fig. 5-3*B*). This bilayer of stretched-out parietal peritoneum takes on the name of **dorsal mesentery**, and the term "parietal peritoneum" is then reserved for all the rest of the wall of the peritoneal sac. The site where parietal peritoneum turns to become mesentery is said to be the **root of the mesentery**. Initially, this root lies on the ventral surface of the aorta and, below the aortic bifurcation, on the vertebral bodies. After development of the dorsal mesentery, all structures still in the retroperitoneal space (such as the aorta) and those that will later develop there (such as the suprarenal glands) are said to be **primarily retroperitoneal**. The gut and its derivatives are said to be **primarily mesenteric**. As we shall see later, some of these primarily mesenteric structures will lose their mesenteries and secondarily come to lie in the retroperitoneal space. Intraperitoneal means "within the peritoneal cavity," which in most cases is just fluid.

WALLS OF THE ABDOMINAL CAVITY

The abdominal wall has both bony and muscular components, although the latter quite predominate. The only foreign muscle to have migrated between the superficial fascia of the abdominal wall and its own muscles is the latissimus dorsi.

Bony Components

Above the greater pelvis, the only major bony component of the abdominal wall is the lumbar vertebral column. While the lateral and anterior walls of the abdominal cavity are almost entirely muscular, it is technically true that they have skeletal components contributed by those parts of the lower six costal cartilages that lie inferior to the origin of the abdominal diaphragm. In the region of the greater pelvis, the iliac blades are the bony components of the posterior and lateral walls of the abdominal cavity.

Muscular Components

The reader will recall that the muscular component of the thoracic wall is derived from 11 intercostal muscle blocks, each differentiated into three layers. These intercostal muscle blocks come from the hypaxial portions of the first 11 thoracic dermomyotomes. We might expect that the muscles of the abdominal wall would come from the hypaxial parts of the 12th thoracic-4th lumbar dermomyotomes. Unfortunately, this is not the case. Whereas the epaxial portion of the body wall is uninterrupted throughout the trunk, the hypaxial part is greatly altered by the development of the lower limbs. Almost all of the 2nd-4th lumbar hypaxial dermomyotomes are drawn into the lower limb. As a result, only the 12th thoracic, 1st lumbar, and tiny parts of the 2nd-4th lumbar hypaxial dermomyotomes remain available to form the abdominal wall. This is not enough, and many cells must be borrowed from dermomyotomes above the 12th thoracic.

Most of the abdominal wall is formed from a trilaminar muscle block homologous to the intercostal muscles and derived from hypaxial dermomyotomes T7-L1. In addition, there are muscles of the abdominal wall that have no counterpart in the chest. One of these, the rectus abdominis (derived from hypaxial dermomyotomes T7-T12), makes a major contribution to the anterior abdominal wall. Another, the quadratus lumborum (derived from part of the 1st lumbar hypaxial dermomyotome and all that remains in the abdomen of the 2nd-4th lumbar hypaxial dermomyotomes), makes up part of the posterior abdominal wall above the greater pelvis. The psoas major and iliacus, muscles of the lower limb, form the posterior and lateral walls in the region of the greater pelvis. The psoas also migrates higher to contribute the posterior wall above the pelvis.

One must remember that the abdominal diaphragm is a highly curved structure, so that its back part lies as much posterior to the abdominal cavity as it does superior to it (see Fig. 5-2). Thus, many authors consider the diaphragm to form part of the posterior abdominal wall.

Psoas Major and Iliacus (Fig. 5-4; see Fig. 10-27)

Being muscles of the lower limb, psoas major and iliacus will be discussed in Chapter 10. However, the psoas major has migrated superiorly to form part of the posterior abdominal wall on either side of the lumbar vertebral bodies. It arises from the intervertebral discs, adjacent parts of vertebral bodies, and bases of transverse processes between the lower border of T12 and the upper border of L5. The fibers run inferiorly, and slightly laterally, to enter the greater pelvis, where they continue to descend just above the pelvic brim. Within the greater pelvis, the psoas major lies in contact with the back of the iliacus. Together the two muscles cross the superior ramus of the pubis and anterior surface of the hip joint and go to an insertion on the lesser trochanter of the femur.

Occurring occasionally, and lying on the anterior surface of the psoas major, is a small muscle called the **psoas minor**. It arises from intervertebral disc T12/L1 and the adjacent vertebral bodies. Psoas minor inserts onto the iliopubic eminence (a bump on the os coxae anterior to the acetabulum). The inferior half (or more) of the muscle is entirely tendon. The psoas minor is too small to have any significant mechanical function. Its developmental origin is obscure, though it is probably a part of the psoas major that has lost a femoral insertion.

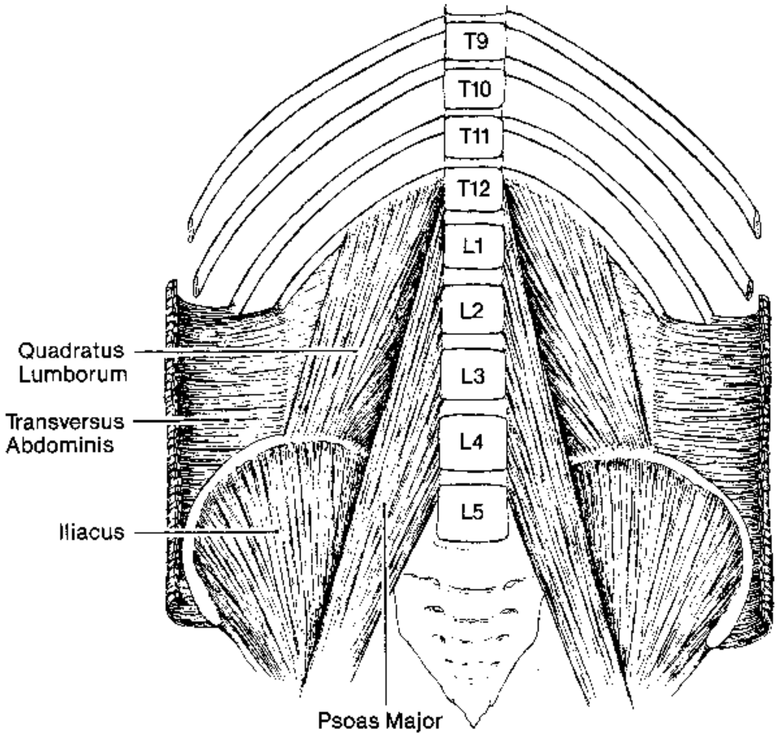


Figure 5–4. Anterior view of the posterior abdominal wall, exclusive of the contribution made by the abdominal diaphragm.

Quadratus Lumborum (see Fig. 5-4)

The quadratus lumborum forms a part of the posterior abdominal wall just lateral to the psoas major. It is formed of fibers that arise from the lower edge of the 12th rib and from the tips of the first four lumbar transverse processes (which after all are ribs). The muscle fibers converge toward an insertion on the crest of the ilium where it borders the posterior part of the iliac fossa (just deep to the origin of latissimus dorsi). The quadratus lumborum is a lateral flexor of the lumbar vertebral column. Being derived from the 1st-4th lumbar hypaxial dermomyotomes, it is innervated by direct branches of the 1st-4th lumbar ventral rami.

A thick sheet of fibrous tissue lies on the posterior surface of the quadratus lumborum separating it from the latissimus dorsi inferiorly and from the iliocostalis superiorly. This sheet is usually called the **anterior layer of thoracolumbar fascia**, to differentiate it from the thick fascia on the posterior surface of the intrinsic back muscles. It is more usefully considered the aponeurosis of origin of the transversus abdominis muscle from lumbar transverse processes.

More About the Abdominal Diaphragm (Fig. 5-5)

Now that we know a bit more about the posterior abdominal wall, it is possible to consider the origin of the posterior fibers of the diaphragm in more detail.

Some of these fibers arise from a fibrous arch that bridges over the anterior surface of the aorta opposite the 12th thoracic vertebra. The ends of this arch descend to attach to the fronts of the 2nd or 3rd lumbar vertebrae. This arch is the called **median arcuate ligament**, and the opening that it surrounds is called the **aortic hiatus** of the diaphragm.

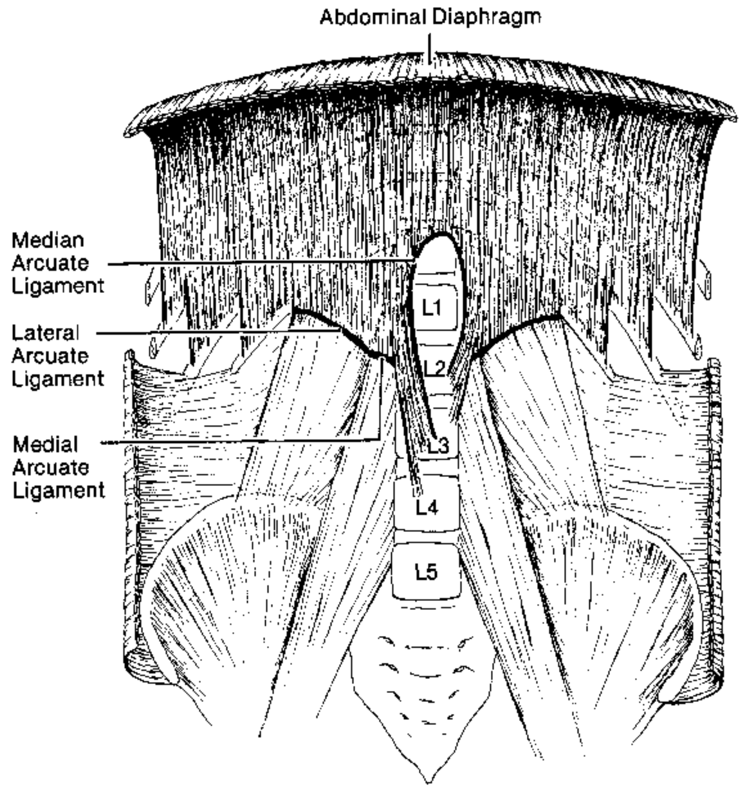


Figure 5-5. Contribution of the abdominal diaphragm to the posterior abdominal wall.

Immediately lateral to those fibers of the diaphragm that arise from the median arcuate ligament are other fibers that take direct origin from the anterolateral surfaces of the upper lumbar vertebral bodies. On the left these fibers form what is called the **left crus of the diaphragm**; on the right they form the **right crus**. Thus, after the aorta enters the abdominal cavity it has the crura of the diaphragm on either side.

Lateral to the crura, at the level of the 2nd lumbar vertebra, muscle fibers of the diaphragm arise from the fascia on the anterior surfaces of the psoas major and quadratus lumborum. The parts of the psoas major and quadratus lumborum superior to the origin of the diaphragm are, technically, within the thoracic cavity. The fascia on the anterior surfaces of the psoas major and quadratus lumborum is thickened where diaphragm fibers take origin. The thickened line of fascia on the psoas major is called the **medial arcuate ligament**; the thickened line of fascia on the quadratus is called the **lateral arcuate ligament**. Lateral to the quadratus lumborum, the diaphragm begins its origin from ribs.

For developmental reasons, the part of the diaphragm arising from the lateral arcuate ligament, and from the 12th rib lateral to this, may be deficient in actual muscle tissue. In such cases, this region of the diaphragm will consist essentially of fused endothoracic and transversalis fascias. The deficient region is said to comprise a **lumbocostal trigone** and is a potential site of herniation of abdominal contents into the thoracic cavity.

Rectus Abdominis

As a rare occurrence in the chest, there may be two narrow longitudinal muscles superficial to the pectoralis major on either side of the sternum. In the abdomen there is no sternum, but there are always two longitudinally running muscles on either side of the anterior midline. These are the rectus abdominis muscles. On each side, a rectus abdominis arises from the xiphoid process and the ventral surfaces of the 5th-7th costal cartilages. The fibers of the rectus abdominis run inferiorly. A few inches above the pubic symphysis they give way to a tendon that inserts onto the crest of the pubis and anterior surface of its body. The right and left rectus abdominis muscles are entirely independent, being separated by a connective structure called the **linea alba** (to be described below).

The superior half of each rectus abdominis is interrupted by three (sometimes four) transverse connective tissue bands called tendinous intersections. It is as if these are perverse representations of ribs that break the rectus abdominis into "intercostal" segments.

The rectus abdominis is innervated by the intercostal nerves of the short spaces (7-11) and the subcostal nerve. (Sometimes also the 6th intercostal nerve sends a branch to the highest fibers of the muscle.) The rectus abdominis is a flexor of the lower trunk, and must contract when intra-abdominal pressure is to be elevated.

In about 80 percent of persons there exists a small muscle--the **pyramidalis**--that arises from the front of the pubis near the insertion of the rectus abdominis and passes upward on the anterior surface of the rectus tendon to insert into the linea alba for a variable distance above the symphysis. Together the two pyramidalis muscles form an equilateral triangle whose base is the pubis and whose apex points to the linea alba. When confining their incisions to the pubic area, gynecologic surgeons may use the pyramidalis as a guide to the linea alba.

Trilaminar Block of Abdominal Muscles

Part of the posterior abdominal wall, all of its lateral wall above the greater pelvis, and much of the anterior wall of the abdominal cavity are formed by a trilaminar block of muscles that is the abdominal counterpart of the intercostal muscles. **Corresponding to the external intercostal muscle is the external abdominal oblique; corresponding to the internal intercostal is the internal abdominal oblique; corresponding to the innermost intercostal and transversus thoracis is the transversus abdominis**. Before these muscles can be adequately described it is necessary to mention a peculiar hole--called the inguinal canal--that passes through them.

Development of the Inguinal Canal Early in embryonic life there forms a cord, composed of connective tissue and smooth muscle, that runs from skin lying anterior to the body of the pubis, up over the pubic crest, and then deeply. This cord, called the **gubernaculum**, bifurcates into one branch that attaches to a spot on the lower front wall of the peritoneal sac, and another that runs around the peritoneal sac to reach the embryonic gonad (Fig. 5-6). The skin from which the gubernaculum arises will become the labium majus (in females) or the scrotum (in males).

The cells that will form the trilaminar muscle block of the anterior abdominal wall and the transversalis fascia that lines it are forced to differentiate around the pre-existing gubernaculum. Thus, from its very inception, the musculofascial layer of the anterior abdominal wall will have a hole, running from deep to superficial, for passage of the gubernaculum. This hole connects the anterior extraperitoneal space with the space occupied by the subcutaneous tissue, and it is located lateral to the rectus abdominis (see Fig. 5-6) very near the inferior limit of the anterior abdominal wall.

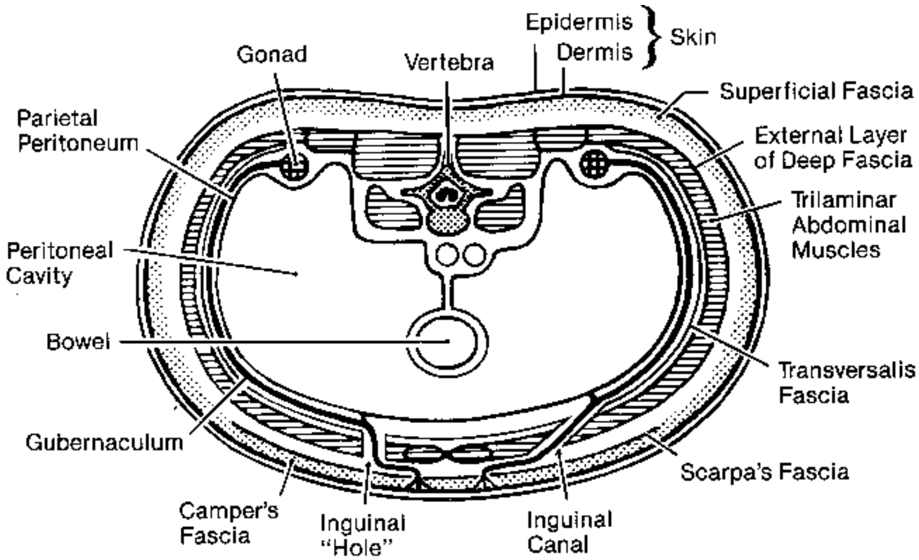


Figure 5–6. Schematic transverse section of the abdomen showing the path of the embryonic gubernaculum. See text for a discussion of why an inguinal canal is far preferable to an inguinal "hole".

The hole through the musculofascial layer of the developing anterior abdominal wall might be called the inguinal hole (L. *inguina*, groin). It probably would be given this name if it ran a short course from deep to superficial as illustrated on the left side of Figure 5-6. But consider the functional implications of such a short course. Every time pressure increased within the abdominal cavity, it would be a simple matter for a part of the bowel, pushing parietal peritoneum in front of it, to pass through the "inguinal hole." The body has solved this problem by having the deep opening to the "inguinal hole" be located substantially further laterally than the superficial opening. Thus the hole runs a long course from deep and lateral to superficial and medial (see Fig. 5-6). Such a long hole deserves the name of **inguinal canal**. Now when intra-abdominal pressure is elevated, the muscle and fascia posterior to the inguinal canal are pushed against the muscle and fascia anterior to the canal, collapsing its cavity and making it rather difficult for any structure to push through the deep opening and traverse the canal toward the skin.

The musculofascial layer of the developing anterior abdominal wall will differentiate into the external abdominal oblique, internal abdominal oblique, and transversus abdominis, with the latter being lined by transversalis fascia. We might expect that each of the derivative layers will have its own hole that contributes to the canal. In fact, three of them do. The hole in the transversalis fascia at the entrance to the canal is called the **deep inguinal ring**. The hole in the external abdominal oblique layer, at the exit of the canal, is called the **superficial inguinal ring**. Why there is only one other hole and why it has no name will be discussed subsequently.

External Abdominal Oblique, EAO (Fig. 5-7*A*). This muscle arises from the lateral surfaces of the lower 6 to 8 ribs. The direction of its fibers is the same as that of the external intercostal fibers. Thus, on the lateral side of the abdomen the fibers run downward and anteriorly; on the anterior surface of the abdomen they run downward and medially.

The most posterior fibers of the EAO (arising from the 12th and 11th ribs) insert into the anterior half of the iliac crest, at first fleshily, but then by means of flat tendon as the anterior superior iliac spine is approached. The remainder of the muscle, arising from higher ribs, becomes tendinous as it curves around to the front of the abdomen. The very broad flat tendon so produced is the **aponeurosis of the external abdominal oblique**. The direction of the tendon bundles continues that of the muscle fibers that give rise to them, i.e., downward and medially.

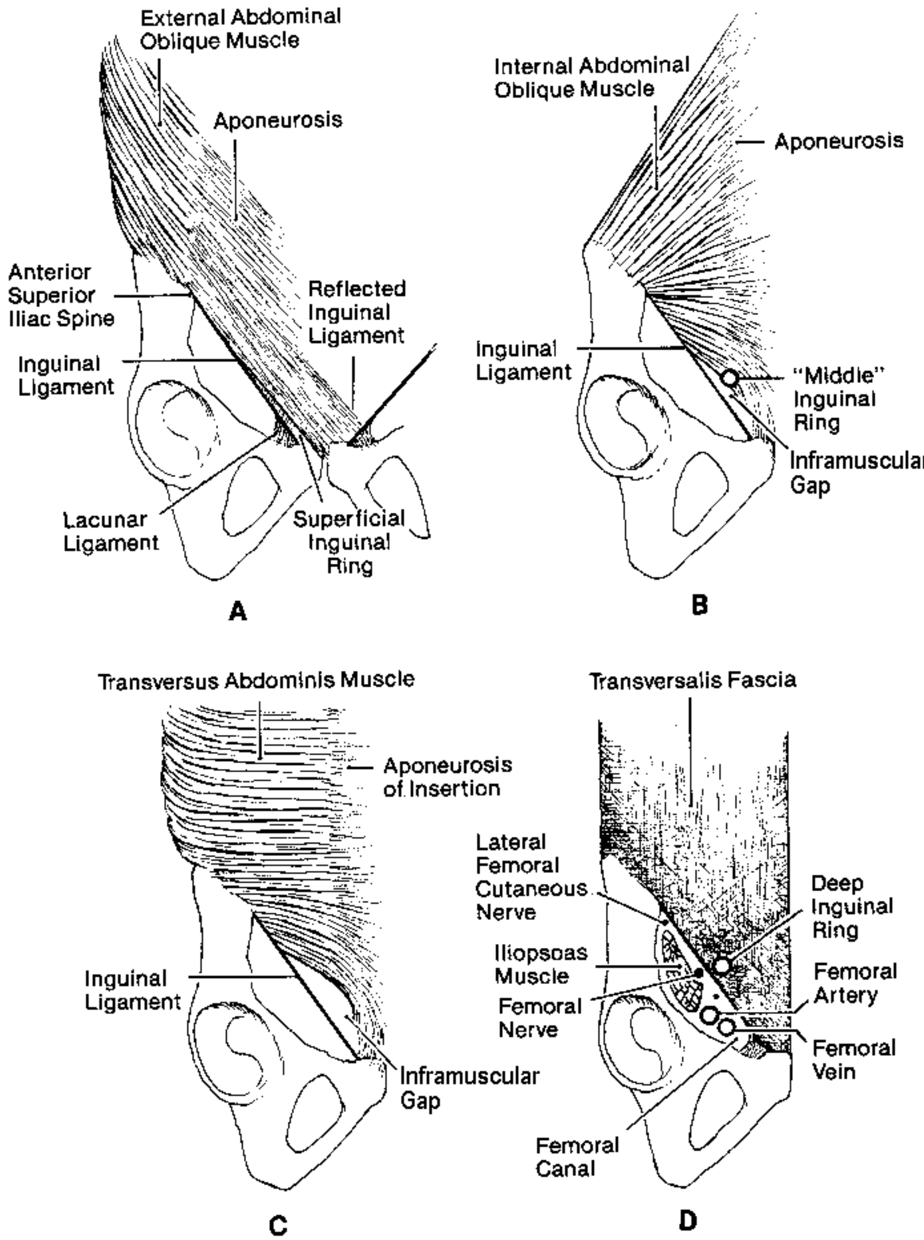


Figure 5–7. The four components of the musculofascial anterior abdominal wall. *A*, External abdominal oblique layer. *B*, Internal abdominal oblique layer. *C*, Transversus abdominis layer. *D*, Transversalis fascia. The last drawing illustrates the structures passing from the abdominal cavity into the thigh via the gap posterior to the inguinal ligament.

The lowest fibers of the EAO aponeurosis skim past the anterior superior iliac spine, attach to it, then continue toward the pubic tubercle. As they approach it, these lowest aponeurotic fibers fan out to attach to the pecten pubis (i.e., pubic part of iliopectineal line) and to the pubic tubercle. Thus, the aponeurosis has a free lower edge that runs from the anterior superior iliac spine to the pecten pubis. There is a peculiar nomenclature associated with these lowest fibers of the external abdominal oblique aponeurosis. They are said to constitute an **inguinal ligament** that runs from the anterior superior iliac spine to the pubic tubercle, and it is said that this inguinal ligament sends an expansion to the pecten pubis, which expansion is called the **lacunar ligament**.

The lateral third of the inguinal ligament has a fibrous connection to the fascia of the iliacus muscle which lies behind it. This creates a thickening in the iliacus fascia called the **iliopectineal arch**. The medial third of the inguinal ligament is partly rolled under itself so that it presents superiorly what surgeons call the “shelving edge” of the inguinal ligament, a kind of floor to the inguinal canal. The fascia lata of the thigh (see Chapter 10) is attached to the external surface of the inguinal ligament along its entire course, a few millimeters above its lower edge.

The EAO aponeurotic fibers immediately superior to those that constitute the inguinal ligament insert onto the front of the body of the pubis. As they pass toward their insertion, these fibers diverge from the ligament, which is going to the pubic tubercle. The cause of such divergence is the presence in embryonic life of the gubernaculum passing through the EAO layer. As a result of the divergence, a triangular gap is formed in the EAO aponeurosis. The base of the gap is formed by the crest of the pubis; the apex points superolaterally. Names are given to the parts of the aponeurosis bordering the triangular gap. Those tendinous fibers that form the superior border of the gap are said to compose a **superior (or medial) crus** of the aponeurosis. The medial half of the inguinal ligament forms the inferior border of the gap and is often called the **inferior (or lateral) crus** of the aponeurosis.

The gubernaculum is a small structure and it only passes through that part of the triangular gap that is immediately superolateral to the pubic tubercle. Connective tissue **intercrural fibers** bridge across the apex of the gap lateral to this site. Thus, the actual hole in the external abdominal oblique aponeurosis is confined to a region just superolateral to the pubic tubercle. This hole is the **superficial inguinal ring**.

Fibers of the EAO aponeurosis just above those that form the superior crus cross the midline (anterior to the rectus abdominis) to insert onto the pecten pubis of the opposite side. Near their insertion they are said to compose the **reflected inguinal ligament**, because it appears (quite incorrectly) that they represent fibers of the opposite side's lacunar ligament that have been reflected (like light rays) upward and medially. The fibers of the reflected ligament provide a reinforcement to the anterior abdominal wall behind the superficial inguinal ring.

All the remaining fibers of the EAO aponeurosis do not reach an insertion on bone. They cross anterior to the rectus abdominis to reach the midline between the two rectus muscles, where they interweave in a most complex manner with abdominal aponeuroses of the opposite side. This line of aponeurotic interweaving located between the right and left rectus abdominis is the **linea alba**.

Lumbar Triangle. Since the origin of the latissimus dorsi from the iliac crest is separated from by a few centimeters from the insertion of the external abdominal oblique, there occurs a small triangular space, whose base is the iliac crest, between the anterior edge of latissimus and the posterior edge of external abdominal oblique. This is called the **lumbar triangle**, and it represents a weakness in the lateral abdominal wall that is a potential, albeit rare, site of hernia.

Internal Abdominal Oblique, IAO (see Fig. 5-7*B*). That abdominal wall muscle serially homologous to the internal intercostal muscles is the internal abdominal oblique. The bulk of its fibers arise fleshily from the anterior three fifths of the iliac crest, as far back as the insertion of the quadratus lumborum. A small portion of the muscle continues the origin superiorly for a short distance along the fascia on the back surface of the quadratus lumborum (which fascia is called the anterior layer of the thoracolumbar fascia). Anterior to the ilium, additional fibers of the internal abdominal oblique actually arise from the iliopectineal arch and inner surface of the inguinal ligament along its lateral half.

The most posterior fibers of the IAO (those from the anterior layer of the thoracolumbar fascia and from the back part of the iliac crest) course upward and laterally to insert on the inferior edges of the 12th, 11th, and 10th ribs. Fibers from the remainder of the iliac crest miss the rib cage. In particular, muscle fibers just in front of those that go to the 10th rib course obliquely upward and anteriorly, toward the general direction of the xiphoid process. Fibers arising progressively closer to the anterior superior iliac spine have directions that are progressively more transverse, so that by the time one encounters fibers coming from this iliac spine, they are seen to run almost directly horizontally. Finally, the fibers arising from the inguinal ligament actually follow a somewhat inferomedial course toward the body of the pubis. All of the muscle fibers that miss insertion onto ribs give rise to a broad flat tendon--the **aponeurosis of the internal abdominal oblique**--as they near the lateral edge of the rectus abdominis.

The IAO aponeurosis does peculiar things. The part superior to the umbilicus splits around the rectus abdominis to reach the linea alba, where the two leaflets rejoin and interweave with aponeurotic fibers from the other side. At some point just below the umbilicus, the IAO aponeurosis declines to split, and instead passes entirely anterior to the rectus abdominis. The aponeurotic fibers deriving from that portion of the muscle arising furthest medially on the inguinal ligament do not even cross the rectus to reach the linea alba. Instead, they turn downward to insert on the front of the pubic body and, crossing behind the tubercle, reach the pecten pubis.

Because the internal abdominal oblique does not arise from the whole length of the inguinal ligament, the free inferior edge of the muscle forms an arc superior to the ligament and just medial to its midpoint. The **"inframuscular gap"** below the arc is a potential weak spot in the anterior abdominal wall.

The IAO does have a hole in it for passage of the gubernaculum. This hole is located between muscle fibers of the arching inferior edge, about halfway between the midpoint of the inguinal ligament and the pubic tubercle. This hole should be called the “middle inguinal ring”, but it isn't.

Transversus Abdominis, TA (see Fig. 5-7*C*). The deepest of the three flat abdominal muscles is the transversus abdominis. It arises from the inner surfaces of the lower six costal cartilages, interdigitating with the origin of the diaphragm. Inferior to the 12th costal cartilage the origin of the transversus abdominis is by means of an aponeurosis that passes posterior to the quadratus lumborum to reach the transverse processes of the lumbar vertebrae (see Fig. 5-4). This aponeurosis is often called the anterior layer of the thoracolumbar fascia. Further inferiorly, muscle fibers of the TA arise from the anterior half of the iliac crest and from the lateral third of the inguinal ligament.

The muscle fibers arising from costal cartilages, from the aponeurosis of origin, and from the iliac crest course transversely around the abdomen toward its anterior surface. As they near the edge of the rectus abdominis, they become tendinous and form the flat **aponeurosis of insertion of the transversus abdominis**. Superior to a point about halfway between the umbilicus and pubic symphysis, the TA aponeurosis of insertion passes deep to the rectus abdominis to reach the anterior midline where it interweaves with aponeuroses of the opposite side in the linea alba. Below this point the aponeurosis of the transversus passes superficial to the rectus abdominis to reach the linea alba. This shift from *behind* to *in front* of the rectus abdominis causes the part that goes behind to have a free lower edge. This edge is called the **arcuate line**.

The fibers of the TA that arise from the inguinal ligament run in a progressively more downward course toward the pubis, just as do the overlying fibers of the internal abdominal oblique. They also insert as do the lowest fibers of the internal oblique, i.e,. by a downward curving tendon that reaches the body of the pubis and, about 10% of the time, also passing behind its tubercle to reach the pecten pubis. It is virtually impossible to separate the lower fibers of the TA from those of the IAO because of their very similar courses.

When both the TA and IAO aponeuroses have an insertion into the pecten pubis (about 3% of the time), the downward curving aponeurotic fibers with this insertion fuse to form what is called a **conjoint tendon**. If only the TA aponeurosis inserts here (7% of the time), this part of its aponeurosis is said to form a **falx inguinalis**. Somewhat more frequently there is a flimsy falx inguinalis that surgeons call “good stuff” because they can suture things to it.

Because the TA arises from even less of the inguinal ligament than does the IAO, the arc formed by the lower edge of the TA is even longer than that of the IAO, and it has an even larger "inframuscular gap." One consequence of this is that the lower edge of the TA lies superior to the path of the gubernaculum and there is no hole in the muscle for its passage. A second consequence is that in the region of the inframuscular gap of the IAO, the musculofascial abdominal wall is composed solely of the aponeurosis of the EAO and the transversalis fascia (see Fig. 5-7*D*). (The latter gains an attachment along the whole length of the inguinal ligament.) Finally, the TA does not exist in the region anterior to the deep inguinal ring and, obviously, cannot provide support to the abdominal wall at this site.

The Rectus Sheath. From what has just been described, it should be clear the rectus abdominis muscle is not only enveloped by its own epimysium, but also has various aponeurotic layers anterior and posterior to it. The muscle is said to be enclosed by an aponeurotic sheath called the **rectus sheath**. The anterior layer of the rectus sheath varies in composition from the xiphoid down to the pubis. Its upper half is composed of the EAO aponeurosis fused to the anterior lamina of the IAO aponeurosis. Below the umbilicus the entire IAO aponeurosis passes into the anterior layer of the rectus sheath, and below the arcuate line so does the TA aponeurosis. Obviously, the posterior layer of the rectus sheath must vary in composition from xiphoid to pubis. Above the umbilicus, the posterior layer of the rectus sheath is composed of TA aponeurosis and the posterior lamina of the IAO aponeurosis. Below the umbilicus, the IAO aponeurosis leaves the posterior layer of the rectus sheath, and a little lower down so does the TA aponeurosis. Thus, below the arcuate line there is no posterior layer of the rectus sheath; here, only the transversalis fascia abuts the epimysium of the rectus abdominis.

Inguinal Canal in the Adult. The situation that has been described, of a narrow inguinal canal composed of deep, "middle," and superficial rings through which only a fibromuscular gubernaculum passes, is essentially the state found in adult females. Only a few changes occur. First, the gubernaculum of the ovary will be broken into two parts by the development of the uterus. The part of the gubernaculum that runs from the ovary to the uterus becomes the **utero-ovarian ligament**; its final location is in the pelvis along with the ovary. The part that runs from the uterus through the inguinal canal to the skin of the labium majus becomes the **round ligament of the uterus**. The round ligament, while maintaining a fairly fibrous nature from the uterus to the deep ring, becomes increasingly fatty in the inguinal canal and emerges from it as a structure that is hard to distinguish from the subcutaneous tissue. In its course through the inguinal canal, the round ligament is accompanied by an artery and vein (of the round ligament) and a branch of the genitofemoral nerve (see further on). None of these structures are sufficiently large to place demands on the canal to enlarge.

In the male, during the seventh month of fetal development, the gubernaculum testis contracts and pulls the testis from its retroperitoneal position downward and forward around the side of the peritoneal sac toward the deep inguinal ring. Having a second attachment to the peritoneum, the gubernaculum also pulls out a little tubular pocket of parietal peritoneum. This tube of parietal peritoneum is called the **processus vaginalis**. As the testis and processus vaginalis approach the deep ring, they meet and adhere. Together they are pulled against the deep ring. This ring is only large enough to pass the gubernaculum. Thus, the testis and processus vaginalis must push out the transversalis fascia around the deep ring in front of them as they are inexorably pulled toward the developing scrotum. They become enveloped in a tube of transversalis fascia; the original deep ring is at the apex of this tube, where it is pierced by the gubernaculum. However, the term "deep ring" is now assigned to the site where the tubular sleeve of transversalis fascia merges with the main sheet of this fascia. The new deep ring is obviously of larger diameter than the original.

The gubernaculum continues its efforts to pull the testis and processus vaginalis toward the scrotum. These structures, now surrounded by a tube of transversalis fascia, pass under the arc of the TA and then encounter the "middle" inguinal ring, which, you will recall, is a hole in the IAO. Unable to squeeze through the "middle" ring, the testis, processus vaginalis, and sleeve of transversalis fascia push out a muscular tube in front of them. Finally, the testis, processus vaginalis, transversalis fascia sleeve, and IAO sleeve are pulled against the superficial ring, which is the hole in the EAO aponeurosis. Aponeurotic connective tissue (peritendineum) is pushed out as a third sleeve around all the others as the gubernaculum eventually succeeds in dragging the testis and processus vaginalis over the pubic crest into the scrotum.

In the course of testicular descent, three new, larger inguinal rings have been formed. Each represents the site where a sleeve of abdominal wall tissue merges with the layer of the wall from which it was stretched (Fig. 5-8). Through each of the new large rings pass the ductus deferens, the arteries, veins, lymphatics, and nerves of the testis, and the processus vaginalis. In addition, through the new "middle" ring passes the transversalis fascia sleeve, and through the new superficial ring passes this sleeve and the surrounding IAO sleeve (see Fig. 5-8).

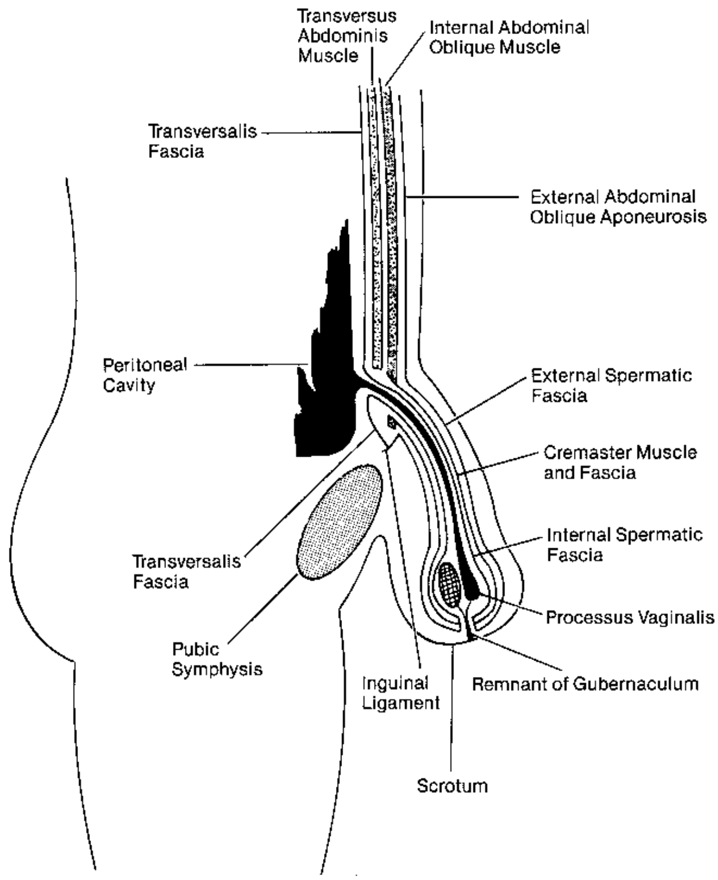


Figure 5-8. Schematic sagittal section through an inguinal canal and spermatic cord of a fetus. The drawing pretends that a single sagittal section could traverse the entire inguinal canal, which in reality follows an oblique path from deep and lateral to superficial and medial.

The sleeves themselves get new names (see Fig. 5-8). The transversalis fascia sleeve is called the **internal spermatic fascia**. The IAO sleeve is called **cremaster muscle**, and the epimysium of the muscle is called **cremaster fascia**. The EAO sleeve is called the **external spermatic fascia**. Beyond the new superficial ring, the entire three-sleeved structure, and the ducts and vessels within it, is called the **spermatic cord**. The spermatic cord lies just deep to the subcutaneous layer of the abdomen and runs down into the scrotum, to lie deep to the **tunica dartos** (superficial fascia) of the scrotum. A relict of the gubernaculum may persist as a fibrous cord connecting the lower pole of the testis and processus vaginalis to the skin of the scrotum. In theory, this relict passes through the three original inguinal rings.

Once descent of the testis has been achieved, that part of the processus vaginalis not in actual contact with the testis degenerates. No longer can one detect its site of origin from the parietal peritoneum. In the scrotum there remains a small sac of peritoneum that adheres to the front and sides of the testis; it is called the **tunica vaginalis testis**. The wall of the tunica that contacts the testis is called the **visceral layer** of the tunica vaginalis. The wall that abuts the internal spermatic fascia is called the

parietal layer of the tunica vaginalis. Being displaced peritoneum, the sac is lined by serous mesothelium that secretes a thin layer of fluid so that the testis may move within the scrotum without friction. The posterior surface of the testis is not covered by visceral tunica vaginalis, and it is along this surface, near the superior pole, that the vessels, nerves, and lymphatics enter and leave the testis. At the same site the ductuli efferentes exit to join the head of the epididymis.

HERNIAS PRESENTING NEAR THE GROIN

The fact that there is a long hole in the muscles and fascia of the anterior abdominal wall, even though the hole is obliquely disposed, offers an opportunity for abdominal contents (e.g., bowel or mesentery) to pass through it. If abdominal contents, pushing parietal peritoneum in front of them, squeeze through the deep ring to travel down the inguinal canal and emerge beneath the skin at the site of the superficial ring, this is called an **indirect inguinal hernia**. In females, the herniated structures will lie alongside the round ligament of the uterus and actually contact superficial fascia once they are beyond the superficial ring. In the male, they will lie alongside the ductus deferens, and may continue within the sleeve of internal spermatic fascia down into the scrotum.

We have also learned that there is another weakness in the anterior abdominal wall not causally related to the inguinal canal. The inframuscular gaps of the IAO and TA create a space where the anterior abdominal wall is thinner than "normal." Fortunately, there exists a mechanism to compensate for this deficiency. When the lowest fibers of the IAO contract, they straighten out the arc formed by their lower edge, reducing the size of the inframuscular gap. It is reported that these lowest fibers of the internal abdominal oblique are continuously active during erect posture so as to obliterate the inframuscular gap. Certainly they are active on exertion. However, as one becomes older, and one's muscles and fascia become weaker, it is possible for a loop of bowel, pushing parietal peritoneum and transversalis fascia before it, to pass through the inframuscular gap and come up against the EAO aponeurosis. The herniated structures may then pass inferomedially, deep to the EAO aponeurosis, until the superficial inguinal ring is encountered. If the herniated structures pass through the superficial ring, the presenting picture will be similar to that of an indirect inguinal hernia, though, in the male, descent into the scrotum is less likely. Nonetheless, this kind of hernia is distinct and is called a **direct inguinal hernia** to differentiate it from one that uses the deep ring and inguinal canal as a passageway[15].

Clinical texts describe a variety of ways in which direct inguinal hernias may present differently than indirect hernias. One that reinforces our knowledge of anatomy is based on the realization that only indirect hernias pass through the deep ring. Often when a patient lies on his or her back, the herniated structures fall back into the abdominal cavity. They can be made to herniate again if the patient strains. If this voluntary reherniation can be prevented by the examiner pressing his or her palm over the site of the deep ring, then the hernia can be diagnosed as being indirect in nature.

There is yet a third kind of hernia that may present as a mass near the groin. There is a considerable space between the inguinal ligament and the bony pelvis (see Fig. 5-7*D*). The lateral half of this "retroligamentous" space is filled in with the iliacus and

[15] The submuscular gap of the internal abdominal oblique lies in a region that surgeons call Hesselbach's triangle, whose three sides are (a) inferiorly, the inguinal ligament, (b) superolaterally, the inferior epigastric artery, and (c) medially, the lateral edge of the rectus abdominis.

psoas major muscles as they are leaving the abdominal cavity to enter the lower limb. Medially, this space is filled by the lacunar ligament, the reflected ligament, and some thickened transversalis fascia. Between these last-named structures and the iliopsoas muscle are the femoral artery (inferior to a point halfway between the anterior superior iliac spine and the pubic symphysis), the femoral vein (medial to the artery), and a fat-filled channel containing lymphatics (between the femoral vein and the thickened transversalis fascia.. The fat-filled channel is called the **femoral ring**, and it represents a site of weakness behind the inguinal ligament. A loop of bowel (pushing peritoneum in front of it) may pass through the femoral ring into the thigh deep to the fascia lata. Such a **femoral hernia** reaches the superficial fascia by passing through the saphenous opening of the fascia lata (see Chapter 10).

FREQUENCY OF HERNIAS

The frequencies of indirect inguinal hernias, direct inguinal hernias, and femoral hernias are highly dependent on sex and age. This topic has been reviewed by Rutkow (Surg. Clinics North Amer., 78:941-951, 1998). While statistics vary from study to study, the following table is not far off the mark in presenting the expected distribution of 100 hernias of the groin by sex.

TABLE 5 -1
EXPECTED DISTRIBUTION OF 100 HERNIAS PRESENTING IN THE GROIN

	Inguinal	**Femoral**
	58 indirect	
MALES	29 direct	
	87 total	2
	6.6 indirect	
FEMALES	.4 direct	
	7 total	4

Not reflected in these numbers is the fact that the ratio of indirect to direct inguinal hernias in males is influenced by age, there being a much higher proportion of indirect inguinal hernias in young boys because (a) so many inguinal hernias in young males are due to partial persistence of processus vaginalis, and (b) as one becomes older musculofascial weakness predisposes to direct inguinal hernias. Some persons believe that indirect inguinal hernias in females can be traced to the abortive development of a processus vaginalis. The abortive processus vaginalis of females is called the **canal of Nuck**. The great rarity of direct inguinal hernias in women may be related to behavioral differences (i.e., less tendency for older women to engage in physically strenuous activities that promote hernias), or it may be that women actually have smaller inframuscular gaps.

Femoral hernias are more common in women than in men. This seems to be due to the fact that the distance between the anterior superior iliac spine and pubic tubercle, in proportion to overall body size, is greater in women than in men. In other words, the iliopsoas and femoral vasculature do a poorer job of filling up the retroligamentous space in women than in men, with the result that the femoral ring is absolutely wider.

Subcutaneous Layer of the Anterolateral Abdominal Wall

The subcutaneous layer of the anterolateral abdominal wall has an unusual specialization. Below a transverse plane through the umbilicus, the deepest part of this layer is somewhat fibrous, forming a dissectible sheet called **Scarpa's fascia**. Scarpa's fascia ends posteriorly by attaching to the posterior layer of the thoracolumbar fascia. It ends inferiorly by attaching to the iliac crest and to the deep fascia of the thigh just below the inguinal ligament. Scarpa's fascia is overlain by, and bound to, the more typical loose fatty connective tissue that characterizes subcutaneous tissue elsewhere in the body. In the lower half of the anterolateral abdominal wall, this loose fatty layer is called **Camper's fascia**.

NERVES OF THE ABDOMINAL WALL

All of the skin and most of the muscles of the abdominal wall are innervated by the intercostal nerves of the short intercostal spaces (7-11), the subcostal nerve, and the ventral ramus of L1. Only the quadratus lumborum and iliopsoas are innervated by other nerves.

Before one summarizes the distribution of nerves to the abdominal wall, some preliminary information on the subcostal nerve and the upper four lumbar ventral rami must be presented.

Lumbar Plexus (Fig. 5-9; see Fig. 10-6)

Since the psoas major occupies the paravertebral space between the bottom of T12 and the top of L5, the ventral rami of the 12th thoracic-4th lumbar spinal nerves enter the mass of the muscle (near its back surface) immediately after leaving their intervertebral foramina. Within the psoas major, the ventral ramus of T12 often gives off a small branch that joins L1. The rest of the 12th thoracic ventral ramus then continues out of the psoas as the subcostal nerve. Also within the psoas major the ventral rami of the upper four lumbar nerves branch into several smaller bundles that join one another in rather complex manner that is called the lumbar plexus (see Fig. 10-6). What emerges from the psoas (see Fig. 5-9) are the recombinant products of these joinings:

1. Iliohypogastric and ilioinguinal nerves, carrying fibers of L1 and, sometimes, T12;
2. Genitofemoral nerve, carrying fibers of L1 and L2;
3. Lateral femoral cutaneous nerve, carrying fibers of L2 and L3;
4. Femoral nerve, carrying fibers of L2, L3, and L4;
5. Obturator nerve, carrying fibers of L2, L3, and L4;
6. Direct branches from L1-L4 to the quadratus lumborum;
   and occasionally
7. Accessory obturator nerve, carrying fibers from L3 and L4.

Of the nerves that exit from the psoas major, one (the subcostal) emerges from the muscle in the thoracic cavity, i.e., above the origin of the diaphragm, three (the iliohypogastric, ilioinguinal, and genitofemoral) emerge from the muscle in the abdomen above the iliac crest, and three (the lateral femoral cutaneous, femoral, and obturator) emerge from the muscle into the abdominal cavity below the iliac crest (i.e., into the false pelvis). The subcostal, iliohypogastric, ilioinguinal, lateral femoral cutaneous, and femoral nerves come out the lateral surface of the psoas major at its posterior edge. The genitofemoral nerve comes out the muscle's anterior surface. The obturator nerve emerges from its medial surface near its posterior edge. When an accessory obturator nerve exists, it exits the psoas very near the obturator nerve.

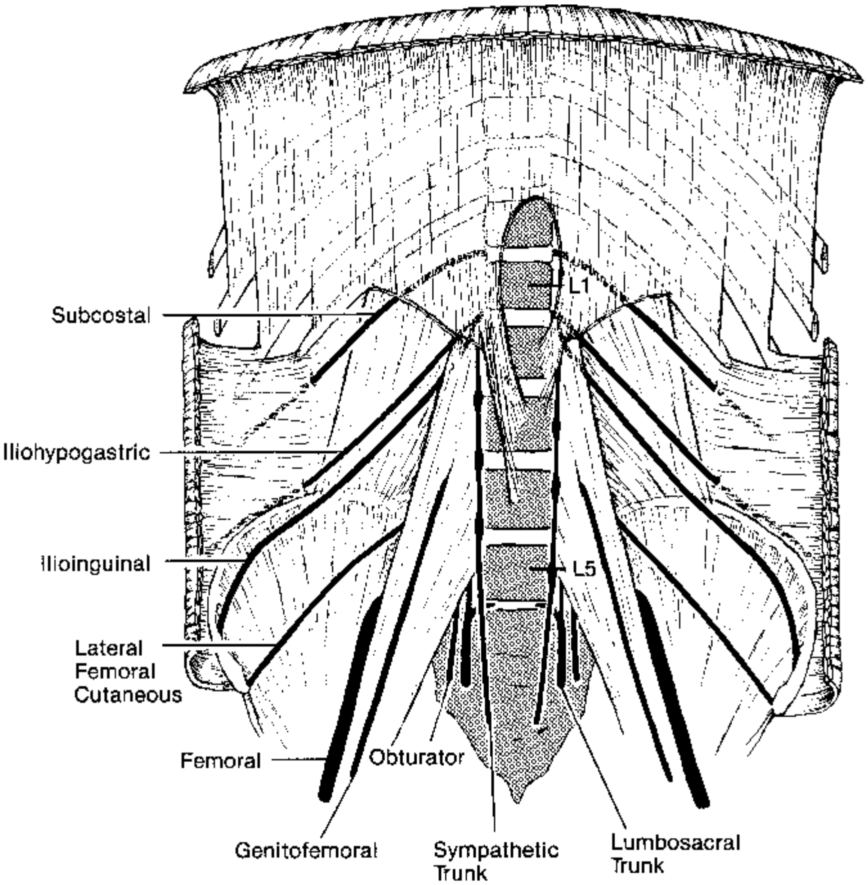


Figure 5–9. Nerves on the posterior abdominal wall.

The lateral femoral cutaneous, femoral, obturator, and accessory obturator nerves are branches of the lumbar plexus destined for lower limb structures. Although the intra-abdominal courses of these nerves is described below, their distribution to the lower limb will be considered in Chapter 10.

Lumbosacral Trunk (see Fig. 5-9)

Emerging from the psoas major just posterior to the obturator nerve is a communicating branch running from the 4th lumbar ventral ramus down to the 5th lumbar ventral ramus (which itself comes into view medial to the psoas, but inferior to its origin, from the intervertebral foramen between L5 and S1). The bundle produced by their joining is called the **lumbosacral trunk**. It immediately leaves the abdominal cavity by descending across the sacral ala into the pelvis.

Innervation of the Skin, Trilaminar Muscle Block and Rectus Abdominis--Intercostal, Subcostal, Iliohypogastric, and Ilioinguinal Nerves

Only the long intercostal spaces (1-6) reach the sternal margin. However, although the short intercostal spaces (7-11) fail to reach the anterior midline by a fair amount, the body wall doesn't. The abdominal muscles continue the body wall beyond the limits of the short intercostal spaces. At the medial ends of the short intercostal spaces, the intercostal nerves leave the thorax to enter the abdominal wall by piercing the diaphragm. These nerves stay on a plane between the innermost and internal muscle layers, which layers are represented by the TA and IAO, respectively. The 7th-11th intercostal nerves then continue toward the anterior midline supplying the TA, IAO and EAO along the way. When the nerves reach the rectus abdominis they pierce its sheath to supply this muscle.

Like all the other intercostal nerves, the 7th-11th terminate near the anterior midline by becoming anterior cutaneous nerves. It is simply that the anterior cutaneous branches of the first six intercostal nerves emerge from the anterior ends of intercostal spaces, whereas the anterior cutaneous branches of the 7th-11th intercostal nerves enter the subcutaneous tissue by piercing the anterior layer of the rectus sheath. **For reference, it is useful to keep in mind that the abdominal skin over the xiphoid process is innervated by intercostal nerve 7, and the skin around the umbilicus by intercostal nerve 10**. The lateral cutaneous branches of these same intercostal nerves also contribute to the innervation of the skin of the abdominal wall.

Only the inferior parts of the muscles and skin of the abdominal wall are innervated by the subcostal nerve and ventral ramus of L1. The **subcostal nerve** exits the lateral surface of the psoas major and finds itself on the anterior surface of the quadratus lumborum just below the 12th rib, but superior to the lateral arcuate ligament (see Fig. 5-9). The nerve travels inferolaterally (paralleling the 12th rib) behind the lateral arcuate ligament to enter the abdominal cavity. When it reaches the lateral border of the quadratus lumborum, the subcostal nerve passes onto the aponeurosis of origin of the TA, which it pierces to enter the plane between the TA and IAO. From this point on, the subcostal nerve behaves as do the higher intercostal nerves, with the exception that its lateral cutaneous nerve also sends a branch inferiorly to the skin of the hip over the tensor fascias latae.

Whereas the subcostal nerve is pretty much like the intercostal nerves above it, there are several unique characteristics of the 1st lumbar ventral ramus. First, it usually (though not always) gives off its collateral branch while still within the psoas major, thus well before it enters the plane between the two inner layers of the trilaminar muscle block. Regardless of where the branch point actually occurs, anatomists have decided to give separate names to the main trunk and the collateral branch. The former is called the **iliohypogastric nerve**; the latter is called the **ilioinguinal nerve**. The iliohypogastric nerve emerges from the lateral surface of the psoas major onto the anterior surface of the quadratus lumborum below the lateral arcuate ligament (see Fig. 5-9). It crosses the quadratus lumborum inferolaterally, reaching its lateral border *just above the iliac cres*t, where it then passes onto the inner surface of the TA. At this point the iliohypogastric nerve pierces the TA to enter the plane between it and the IAO. As it winds around toward the front of the abdomen, the nerve gives off its lateral cutaneous branch, which descends to the skin of the hip over the gluteus medius. When the iliohypogastric reaches the front of the abdominal wall it does something no higher nerve does. Since the rectus abdominis receives no cells from the 1st lumbar dermomyotome, there is no need for the iliohypogastric nerve to continue between the transversus and internal oblique to reach the rectus. Thus, the nerve pierces the IAO muscle to enter the plane between it and the EAO aponeurosis. What we have here is a long anterior cutaneous branch that will run deep to the EAO aponeurosis until near the midline above the pubis, where it then pierces the aponeurosis to enter the subcutaneous tissue and skin. Thus, **the skin just superior to the pubic symphysis is innervated by L1**.

When the ilioinguinal nerve is given off in the psoas major, it exits the lateral surface of the muscle just below the iliohypogastric nerve. Again, this path carries it onto the anterior surface of the quadratus lumborum, where the ilioinguinal nerve runs parallel to the iliohypogastric nerve (see Fig. 5-9). The ilioinguinal nerve runs on the quadratus lumborum toward the iliac crest and then *crosses the crest* onto the surface of the iliacus. The nerve runs on the iliacus toward the anterior superior iliac spine. When it passes the spine, the ilioinguinal nerve pierces the TA (which arises here) and enters the plane between the two inner abdominal muscles. About one third of the time the ilioinguinal nerve simply expends itself supplying the lower fibers of TA and IAO. However, in the majority of cases, the ilioinguinal nerve (like its main trunk partner) pierces the IAO muscle to assume a position between it and EAO aponeurosis. This now represents a cutaneous branch of a collateral branch. It runs toward the superficial inguinal ring and passes through it on the anterolateral aspect of the spermatic cord or round ligament. In the female, the ilioinguinal nerve is cutaneous to the mons pubis, anterior regions of the labia, and adjacent part of the inner thigh. In the male, it pierces the external spermatic fascia and is cutaneous to the root of the penis, anterior skin of scrotum, and the adjacent part of the inner thigh.

The cutaneous part of the ilioinguinal nerve is susceptible to injury during careless surgical repair of inguinal hernia. Severing this nerve leads to an unpleasant numbness over the skin it normally supplies.

Innervation of the Cremaster--Genitofemoral Nerve

The cremaster muscle represents stretched-out fibers of the internal abdominal oblique. It is innervated by the genitofemoral nerve. This nerve passes through the psoas major to emerge onto its anterior surface (see Fig. 5-9), on which the nerve runs toward the inguinal ligament. At the inguinal ligament, the genitofemoral nerve divides into its **genital and femoral branches**. The genital branch enters the deep inguinal ring for supply of the cremaster muscle. The femoral branch passes behind the inguinal ligament, on the anterior surface of the femoral artery (see Fig. 5-7), to enter the thigh. Here it pierces the fascia lata to supply the skin and superficial fascia just below the medial half of the inguinal ligament.

The genital branch of the genitofemoral nerve may carry some or all of the cutaneous fibers that normally run with the ilioinguinal nerve. If it does, these fibers emerge from the superficial inguinal ring posterior to the spermatic cord.

The skin on the medial part of the upper thigh is innervated by either the ilioinguinal or genitofemoral nerves, predominantly L1. The cremaster muscle is innervated by the genitofemoral nerve, L1,2. In males, a light scratch applied to the inner aspect of the upper thigh normally produces elevation of the testis by the cremaster muscle. This is called the **cremaster reflex** and is considered to be a test for integrity of the L1 segment of the spinal cord.

Innervation of the Quadratus Lumborum--Direct Branches of the Lumbar Ventral Rami

It has already been mentioned that the quadratus lumborum is derived from some cells of the 1st lumbar hypaxial dermomyotome and those few cells of hypaxial dermomyotomes L2-L4 that do not migrate into the lower limb. It is innervated by small branches of the upper four lumbar ventral rami given off while they are within the psoas.

Innervation of the Psoas Major and Iliacus--Direct Branches of L2-L4 Ventral Rami and the Femoral Nerve

The psoas major and iliacus are muscles of the lower limb. Psoas major is innervated by small branches given off from the contributions of the 2nd-4th lumbar ventral rami to the femoral nerve. The **femoral nerve** exits from the lateral surface of the psoas major an inch or two below the iliac crest (see Fig. 5-9). It runs in the groove between the psoas and iliacus, supplying the latter, and then passes behind the inguinal ligament into the thigh with these two muscles (see Fig. 5-7*D*).

Two Nerves That Run in the Abdominal Cavity But Don't Innervate Anything in It--Lateral Femoral Cutaneous and Obturator Nerves

The **lateral femoral cutaneous nerve** emerges from the lateral surface of the psoas major just *below the iliac crest* (thus, between the ilioinguinal and femoral nerves) (see Fig. 5-9). It runs toward the anterior superior iliac spine on the inner surface of the iliacus, following a course that is below that of the ilioinguinal nerve. The lateral femoral cutaneous nerve exits the abdominal cavity with the iliacus, just behind the inguinal ligament and very near that ligament's origin from the anterior superior iliac spine. The nerve is thus brought into the thigh for innervation of the skin on its lateral surface.

The **obturator nerve** emerges from the medial surface of the psoas major opposite the 5th lumbar vertebra. It descends and leaves the abdominal cavity by crossing the pelvic brim to enter the true pelvis. It then runs on the surface of the obturator internus toward the obturator groove that lies on the undersurface of the superior pubic ramus. The nerve enters the groove to reach the thigh.

The **accessory obturator nerve**, if it occurs, exits the psoas just anterior the obturator nerve, but does not enter the true pelvis. Instead, it stays on the medial surface of the psoas and travels with it behind the inguinal ligament to enter the thigh. The accessory obturator nerve, when it exists, is for supply of the pectineus.

ARTERIES OF THE ABDOMINAL WALL

The reader will recall that the thoracic wall is supplied by posterior intercostal arteries (mainly from the aorta) and anterior intercostal arteries (from the internal thoracic and musculophrenic arteries). The arterial supply of the abdominal wall follows a pattern quite similar to that of the thoracic wall. Some arteries arise from the abdominal aorta at the back, and others arise from more anterior vessels. The abdominal aorta (Fig. 5-10) will be described in detail later in this chapter, but a few basic facts must be mentioned at this time. The aorta enters the abdominal cavity by passing through the aortic hiatus of the diaphragm. The vessel then descends along the left anterior surface of the lumbar vertebral column

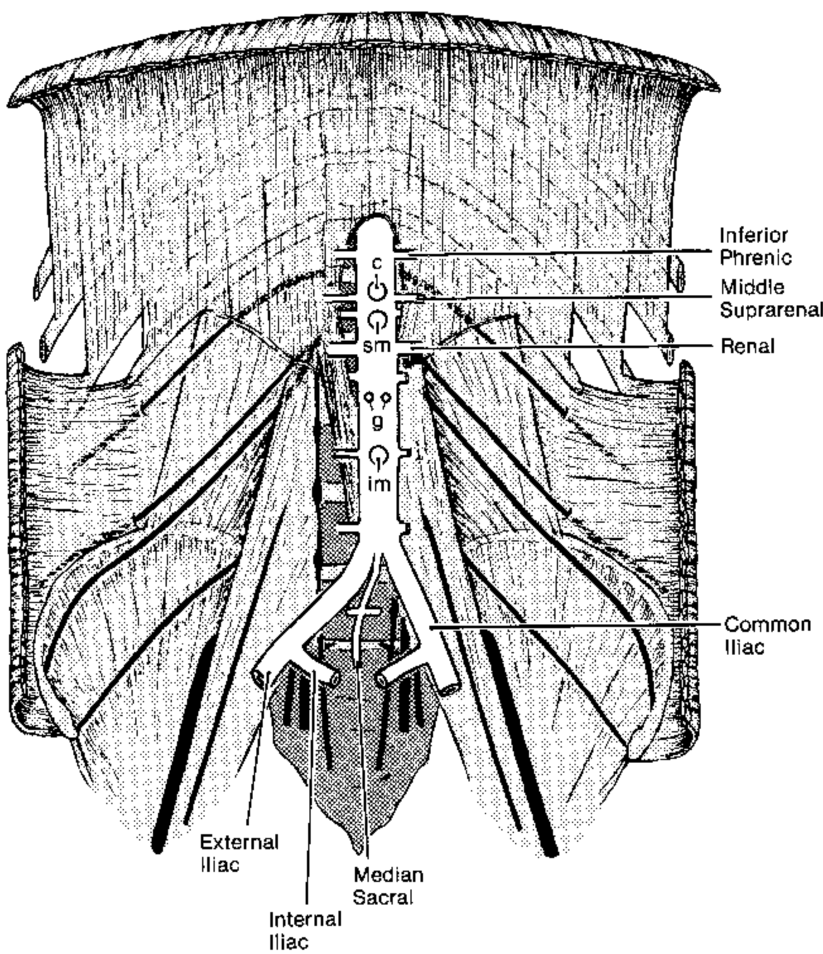


Figure 5-10. The position of the abdominal aorta (in white) and the sites of origin of its branches. c = celiac artery, sm = superior mesenteric artery, g = gonadal arteries, im = inferior mesenteric artery. Unlabelled branches are the lumbar arteries.

until the lower half of L4, where it bifurcates into right and left common iliac arteries. Each of these gives off an internal iliac artery that passes into the pelvis, and then itself continues as the external iliac artery toward the retroligamentous gap a bit medial to the midpoint of the inguinal ligament (see Fig. 5-7*D*). The external iliac artery passes out of the abdominal cavity into the thigh and, once in the thigh, changes its name to the common femoral artery.

Arteries Supplying the Diaphragm--Inferior Phrenic

The major arterial supply to the diaphragm comes from vessels that lie in the thorax: the musculophrenic and pericardiacophrenic branches of the internal thoracic artery, and the superior phrenic branches of the thoracic aorta. However, as soon as it is within the abdominal cavity, the aorta gives off right and left inferior phrenic arteries. These pass laterally across their respective diaphragmatic crura and then branch to share in the supply of the posterior regions of the diaphragm.

Arteries Supplying the Posterior and Lateral Abdominal Walls--Posterior Intercostals 10 and 11, Subcostal, and Lumbar

The two posterior intercostal arteries of the open intercostal spaces (10 and 11) and the subcostal artery are given off from the thoracic aorta and contribute substantially to the supply of the muscles and skin of the posterior and lateral abdominal walls. They anastomose with arteries that supply the anterior abdominal wall.

In the abdomen, the aorta gives off four paired **lumbar arteries**. These lumbar arteries are essentially posterior intercostal arteries below the ribs. From its origin, each lumbar artery turns posteriorly along the side of the corresponding lumbar body, medial to the psoas major. When it reaches the root of the lumbar transverse process, the vessel gives off a dorsal branch to the back muscles and skin. In turn, this dorsal branch sends a spinal artery through the intervertebral foramen into the vertebral canal. After giving off its dorsal branch, the lumbar artery turns laterally, runs behind the psoas, and (unlike the subcostal artery) also runs posterior to the quadratus lumborum. Upon reaching the lateral border of the quadratus, each lumbar artery pierces the TA to course in the plane between the inner two layers of the trilaminar block, supplying the muscles and skin of the posterior and lateral abdominal walls.

From the back of the aorta at the level of L4 comes a small vessel that descends in the midline on the anterior surface of L5 and, crossing the sacral promontory, enters the pelvis to continue to the coccyx. This is called the **median sacral artery**. As it lies on the surface of L5 it gives off 5th lumbar arteries that pass to the side to supply the psoas and iliacus. The intrapelvic part of the median sacral artery supplies the posterior wall of the pelvis, and will be described subsequently.

The dorsal branch of one of the lower intercostal, subcostal, or upper lumbar arteries gives rise to a particularly large artery for supply of the spinal cord. This is called the **artery of Adamkiewicz**. Surgical procedures that require cross clamping of the thoracic aorta such that blood flow to the lower intercostal, subcostal, and upper lumbar arteries is stopped, poses a significant risk of lower spinal cord ischemia and, consequently, paraplegia.

Arteries of the Anterior Abdominal Wall--Superior Epigastric, Musculophrenic, Inferior Epigastric, Deep Circumflex Iliac, Superficial Epigastric, and Superficial Circumflex Iliac

The anterior abdominal wall above the umbilicus is supplied by the **superior epigastric** and **musculophrenic** arteries. These are the terminal branches of the internal thoracic artery. It will be recalled that the musculophrenic anastomoses (through its anterior intercostal branches) with the posterior intercostal arteries of the short bounded intercostal spaces (7-9), but that it also sends medially directed branches into the anterior abdominal wall. These end by entering the rectus sheath to anastomose with the superior epigastric artery that lies between the posterior wall of the sheath and the epimysium of the rectus abdominis. The superior epigastric and musculophrenic arteries send cutaneous branches through the muscles to supply the skin.

The two deep arteries of the lower anterior abdominal wall are like upside down versions of the superior epigastric and musculophrenic. The **inferior epigastric** and **deep circumflex iliac** arteries are branches of the external iliac given off immediately before it leaves the abdominal cavity by passing behind the inguinal ligament.

The inferior epigastric artery passes in the anterior extraperitoneal space following a superomedial course toward the arcuate line. It raises a ridge of peritoneum called the **epigastric fold**. The path of the inferior epigastric artery takes it past the medial edge of the deep inguinal ring. Here, two branches are given off. One is a small artery that enters the inguinal canal through the deep ring. In the male, this is called the **cremasteric artery** and supplies tissues of the spermatic cord. In the female, it is called the **artery of the round ligament**. The other is a **pubic branch** that descends into the pelvis behind the superior pubic ramus.

The pubic branch of the inferior epigastric artery, or one of its branches that travels medially, can be injured during surgery to repair inguinal hernias. The resulting bleeding may be extensive. This has given rise to the name “arteria corona mortis” (arterial crown of death) for this artery and its branches.

Along its course toward the rectus abdominis, the inferior epigastric artery gives off branches to abdominal muscles. Lateral branches of the inferior epigastric artery enter the plane between the TA and IAO, supplying them and anastomosing with the lower two intercostal arteries and the subcostal artery.

When it achieves a position deep to the rectus abdominis the inferior epigastric artery pierces the transversalis fascia and passes anterior to the arcuate line to enter the rectus sheath between its posterior layer and the epimysium of the muscle. Within the rectus abdominis, the inferior and superior epigastric arteries anastomose. This anastomosis provides an important route for arterial blood to reach the lower limb if there is coarctation of the aortic arch.

The **deep circumflex iliac artery** follows a superolateral course in the anterior extraperitoneal space toward the anterior superior iliac spine. The vessel lies deep to the lateral half of the inguinal ligament and the muscles arising therefrom. Near the anterior superior iliac spine the deep circumflex iliac artery pierces the transversalis fascia and TA muscle to enter the plane between the two inner layers of abdominal muscle. It runs in this plane along the upper border of the iliac crest, giving branches up to abdominal muscles and down to muscles of the hip, including the iliacus. Its abdominal branches anastomose with the lumbar arteries and all the arteries feeding the lower half of the anterolateral abdominal wall.

Whereas the lumbar, lower intercostal, subcostal, musculophrenic, and superior epigastric arteries have significant cutaneous branches for the skin of the abdominal wall, the inferior epigastric and deep circumflex iliac arteries seem to have lost their large cutaneous branches. Thus, the skin overlying that part of the muscular abdominal wall supplied by these two arteries is in fact supplied by two other vessels designed solely for this purpose. These superficial arteries parallel their deeper counterparts, but within the subcutaneous layer. A **superficial epigastric artery** supplies the skin that the inferior epigastric should have supplied, and a **superficial circumflex iliac artery** supplies the skin that the deep circumflex iliac should have supplied. They do anastomose with small cutaneous twigs of their deeper partners, as well as with the cutaneous branches of the other arteries of the abdominal wall. Both superficial arteries are branches of the common femoral just below the inguinal ligament.

VEINS OF THE ABDOMINAL WALL AND THEIR ROLE IN ANASTOMOSES BETWEEN THE VENAE CAVAE

For every artery previously mentioned, there is an accompanying vein. The **lumbar veins** drain to the abdominal parts of the azygos and hemiazygos veins, which are called **ascending lumbar veins**. These ascending lumbar veins run vertically, crossing the bases of lumbar transverse processes deep to the psoas major. They have major anastomotic connections to the common iliac veins, the renal veins, and the inferior vena cava.

If the inferior vena cava is occluded, one route by which venous blood may flow back to the heart is via the ascending lumbar/azygos/hemiazygos channels. A second route would be the anastomoses between the musculophrenic and superior epigastric veins on the one hand, with the deep circumflex iliac and inferior epigastric veins on the other. Although the veins along these two routes will become dilated in cases when they must transfer blood from one vena cava to another, they lie so deeply that such dilatation is imperceptible on physical examination. This is not the case for the third route about to be discussed.

The two superficial arteries of the lower abdominal wall are accompanied by corresponding veins. These drain to the great saphenous vein just before it terminates in the femoral vein (see Chapter 10). The superficial epigastric and superficial circumflex iliac veins communicate extensively with each other and with superficial veins above the umbilicus. The latter drain primarily to the lateral thoracic vein (but also to intercostal and the internal thoracic veins). Often the superficial veins on the front of the trunk are simply referred to as **thoraco-epigastric veins**..

This great network provides a third route of venous flow if either the superior or inferior vena cava is occluded If one sees a patient with dilated superficial veins of the trunk which run in a generally vertical direction between the groin and the armpit, an obstruction of one of the vena cava should be sought. It is possible to discover which vena cava is blocked by determining the direction of blood flow within one of these dilated venous channels. Two fingers are placed next to one another across a dilated superficial vein. The fingers are then spread, expressing blood out of the vein in the region between the fingers. One of the fingers is lifted, and the examiner assesses how long it takes for blood to refill the vein. The procedure is repeated lifting the other finger first. Blood is flowing in the direction in which the vein fills most quickly.

PRIMARILY RETROPERITONEAL ORGANS

Lying on the anterior surface of the posterior abdominal wall, thus in contact with many muscles and nerves just described, are a variety of organs that develop in the retroperitoneal space. These are the primarily retroperitoneal structures of the abdomen. They comprise the aorta and some of its branches, the subdiaphragmatic plexus of nerves and ganglia, the lumbar sympathetic chain, inferior vena cava, kidneys and ureter, suprarenal glands, and, in the embryo, gonads.

Abdominal Aorta and Some of Its Branches (see Fig. 5-10)

The aorta passes through the aortic hiatus of the diaphragm on the surface of the 12th thoracic vertebral body, immediately to the left of the midline. The aorta descends along the left anterior surface of the vertebral column until the lower half of the 4th lumbar body, where it bifurcates into the right and left **common iliac arteries**. Each passes inferolaterally to contact the medial surface of the psoas major and, opposite the L5/S1 intervertebral disc, gives off an **internal iliac artery** that crosses the pelvic brim to enter the pelvic cavity. The continuation of the common iliac is called the **external iliac artery**. It maintains its place along the medial surface of the psoas major and leaves the abdominal cavity with the muscle by passing behind the inguinal ligament at the so-called midinguinal point, located halfway between the anterior superior iliac spine and the pubic *symphysis* (see Fig. 5-7*D*). The external iliac artery has only two branches: the **inferior epigastric artery** and the **deep circumflex iliac artery** (described earlier). These are given off immediately before the external iliac exits the abdominal cavity.

Along the way, the abdominal aorta gives rise to several branches that supply the abdominal wall. Already described, these are the **inferior phrenic**, four **lumbar**, and the **median sacral arteries**. It also gives off three pairs of arteries to the primarily retroperitoneal organs: the **middle suprarenal**, **renal**, and **gonadal arteries**. Finally, from the anterior surface of the abdominal aorta come three arteries for supply of the gut and its derivatives: the **celiac**, **superior mesenteric**, and **inferior mesenteric arteries**. The arteries for primarily retroperitoneal organs and the arteries for the gut will be discussed in the sections dealing with these structures.

Subdiaphragmatic Nerve Plexus

On the anterior surface of the abdominal aorta and, below this vessel's bifurcation, on the anterior surface of the vertebral column is a network of ganglionated nerve strands[16] called the subdiaphragmatic plexus. The cell bodies, be they in dissectible ganglia or scattered along nerve bundles, are part of the sympathetic system. In a sense they are displaced paravertebral ganglia. Further details on the subdiaphragmatic plexus will be presented later, when innervation of the abdomen and pelvis is discussed.

Sympathetic Chain

It will be recalled that throughout most of the thorax each sympathetic chain passes downward crossing the heads of the ribs. However, as it approaches the abdominal diaphragm the chain moves onto the lateral surfaces of vertebral bodies, so that by the time it reaches the origin of the psoas major (bottom of T12), a sympathetic chain has attained a position along the anteromedial edge of this muscle (i.e., on the sides of vertebrae just where the most anterior fibers of the psoas arise). Each chain enters the abdominal cavity by running behind the medial arcuate ligament and then maintain its position on vertebral bodies at the anteromedial edge of the psoas throughout its entire descent in the abdomen (see Fig. 5-10). Each sympathetic chain passes posterior to the common iliac vessels of the same side and enters the pelvic cavity to become the sacral portion of the sympathetic trunk.

The lumbar arteries, like their intercostal siblings, pass from the aorta behind the sympathetic chain on their way to the muscles of the posterior abdominal wall. The lumbar ventral rami, within the psoas major, connect to the posterior edge of the sympathetic trunk by means of the rami communicantes. From the anterior edge of the trunk come the lumbar splanchnic nerves that pass ventrally, along the sides of the aorta to reach the pre-aortic and lower parts of the subdiaphragmatic plexus.

---

[16] Pick, J: The Autonomic Nervous System. JB Lippincott, Philadelphia, 1970.

Inferior Vena Cava and Iliac Veins (Fig. 5-11)

Although accuracy would demand that the iliac veins and inferior vena cava be described as starting inferiorly and then be traced upward, in the direction of the blood flow, it is easier to visualize the inferior vena cava as a vessel that "descends" through the abdomen and "bifurcates" (like an artery) into smaller veins.

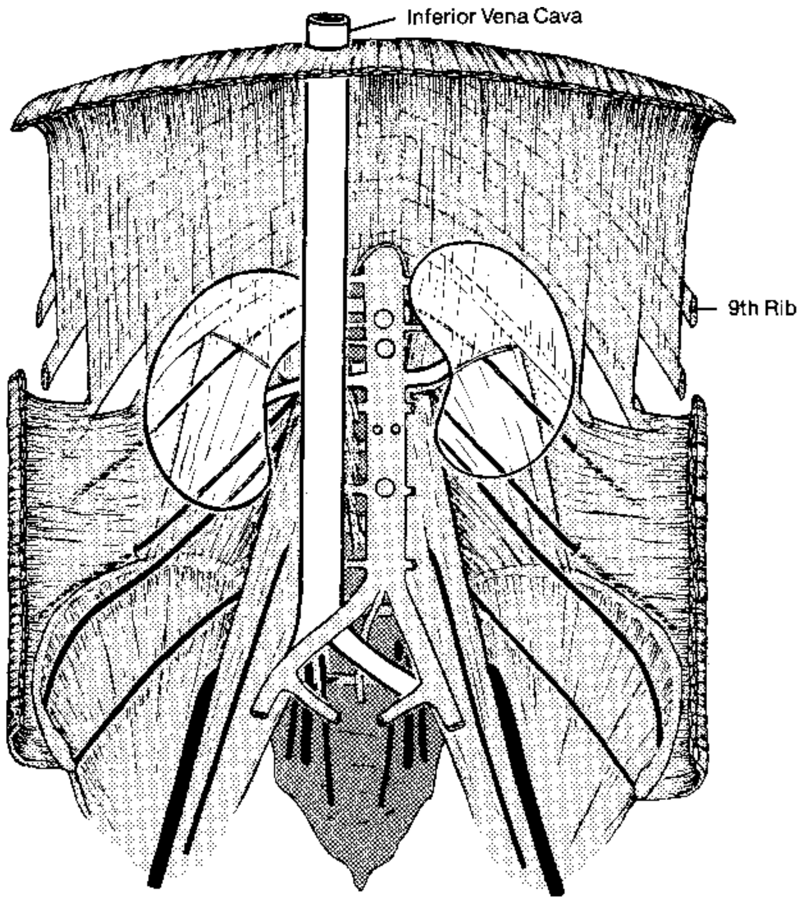


Figure 5-11. The positions of the inferior vena cava, kidneys, and renal arteries.

The inferior vena cava enters the abdominal cavity by piercing the central tendon of the diaphragm to the right of the midline opposite the T9 vertebra. It immediately encounters the liver and runs backward and downward in a groove on its surface. By the level of T12, the inferior vena cava has attained its definitive position along the right side of the abdominal aorta (at first separated from it by the right crus of the diaphragm), and stays in this position all the way down the abdomen. Below the medial arcuate ligament, the inferior vena cava lies anterior to the right sympathetic trunk, overlapping onto the right psoas major laterally and the vertebral column medially.

The inferior vena cava descends through the abdomen until the 5th lumbar vertebra where it "bifurcates" into the common iliac veins. The left common iliac vein passes posterior to the right common iliac artery, then inferior to the aortic bifurcation, and reaches the medial surface of the left psoas major posterior to the left common iliac artery. The vein "gives off" its internal iliac tributary and then continues as the external iliac vein on the medial surface of the psoas major posterior to the external iliac artery. As the external iliac vessels approach the inguinal ligament, the vein moves to the medial side of the artery and together they pass out of the abdominal cavity behind the ligament (see Fig. 5-7*D*).

The right common iliac vein passes behind the right common iliac artery, "gives off" its internal iliac branch, and then continues as the external iliac vein on the medial surface of the right psoas major posterior to the right external iliac artery. Near the inguinal ligament, the vein moves medial to the artery and together they exit the abdominal cavity.

The inferior vena cava receives fewer tributaries than there are arteries given off by the abdominal aorta. This is because (1) veins that accompany arteries to the gut do not return to the inferior vena cava, (2) the lumbar veins do not return to the inferior vena cava (see earlier), (3) on the left side some veins that ought to go the inferior vena cava empty first into the renal vein, and (4) the median sacral vein goes to the left common iliac vein where it lies inferior to the aortic bifurcation.

The tributaries of the inferior vena cava are (1) **hepatic veins**, just below the diaphragm; (2) **inferior phrenic veins**, just below the hepatic veins; (3) **renal veins**; (4) **right suprarenal and gonadal veins**; and (5) large **anastomotic vessels from the ascending lumbar veins**.

Kidneys and Renal Vessels (see Fig. 5-11; Fig. 5-12)

The kidneys form as bilateral retroperitoneal structures in the true pelvis. Their development is induced by two diverticula that grow from the embryonic bladder. These diverticula become the **ureters**. The site where the ureter enters the kidney is called the **hilum**. In the embryo, renal blood vessels from the common iliac artery and vein also enter at this site.

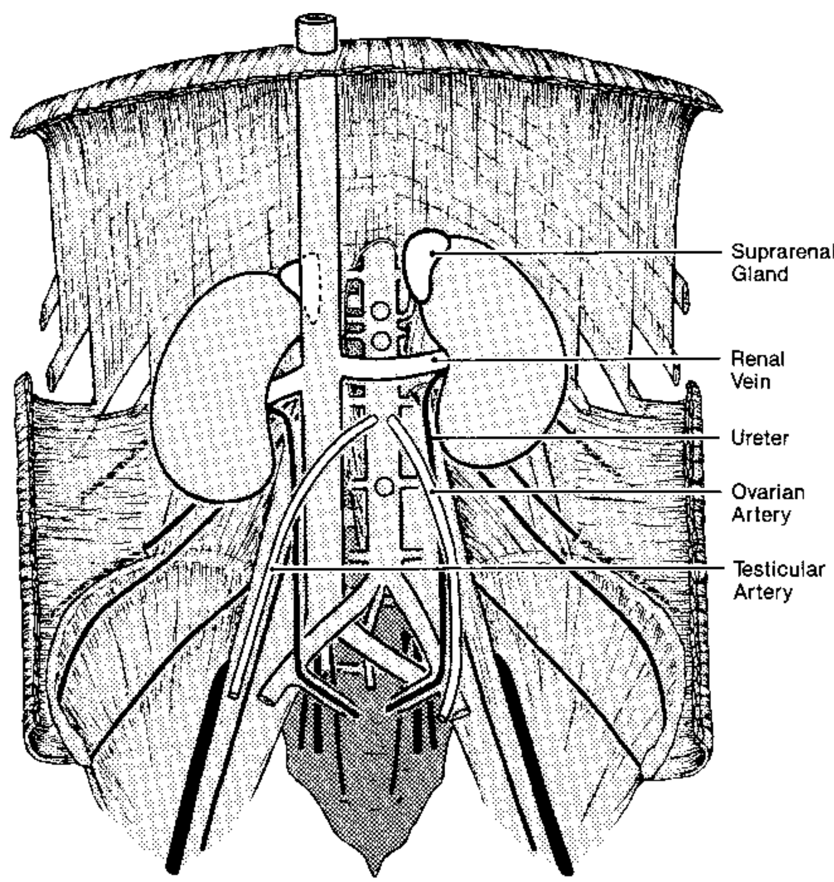


Figure 5-12. The positions of the suprarenal glands, renal veins, ureters, and gonadal arteries (testicular illustrated on one side, ovarian on the other).

Once within the kidney the ureter expands to become the **renal pelvis**. (The space in the kidney occupied by the pelvis, larger vessels, and bit of surrounding fat is called the **renal sinus**.) The renal pelvis bifurcates, or trifurcates into **major calyces**. In turn, each major calyx bifurcates, trifurcates, or otherwise divides into **minor calyces**, which are the structures that actually surround the papillae of the renal pyramids. The pyramids are composed of collecting tubules that conduct urine from the nephrons that form the renal cortex and the renal columns.

During development each kidney migrates superiorly out of the pelvic cavity onto the anterior surface of the psoas major. It continues this upward migration within the retroperitoneal space of the abdominal cavity until its hilum is opposite the disc between the 1st and 2nd lumbar vertebrae (see Fig. 5-11). (The right kidney usually stops just short of this level, whereas the left goes a bit higher.) During this migration the ureters become much longer. The original vasculature, rather than becoming longer, simply degenerates and the kidneys pick up new vessels from the aorta and inferior vena cava. A series of arteries and veins from the lower half of the aorta and inferior vena cava are formed and then lost as the kidney continues its upward movement. If all goes normally, the final renal arteries come off the aorta opposite the upper edge of the 2nd lumbar vertebra, just below the origin of the superior mesenteric artery (see Fig. 5-11). The right renal artery passes behind the inferior vena cava (presumably because it would constrict this large vein if it passed in front of it). The right renal vein takes a short course to the inferior vena cava. The left renal vein passes anterior to the aorta (presumably to avoid constriction of the vein by the aorta), inferior to the origin of the superior mesenteric artery, to reach the inferior vena cava. Both renal arteries, on their way to the kidneys, give off tiny but important branches that feed the ureters.

The kidneys and suprarenal glands are surrounded by a layer of fat (**perirenal fat**), which in turn is enclosed by a well defined fascia know as the **renal** (or **Gerota's**) **fascia**. It limits spread of blood from a torn kidney and of pus from an infected kidney. The anterior and posterior layers of Gerota's fascia do not fuse inferior to the kidney, so that blood or pus that enters the space occupied by perirenal fat may spread inferiorly as far as the true pelvic brim.

It is not uncommon that one of the lower (embryonic) renal arteries or veins be retained along with the "normal" ones. It is also possible that one or both kidneys will fail to migrate as high as they should. One certain cause of malmigration is an anomaly in which the lower poles of the two kidneys become fused across the midline. The resulting horseshoe (-shaped) kidney is prevented from complete migration as the conjoined lower poles encounter the origin of the inferior mesenteric artery.

While in the pelvis, the hili of kidneys face anteriorly. During the upward migration the kidneys settle in against the posterior abdominal wall with their medial borders lying up against the psoas major. As this settling occurs, the hili come to point ~45 degrees anteromedially, and the medial edge of the kidney, like the lateral edge of the psoas major, runs an oblique course from superomedial to inferolateral. Each ureter passes downward on the anterior surface of the psoas major (in the same sagittal plane as the tips of the lumbar transverse processes). When it reaches the pelvic brim, a ureter crosses medial to the bifurcation of the common iliac artery and enters the pelvic cavity alongside the internal iliac artery. Once in the pelvis, the ureters turn forward beneath the inferior wall of the peritoneal sac and run an anteromedial course to reach the back of the bladder.

Suprarenal (Adrenal) Glands and Vessels (see Fig. 5-12)

The suprarenal glands form in the retroperitoneal space, on either side of the midline opposite the 12th thoracic and 1st lumbar vertebrae. The suprarenal medulla is derived from neural crest cells and may be viewed as a displaced, and highly specialized, paravertebral ganglion. The cortex is derived from mesoderm into which these neural crest cells have migrated. When the kidney ascends in the retroperitoneal space, its upper pole bumps into the suprarenal gland, hence that gland's name. More accurately, each gland covers the medial surface of the upper pole of its corresponding kidney.

Each suprarenal gland is initially supplied blood by two arteries: one is a branch of the inferior phrenic artery, the other comes directly off the aorta between the origins of the celiac and superior mesenteric arteries. After migration of the kidney and formation of the definitive renal artery, the suprarenal gland also receives blood from a branch of the renal artery before that vessel enters the kidney. Thus, each suprarenal gland typically gets three arteries, a **superior suprarenal** from the inferior phrenic, a **middle suprarenal** from the aorta, and an **inferior suprarenal** from the renal.

Usually only one suprarenal vein exits each gland. The right suprarenal vein takes a *very* short course to the inferior vena cava, which lies on the anterior surface of the suprarenal gland. The left suprarenal vein, rather than crossing over the aorta to the inferior vena cava, takes a short course downward to the left renal vein.

Gonads and Gonadal Vessels

In the adult, neither the testes nor the ovaries are retroperitoneal organs of the abdominal cavity. However, both started out that way, forming inferior to the suprarenal glands. As the kidneys move up from the pelvic cavity into the abdominal cavity, the gonads migrate downward, passing anterior to the ureters. The testis ends up being pulled through the anterior abdominal wall into the scrotum. The ovary is drawn into the true pelvis because the gubernaculum of the female has an attachment to the uterus.

Despite the inferior migrations of both gonads, they retain a vascular and nerve supply signaling their abdominal origins. The tiny gonadal arteries arise from the front of the aorta somewhere between the superior and inferior mesenteric arteries (see Fig. 5-12). The **testicular artery** (see Fig. 5-12, right side of body) crosses onto the surface of the psoas major. The vessel encounters the ureter, crosses it anteriorly, and then continues downward on the anterior surface of psoas major, diverging from the ureter. Upon reaching the level of the inguinal ligament, the testicular artery passes through the deep inguinal ring to enter the spermatic cord. The **ovarian artery** (see Fig. 5-12, left side of body) also passes onto the anterior surface of the psoas major and crosses in front of the ureter. But, rather than diverging from the ureter as it descends, the ovarian artery parallels the ureter but lateral to it, thus crossing the beginning of the external iliac artery to enter the pelvic cavity and reach the infundibulopelvic ligament, which carries it the ovary. The artery also supplies the lateral part of the uterine tube.

The veins of the gonads follow the arteries backward toward their origin. The right gonadal vein ends in the inferior cava. The left gonadal vein, rather than crossing the aorta to reach the inferior vena cava, diverges from the artery and continues on a superior course to the left renal vein.

MESENTERIC AND SECONDARILY RETROPERITONEAL STRUCTURES--THE GUT AND ITS DERIVATIVES

The gut of the adult is far from the simple linear tube that one sees in embryonic life. The mesentery of the adult is far from the simple embryonic bilayer of peritoneum reflected from a midline root on the anterior surface of the aorta. In order to appreciate the adult anatomy of the gut, mesentery, and peritoneal cavity, one must understand the development of these structures.

Embryonic Peritoneal Cavity

The bulk of the embryonic peritoneal cavity reaches no further cranially than the septum transversum. However, two coelomic channels pass through the septum, on either side of the gut tube, to connect up with the pleural cavities in the thorax. Only the cranial surface of the septum will participate in formation of the abdominal diaphragm. When the pleuroperitoneal membranes join this surface, the two communicating channels between peritoneal and pleural cavities are simply converted into right and left cranial diverticula of the peritoneal cavity. These diverticula are embedded within the nondiaphragmatic part of the septum transversum.

The embryonic peritoneal cavity has yet one other diverticulum. Just caudal to the septum transversum it sends a blind tubular protrusion from its ventral wall into the umbilical cord (Fig. 5-13). This is the remnant of the extraembryonic coelom.

Embryonic Gut Tube

The embryonic gut is essentially a simple tube that runs from the mouth to the anus (see Fig. 5-13). However, just caudal to septum transversum this tube sends a diverticulum from its ventral surface into the extraembryonic coelom within the umbilical cord (see Fig. 5-13). This gut diverticulum is the remnant of the yolk sac and is called the **vitelline duct**.

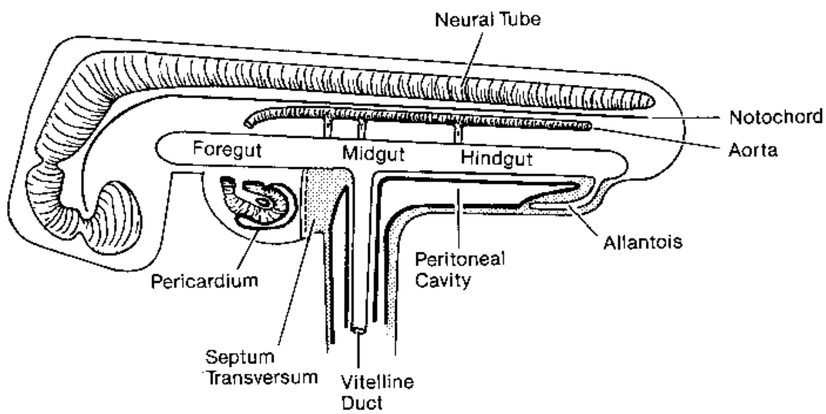


Figure 5–13. Schematic median sagittal section through a fourth-week embryo, illustrating the three different regions of the gut tube. The abdominal portion of the foregut receives the celiac artery from the aorta; the midgut receives the superior mesenteric artery; the hindgut receives the inferior mesenteric artery. The dashed line through the septum transversum demarcates the portion on its cranical surface that will become part of the abdominal diaphragm. On either side of the foregut, the peritoneal cavity sends a channel through the dorsal part of the septum transversum to connect with the ipsilateral pleural cavity. When each such connection is broken (by growth of the pleuroperitoneal membranes that join the developing diaphragm), the peritoneal channels are thereby converted to right and left cranial diverticula of the peritoneal cavity.

The existence of the vitelline duct allows one to distinguish three parts of the gut tube (see Fig. 5-13). The short segment of the gut tube from which the vitelline duct arises is called the **midgut**. All of the gut tube caudal to vitelline duct is the **hindgut**. All of the tube cranial to the vitelline duct is called the **foregut**. The thoracic esophagus is part of the foregut, as is the pharynx above it. The abdominal part of the foregut consists of that segment of the gut tube that is passing through the nondiaphragmatic part of the septum transversum between the cranial diverticula of the peritoneal cavity.

The abdominal foregut will develop into the abdominal part of the esophagus, the stomach, the 1st and most of the 2nd parts of the duodenum, the liver, the gallbladder, and the pancreas. The midgut becomes the rest of the duodenum, the jejunum, ileum, cecum, appendix, ascending colon, and most of the transverse colon. The hindgut becomes the last part of the transverse colon, the descending colon, sigmoid colon, and rectum.

Each part of the abdominal gut tube receives its own artery off the ventral surface of the aorta (see Fig. 5-13). The abdominal foregut artery is called the **celiac**. The midgut artery is called the

superior mesenteric; the hindgut artery is called the **inferior mesenteric**. Each region of the gut is innervated by specific segments of the spinal cord: the foregut by T5-T9, the midgut by T9-T12, the hindgut by T12-L2. (To help memorization, one should note that five segments innervate the abdominal foregut, four segments the midgut, and three segments the hindgut.)

Foregut Diverticula and Foregut Mesenteries

The abdominal foregut passes through the septum transversum. On either side are the cranial diverticula of the peritoneal cavity, which approach one another dorsal to the foregut to create a dorsal mesentery (Fig. 5-14*A*).

From the foregut arise two diverticula (Fig. 5-15*A*). Near the caudal surface of the septum transversum a diverticulum grows from the ventral wall of the foregut into the septum, pushing septal cells out of the way. This is the **hepatopancreatic diverticulum**. A bit cranial to this, but from the dorsal wall of the foregut, a second diverticulum grows toward the aorta, insinuating itself between the layers of the dorsal mesentery (Fig. 5-14*B*). This is the **dorsal pancreatic diverticulum**.

The hepatopancreatic diverticulum soon bifurcates into **hepatocystic** and **ventral pancreatic diverticula** (see Fig. 5-15*A*). The latter will differentiate into a part of the pancreas and pancreatic duct (see further on). The hepatocystic diverticulum, after elongating a bit, bifurcates into (1) an **hepatic diverticulum** that becomes the common hepatic bile duct, intrahepatic biliary system, and liver; and (2) a **cystic diverticulum**, which becomes the cystic duct and gallbladder. The common stem of the hepatocystic diverticulum will become the common bile duct. The fact that the ventral pancreas and bile duct system start out as a single diverticulum explains why the pancreatic and common bile ducts of the adult join one another just prior to emptying into the gut.

The ventral pancreatic diverticulum bulges out the peritoneum on the caudal surface of the septum transversum (Fig. 5-15*B*). The cystic diverticulum stays along the caudal surface of the septum, in contact with the peritoneum (see Fig. 5-15*B*). Caudally, on either side of the gallbladder, the liver contacts the peritoneum on the caudal surface of the septum transversum. The hepatic diverticulum grows tremendously. Its cranial surface actually comes to contact the inferior surface of the developing diaphragm (see Fig. 5-15*B*). Most of the septal tissue itself becomes incorporated as connective tissue of the liver.

As the liver grows into the septum transversum, the cranial peritoneal diverticula on either side of the foregut start to expand ventrally. They approach one another between the developing liver and the foregut (see Fig. 5-14*B*), then pass around the sides of the liver and again approach one another between the liver and anterior abdominal wall (Fig. 5-16*A*). As a result of this ventral expansion of the peritoneal diverticula, a **ventral mesentery** (bilayer of peritoneum) forms between the foregut and the liver, and between the liver and anterior abdominal wall. The part between the gut and the liver is called the **lesser omentum**. In its free caudal edge runs the common bile duct. The mesentery between the liver and abdominal wall is called the **falciform ligament**. Between its leaflets runs the umbilical vein toward the liver. The part of the liver to the right of the ventral mesentery is the embryonic right lobe; the part to the left of the ventral mesentery is the embryonic left lobe (see Fig. 5-16*A*). The lateral surfaces of the liver, as well as its caudal surface, are now covered by visceral peritoneum. The gallbladder is interposed between liver and the visceral peritoneum on its caudal surface.

If the peritoneal diverticula from each side were to interpose themselves between the liver and diaphragm, there would be created a "cranial" mesentery of the liver running between it and the diaphragm. This "cranial" mesentery would be continuous ventrally with the falciform ligament and dorsally with the lesser omentum. If the peritoneal diverticula were to make absolutely no effort to interpose themselves between the diaphragm and liver, the entire superior surface of the liver would be "bare", i.e., in contact with the undersurface of the diaphragm. In this case, visceral peritoneum on the sides of the liver would pass into parietal peritoneum on the undersurface of the diaphragmatic periphery. In fact, what occurs is a combination of these two alternatives. The peritoneal diverticula do interpose themselves between the diaphragm and the ventral part of the superior surface of the liver. Thus, the

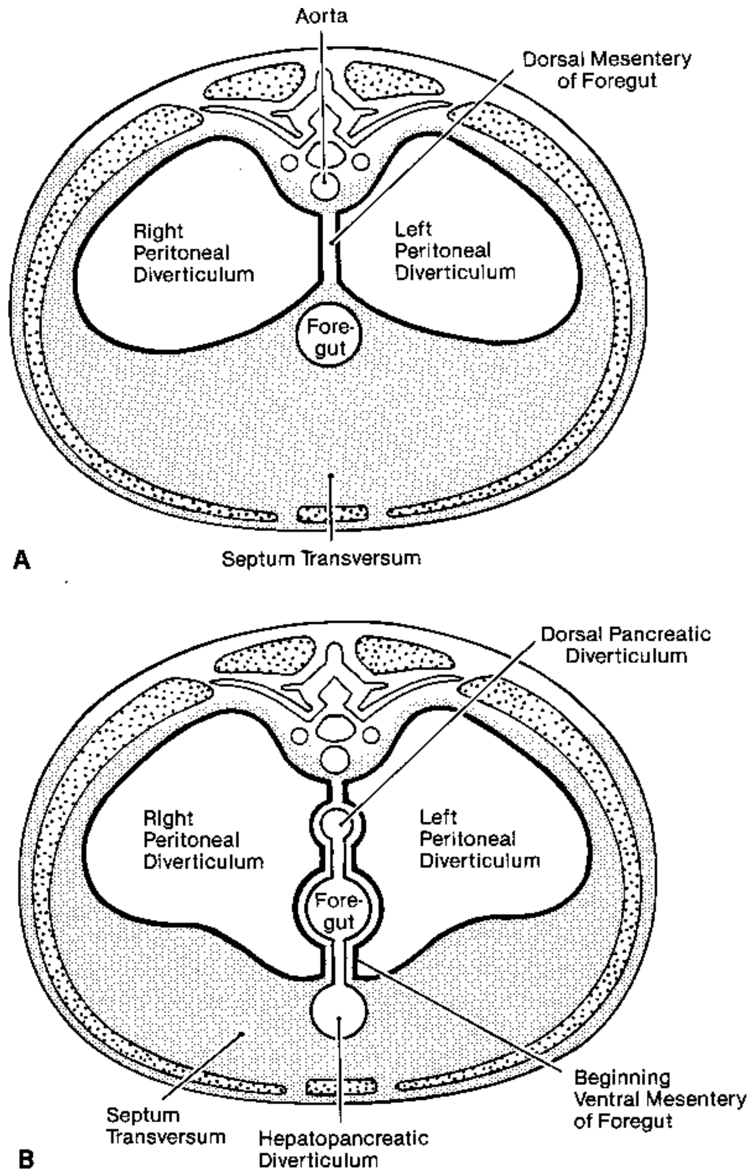


Figure 5-14. Schematic transverse sections (at sequential stages of development) through the embryonic abdomen at the level of the foregut and septum transversum. *A*, An early stage that is prior to the development of any glandular diverticula. *B*, A later stage, in which the dorsal pancreatic diverticulum has pushed between the layers of the dorsal mesentery, and the hepatopancreatic diverticulum has grown into the septum transversum. Ventral expansions of the peritoneal diverticula are beginning to create a bilayered ventral mesentery of the foregut. Note: This drawing pretends that a single transverse section could pass through both glandular diverticula of the foregut.

falciform ligament is continued onto the upper surface of the liver as a "cranial" mesentery. However, theback part of the superior surface of the liver remains in contact with the diaphragm. This area of contact comprises the **bare area of the liver**. Around the margins of the bare area, the visceral peritoneum passes into (or reflects onto) the parietal peritoneum lining the undersurface of the diaphragm. This reflection is called the **coronary ligament** of the liver. The falciform ligament runs into it from its front side; at the back of the liver the coronary ligament merges with the lesser omentum.

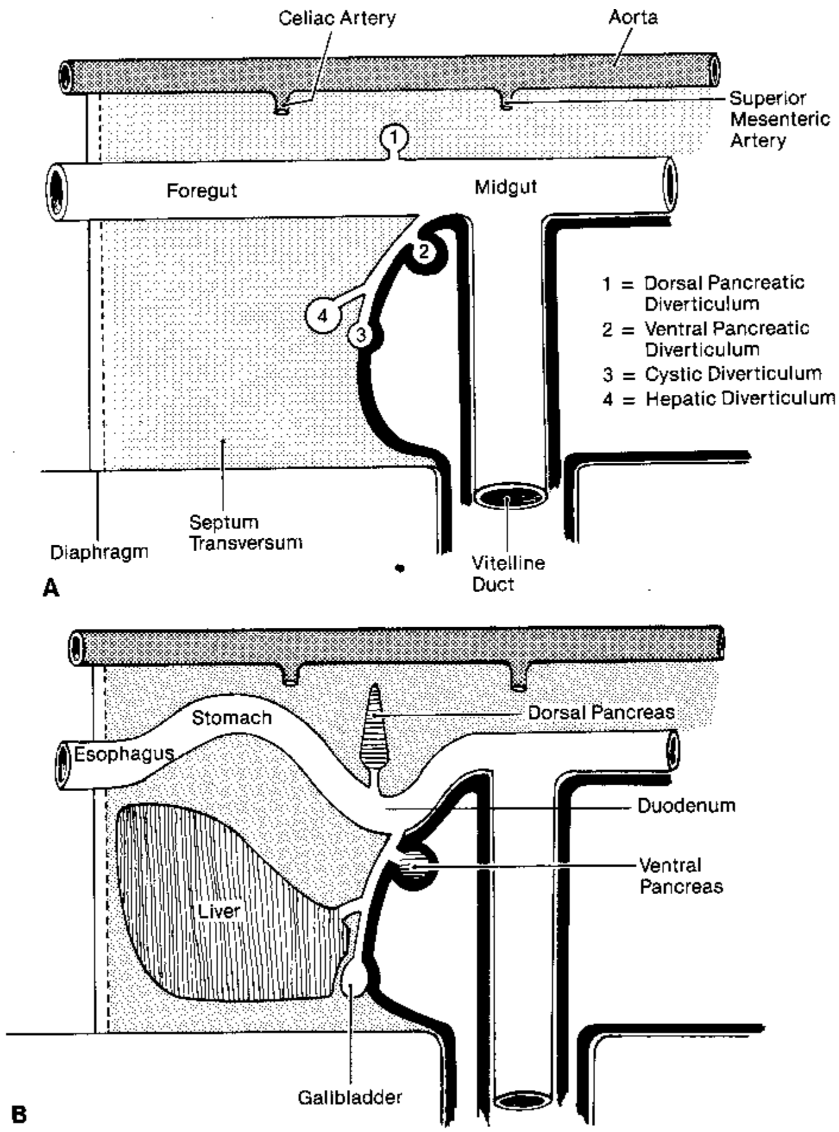


Figure 5–15. Schematic median sagittal "sections" (at sequential stages in development) through the embryonic foregut and related structures. *A*, A stage corresponding to Figure 5–14*B*, depicting initial outgrowth of dorsal pancreatic and hepatopancreatic diverticula. *B*, A later stage, in which the glandular diverticula are more differentiated and the foregut has developed curvatures that allow us to distinguish the stomach from the duodenum.

None of the changes that have been described in any way alter the fact that the peritoneal cavity in the region of the foregut is divided into right and left channels; it is simply that the channels are now much more extensive than they used to be . Caudal to the ventral mesentery and liver, these two channels open into the single peritoneal cavity of the rest of the abdomen.

Initial Development of the Stomach and Duodenum

As the hepatopancreatic and dorsal pancreatic diverticula are arising, and the anterior peritoneal diverticula are enlarging so as to create the ventral mesentery of the foregut, the foregut itself is changing too. Immediately caudal to the diaphragm the foregut develops a dorsally looping bend (see Fig. 5-15*B*). The dorsally looping bend is the future **stomach**. The dorsal convexity of the stomach is its **greater curvature**, the ventral concavity is its **lesser curvature**. In the region of the dorsal pancreatic and

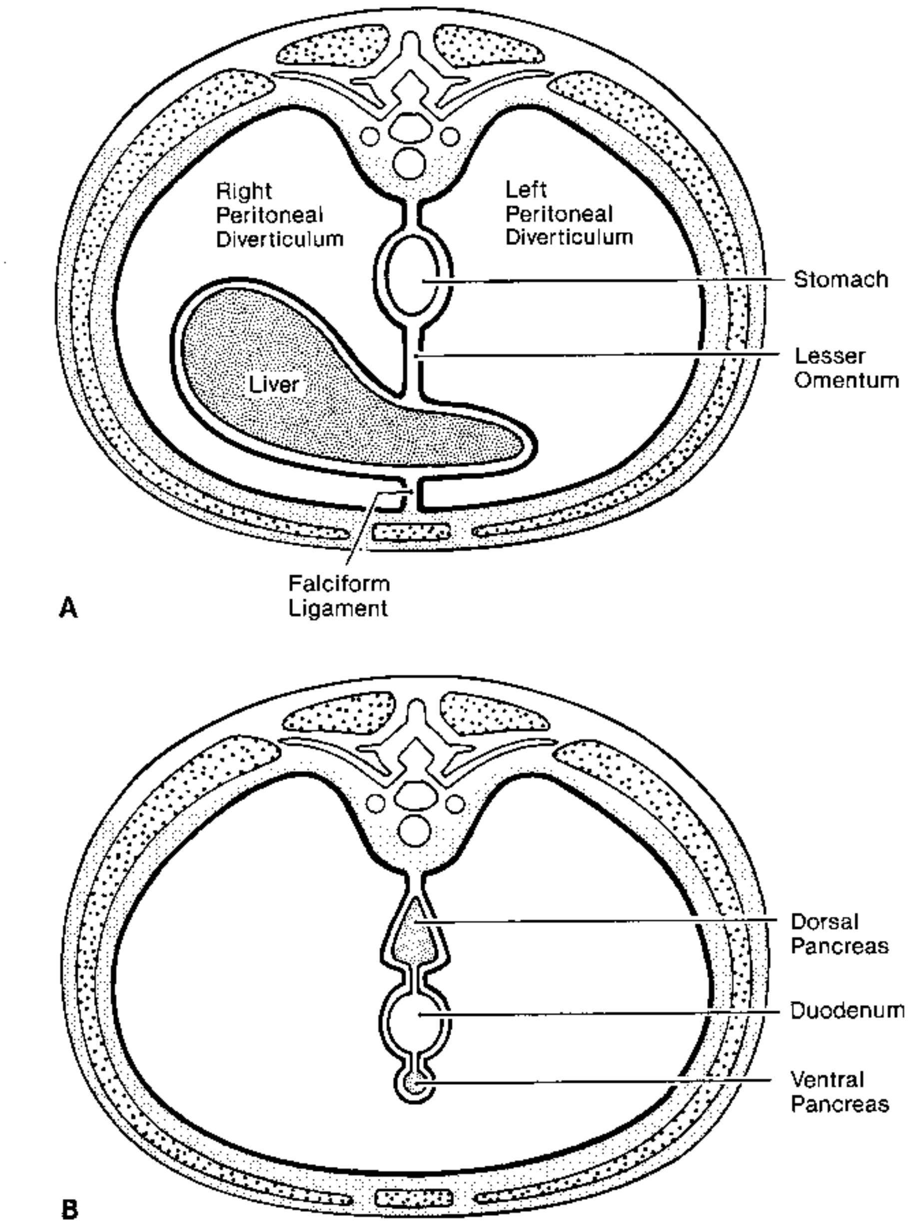


Figure 5-16. Schematic transverse sections of an embryonic abdomen at a stage in development corresponding to Figure 5-15*B*. *A*, A section taken through the stomach and liver, showing how continued ventral expansion of the peritoneal channels has completed the development of a ventral mesentery divided into two regions by the liver. *B*, A section through the duodenum and pancreata just caudal to the caudal edge of the ventral mesentery. Note: This last drawing pretends that a single transverse section could pass through both the dorsal pancreatic and ventral pancreatic diverticula.

hepatopancreatic diverticula, the foregut starts to loop ventrally as the **duodenum**. The most cranial part of the midgut will complete this loop. Thus, the duodenum is derived from two regions of the embryonic gut. The hepatopancreatic diverticulum arises from the caudalmost region of foregut's contribution to the duodenum. The duodenum too may be said to have a greater curvature (ventrally) and a lesser curvature (dorsally).

When a stomach and duodenum can be identified, we have the opportunity to assign more names to things. The region of the lesser omentum that runs from the lesser curvature of the stomach to the liver is called the **hepatogastric ligament**. The region of the lesser omentum that runs from the duodenum to liver is called the **hepatoduodenal ligament**. The common bile duct runs in the caudal edge of the hepatoduodenal ligament. The region of the dorsal mesentery that runs to the greater curvature of the stomach is called the **mesogastrium**. The region of the dorsal mesentery that runs to the duodenum is the **mesoduodenum**. The dorsal pancreas is growing into the mesoduodenum.

Rotation and Growth of the Stomach; Change in Position of the Right Peritoneal Diverticulum

As the gastric and duodenal loops enlarge they undergo a rotation around a craniocaudal axis. The stomach is thrown toward the left, the duodenum to the right, and the lesser omentum comes to lie in a coronal rather than a sagittal plane (Fig. 5-17*A*). The displacement of the stomach to the left forces the liver to grow unevenly. Thus, that portion to the right of the ventral mesentery becomes much larger than that to the left (see Fig. 5-17*A*). The bare area and coronary ligament are largely confined to the right lobe. The small portion of the coronary ligament to the left of the midline is called the **left triangular ligament**; the rightmost portion of the coronary ligament is called the **right triangular ligament**.

The changes described above have had a profound effect on the right peritoneal channel. Much of it still lies to the right of the liver and falciform ligament, but an even bigger portion now lies posterior to the reoriented lesser omentum and stomach (see Fig. 5-17*A*).

Growth of the stomach allows its different regions to be identified (Fig. 5-18). The region into which the esophagus empties is called the **cardia**; the bulge above the cardia is the **fundus**; below the cardia and fundus is the **body**. The lower part of the body turns toward the right and is then called the **antrum**, which ends in a narrow passageway, the **pylorus**, that leads to the duodenum. The upper half of the greater curvature, corresponding to the fundus, now faces toward the left, while the lower half, corresponding to the antrum, faces inferiorly (see Fig. 5-18). The part of the mesogastrium that goes to the leftward-facing segment of the greater curvature is the **upper mesogastrium**; the part that goes to the downward-facing segment of the greater curvature is the **lower mesogastrium** (Fig. 5-18). To accommodate the new position of the stomach, the upper mesogastrium has grown in length.

Rotation and Growth of the Duodenum

The rotation of the foregut throws the duodenal loop toward the right (see Figs. 5-17*B*, 5-18). With continued growth it forms a C-shaped segment of bowel. That part extending from the pylorus to the right of the midline is the first part; that which turns caudally is the second part; that which turns back to the left to reach the midline once again is the third part; the fourth part of the duodenum takes a short, cranially directed course just to the left of the midline before it joins the rest of the midgut. The first and most of the second part (up to and including the site of entrance of the common bile duct) are foregut derivatives. The remainder of the duodenum is from the midgut.

The dorsal pancreas, which comes off the lesser curvature of the second part of the duodenum, now runs toward the left in the mesoduodenum (Fig. 5-19; see Fig. 5-17*B*). The opening of the hepatopancreatic diverticulum should now be coming off the right surface (i.e., greater curvature) of the duodenum a little below the opening of the dorsal pancreatic duct, but the ventral pancreas is "attracted" to its dorsal partner and it undergoes a migration behind the duodenum to end up in its lesser curvature in contact with the dorsal pancreas (see Figs. 5-17*B*, 5-19). During this leftward migration of the ventral pancreas, the opening of the hepatopancreatic diverticulum is "dragged" onto the posterior surface of the duodenum near its lesser curvature. This constrains the common bile duct to follow a course posterior to both the first part of the duodenum and the ventral pancreas on its way to its opening (see Figs. 5-17*B*, 5-19). The free edge of the lesser omentum, in which the common bile duct runs, now faces to the right instead of caudally.

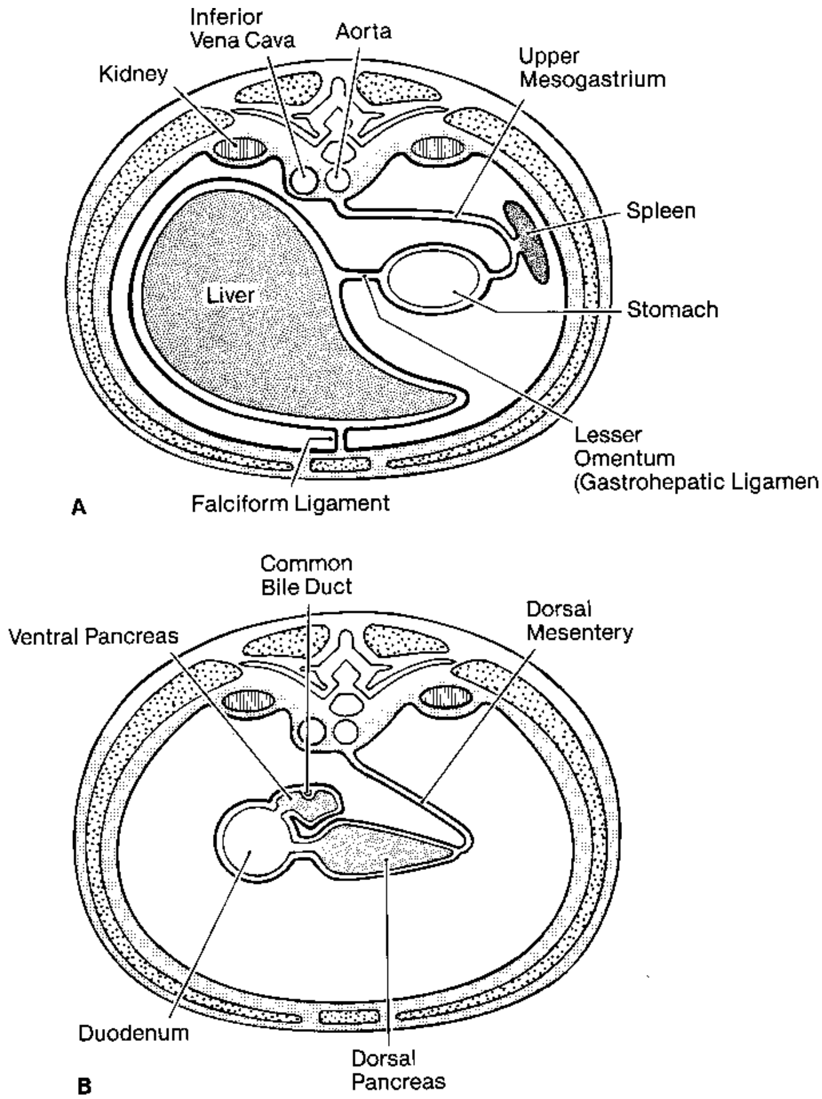


Figure 5-17. Schematic transverse sections of an embryonic abdomen at a stage in development subsequent to that depicted in Figure 5-16. *A*, A section through the stomach and liver after the former has rotated to the left and growth of the right lobe of the liver has carried it toward the posterior abdominal wall near the site where the inferior vena cava and right kidney are developing. *B*, A section through the duodenum and pancreata after the former has rotated to the right and the ventral pancreas has come to lie behind the dorsal pancreas and its duct. Note: This last drawing pretends that a single transverse section could pass through both the dorsal pancreatic and ventral pancreatic diverticula.

The Upper Mesogastrium Shifts Its Root

Now we come to the first in a series of fusions between visceral peritoneum or mesentery, on the one hand, and the parietal peritoneum of the posterior abdominal wall, on the other. Because of the displacement of the stomach, the upper mesogastrium must sweep from its midline root toward the left side to reach the leftward-facing greater curvature (see Fig. 5-17*A*). As it does so the region of the upper mesogastrium nearest the root is "thrown" against the parietal peritoneum covering the posterior abdominal wall to the left of the midline. Remember, the mesentery is a bilayer of peritoneum. Where the back (originally left) layer of the upper mesogastrium contacts parietal peritoneum, they fuse and "dissolve" into loose connective tissue (Fig. 5-20*A*). The front (originally right) layer of the mesentery takes on the characteristics of parietal peritoneum and is no longer distinguished from it. This fusion of

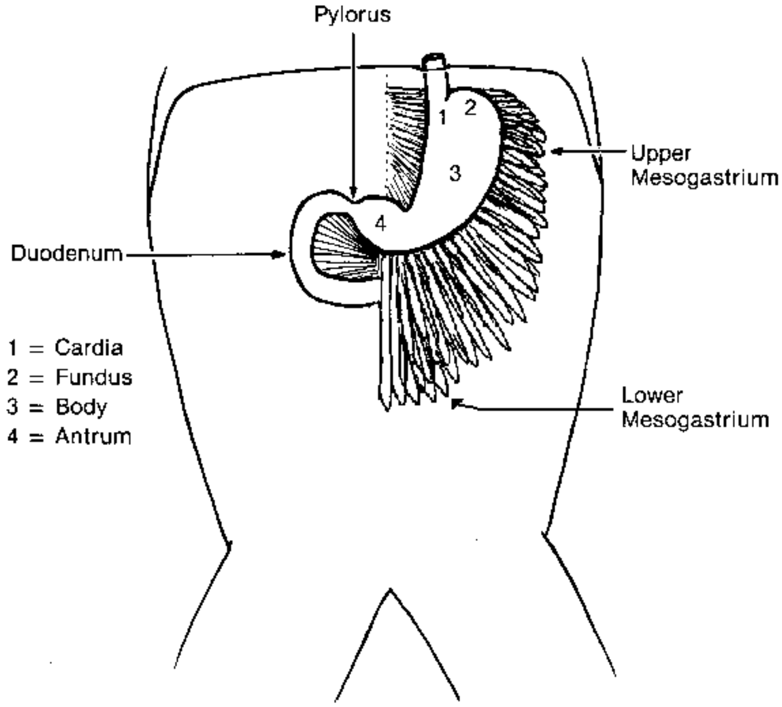


Figure 5–18. Schematic anterior view of embryonic abdominal cavity showing only the stomach, duodenum, and their mesenteries at a stage subsequent to rotation of the foregut (see Fig. 5–17).

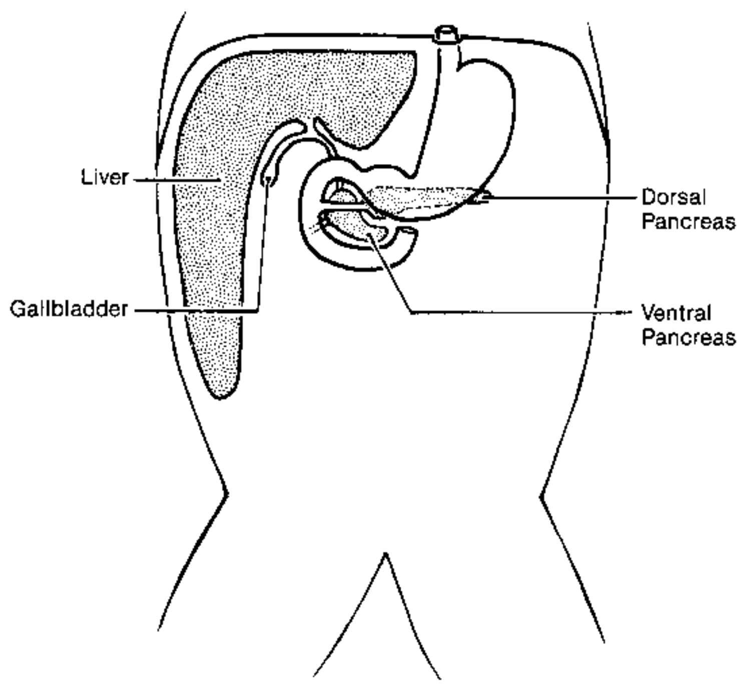


Figure 5–19. Schematic anterior view of embryonic abdominal cavity at same stage in development as depicted in Figure 5–18, but showing only stomach, duodenum, and their glandular diverticula.

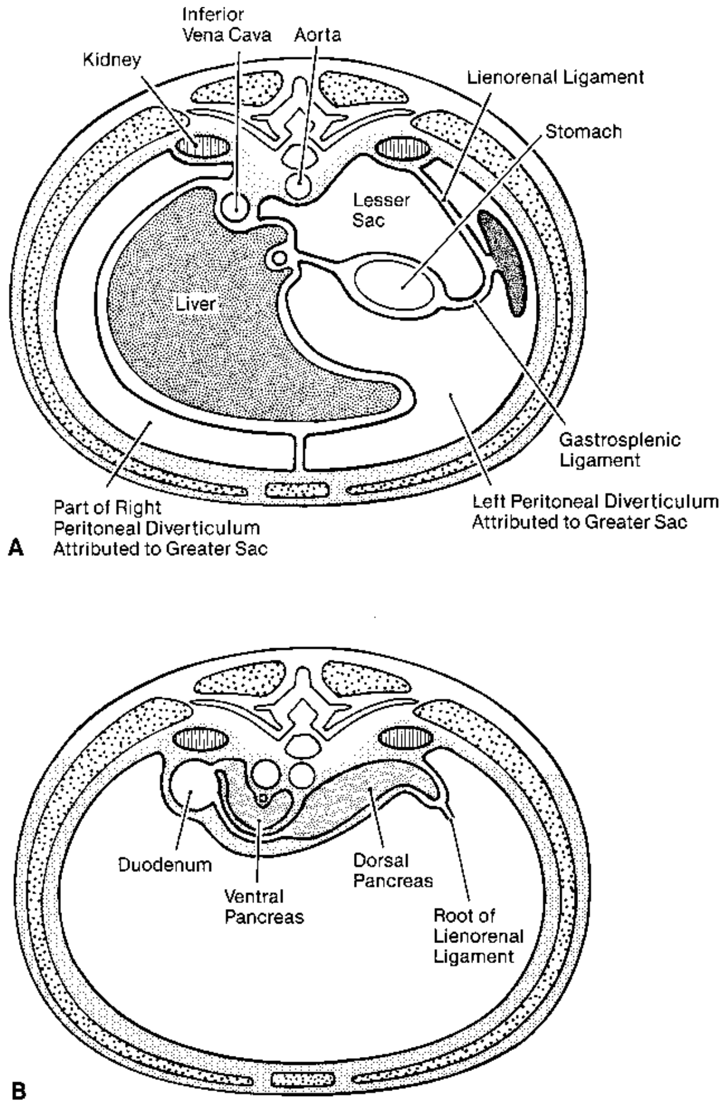


Figure 5-20. Schematic transverse section of embryonic abdomen at a stage in development subsequent to that depicted in Figure 5–17. *A*, A section through stomach and liver showing that the root of the upper mesogastrium has shifted to the left, and that the visceral peritoneum of the liver has fused with the parietal peritoneum over the inferior vena cava, then dissolved. The resulting contact between liver and inferior vena cava seals off the lesser sac from the greater sac except at the site of the epiploic foramen. *B*, A section through the duodenum and pancreata after they have become secondarily retroperitoneal. Note: This last drawing pretends that a single transverse section could pass through both the dorsal pancreatic and ventral pancreatic diverticula.

upper mesogastrium to parietal peritoneum will obviously shift the root of the upper mesogastrium. The precise region of fusion is such that there results a progressive shift in the root of the upper mesogastrium toward the left as one passes from cranial to caudal. The product is an upper mesogastrial root that starts in the dorsal midline just inferior to the diaphragm and travels downward and to the left, first across the diaphragm and then passing onto the anterior surface of the left kidney (see Fig. 5-20*A*).

The displacement of the duodenum, ventral pancreas, mesoduodenum, and dorsal pancreas brings these structures against the parietal peritoneum on the posterior abdominal wall. At every site where visceral peritoneum on the posterior surfaces of these structures contacts the parietal peritoneum, the two layers first fuse and then "dissolve" into loose connective tissue (called by clinicians “anterior pararenal fascia). The visceral peritoneum on the anterior surfaces of the duodenum and pancreas becomes indistinguishable from the surrounding parietal peritoneum and, henceforth, will be considered as parietal peritoneum. The duodenum and most of the pancreas are now retroperitoneal (Fig. 5-20*B*), though only secondarily so, since they once had mesenteries. The second part of the duodenum lies on the right renal vein and hilum of the right kidney. The ventral pancreas comes to lie on the inferior vena cava, termination of the left renal vein, and to a small extent, the aorta. The dorsal pancreas extends toward the left, crossing the aorta to reach the left renal hilum. The common bile duct is trapped behind the ventral pancreas, between it and the inferior vena cava (see Fig. 5-20*B*).

With the mesoduodenum having been lost, the root of the lower mesogastrium now runs along the lower border of the dorsal pancreas, and the very end of the dorsal pancreas passes in between the layers of the upper mesogastrium (see Fig. 5-20*B*).

The final root of the mesogastrium starts in the dorsal midline just inferior to the diaphragm and travels downward and to the left, first across the diaphragm and then passing onto the anterior surface of the left kidney until it reaches the dorsal pancreas, where it dramatically shifts direction to run toward the right along this structure's lower border. **The original dorsal midline root of the mesogastrium is gone.**

The lower mesogastrium, whose root now lies along the lower border of the pancreas, grows tremendously in length (Fig. 5-21). Since the distance between the pancreas and the stomach remains short, the lower mesogastrium folds down into the lower abdomen (ventral to the rest of the bowel, which has yet to be described). In other words, from its root, the lower mesogastrium passes inferiorly almost to the pelvis and then makes a U-turn to travel back up again to the downward-facing segment of the greater curvature of the stomach. The part of the lower mesogastrium that passes from its root down toward the pelvis is called the posterior sheet; the part that passes from the bend back up to the stomach is the anterior sheet. The right peritoneal channel extends from its location behind the stomach down between the sheets of the lower mesogastrium (see Fig. 5-21).

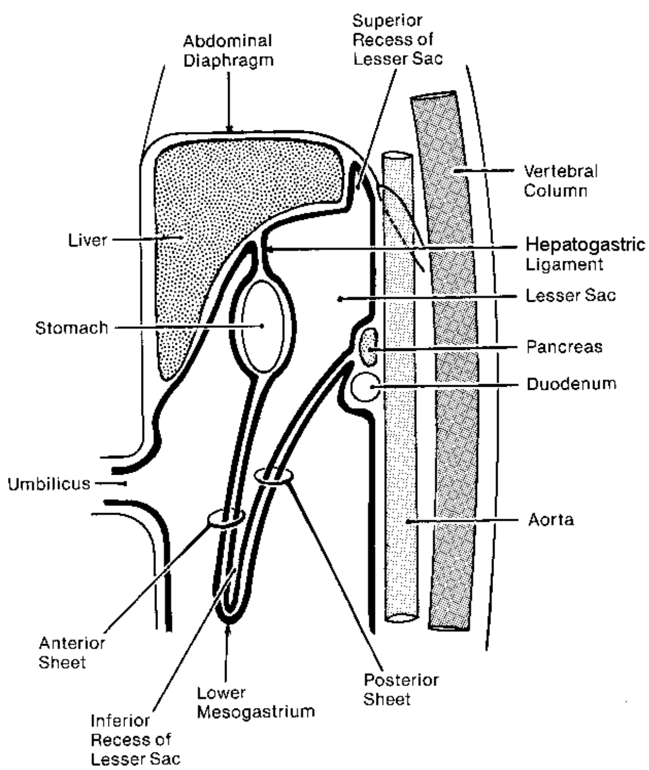


Figure 5-21. Schematic median sagittal section of embryonic abdomen showing the mesenteries of the stomach and the lesser sac.

Spleen

Lymphoid cells accumulate between the layers of the upper mesogastrium to become the spleen (see Fig. 5-17*A*). As the spleen grows, it bulges out the left of the 2 layers that form the upper mesogastrium. By its development the spleen divides the upper mesogastrium into (1) a region cranial to the spleen, where the mesogastrium runs from the posterior abdominal wall to the stomach; (2) a region from the posterior abdominal wall to the spleen (see Fig. 5-20*A*); and (3) a region from the spleen to the stomach (see Fig. 5-20*A*). The region cranial to the spleen is the **gastrophrenic ligament** (because the root of this mesogastrium lies on the posterior fibers of the diaphragm). The region of the upper mesogastrium between the posterior abdominal wall and the spleen is called the **lienorenal ligament** (because *lien* is Latin for "spleen" and the kidney lies in the retroperitoneal space behind the root of the mesogastrium). The region between the spleen and the stomach is called the **gastrosplenic ligament**.

The Lesser and Greater Sacs of the Peritoneal Cavity

The growth of the right lobe of the liver brings the visceral peritoneum on its posterior surface (near its superior border) into contact with the parietal peritoneum overlying the developing inferior vena cava (see Fig. 5-17*A*). The two peritoneal layers fuse and dissolve, bringing the liver capsule into direct contact with the inferior vena cava (see Fig. 5-20*A*). In a sense, an addition has been made to the bare area of the right lobe of the liver. This has one very important consequence. Prior to the adherence of the liver and inferior vena cava, it was possible to get from the part of the right peritoneal channel that was lateral to the liver into the part that lay behind the stomach simply by passing behind the posterior edge of the right lobe of the liver (see Fig. 5-17*A*). Now this route is blocked (see Fig. 5-20*A*), and there is no way to go directly between these two regions of the right peritoneal channel. In fact, the only way to get into that part of the right channel that lies posterior to the stomach is to pass behind the free edge of lesser omentum as it runs between duodenum and liver (see Fig. 5-19). This passageway is bounded superiorly by the liver, inferiorly by the duodenum and posteriorly by the parietal peritoneum over the inferior vena cava. It is a small passageway called the **foramen of Winslow (or epiploic foramen)**. That part of the right peritoneal channel to which it leads is called the **omental bursa, or lesser sac of the peritoneum**. It lies behind the lesser omentum and stomach (see Fig. 5-20*A*), passes downward (as the **inferior recess of the lesser sac**) between the folds of the lower mesogastrium (see Fig. 5-21), and passes upward (as the **superior recess of the lesser sac**) behind that part of the liver to the left of the inferior vena cava (see Fig. 5-20*A*). The gastrophrenic, gastrosplenic, and lienorenal ligaments form the left wall of the lesser sac. All the rest of the peritoneal cavity, i.e., that part of the right channel that was not sequestered as the lesser sac, the entire left channel, and the single undivided cavity caudal to the two channels compose the **greater sac**.

Liver (Fig. 5-22)

As mentioned above, the embryonic liver is said to be divided into right and left lobes by the line of attachment of the hepatogastric and falciform ligaments. The embryonic right lobe is further divided into named regions by depressions in the liver surface and the attachment site of the hepatoduodenal ligament.

There is a depression on the back surface of the embryonic right lobe caused by the inferior vena cava. This is called the **caval fossa**. It lies in the same sagittal plane as a depression on the inferior (visceral) surface of the liver caused by the gallbladder--the so-called **cystic fossa**. The vena caval and cystic fossae are not continuous, but, since they lie in the same sagittal plane, they are often spoken of together as constituting a **right sagittal fossa.** (A sagittal plane through the liver at the site of the right sagittal fossa is called the "main portal scissura" by surgeons). The **right lobe of the fully developed liver** is only that portion of the organ to the right of the right sagittal fossa.

There exists a narrow groove in the back surface of the liver a few inches to the left of the caval fossa. In fetal life this groove housed the ductus venosus, a vein that received blood returning from the placenta via the umbilical vein. The ductus venosus shunts such blood past the liver and into the inferior vena cava. After birth the ductus venosus degenerates into the **ligamentum venosum**, and the groove

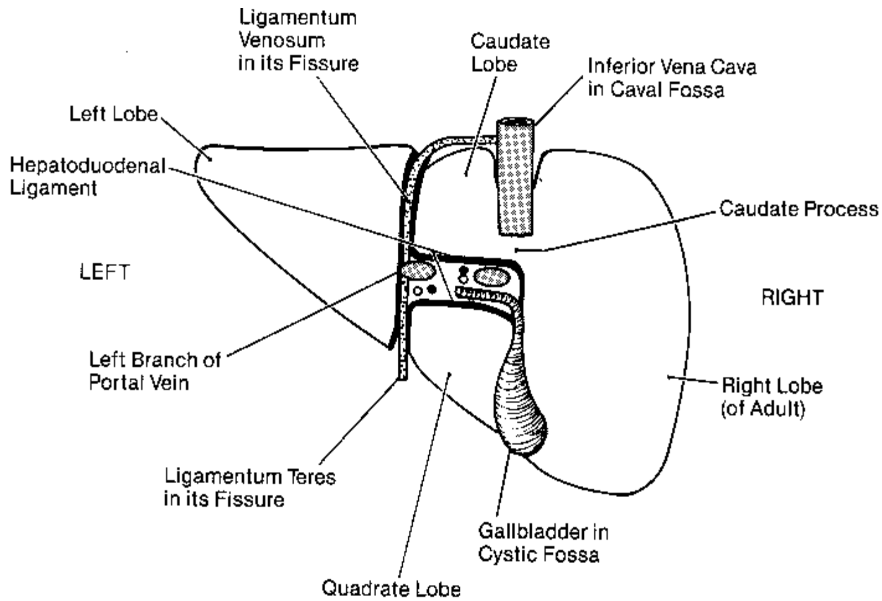


Figure 5–22. Posterior and inferior (visceral) surfaces of the liver.

becomes referred to as the **fissure for the ligamentum venosum**. (which is called "umbilical fissure" by surgeons). The hepatogastric ligament merges with the visceral peritoneum of the liver in the floor of this fissure. The part of the fully developed liver between the caval fossa and the fissure for the ligamentum venosum is called the **caudate lobe**.

There exists a narrow groove on the inferior (visceral) surface of the liver a few inches to the left of the cystic fossa. In fetal life this groove housed the umbilical vein. After birth this vein degenerates into the **ligamentum teres of the abdomen**, and the groove is referred to as the **fissure for the ligamentum teres**. The falciform ligament merges with the visceral peritoneum of the liver in the floor of this fissure. The part of the fully developed liver between the cystic fossa and the fissure for the ligamentum teres is called the **quadrate lobe**.

The fissure for the ligamentum venosum and the fissure for the ligamentum teres are continuous with one another. Together they compose the **left sagittal fissure** of the liver, and serve as a landmark for separating the embryonic left lobe from the embryonic right lobe, or the **left lobe** of the fully developed liver from its caudate and quadrate lobes. Surgeons use a different scheme, based on blood supply, for naming lobes of the liver. I will mention it when I discuss blood supply to the liver.

As mentioned previously, the hepatogastric part of the lesser omentum joins the visceral peritoneum of the liver in the floor of the fissure for the ligamentum venosum. From the site where this fissure meets the fissure for the ligamentum teres, and running toward the right to reach the area between the cystic and caval fossae, is the attachment site of the hepatoduodenal part of the lesser omentum. Thus, the hepatoduodenal ligament has an attachment site that bridges between the midpoints of the left sagittal fissure and the right sagittal fossa. Where the attachment site of the hepatogastric ligament merges with the attachment site of the hepatoduodenal ligament (i.e., at the junction of the two ligamental fissures), the lesser omentum is joined by the falciform ligament (Fig. 5-22).

The hepatoduodenal ligament brings major blood vessels to the liver and serves as the conduit for the common hepatic duct away from the liver. The site where the hepatoduodenal ligament attaches to the liver is called the **porta hepatis** (gate to the liver).

Between the caval fossa and the attachment of the hepatoduodenal ligament, the caudate lobe and right lobe are continuous. The bridge of liver tissue between these two lobes is called the **caudate process**.

Pancreas

The reader will recall that the ventral pancreas had been "attracted" to the dorsal pancreas and migrated to join it within the lesser curvature of the duodenum (see Fig. 5-19). Together they became retroperitoneal, yet they retained separate ducts that emptied into the second part of the duodenum at different sites (Fig. 5-23*A*). This soon changes. The ventral and dorsal pancreata fuse (Fig. 5-23*B*). The ventral pancreas becomes the **head** and **uncinate process**. The dorsal pancreas becomes the **body and tail**. The site of juncture is the **neck**.

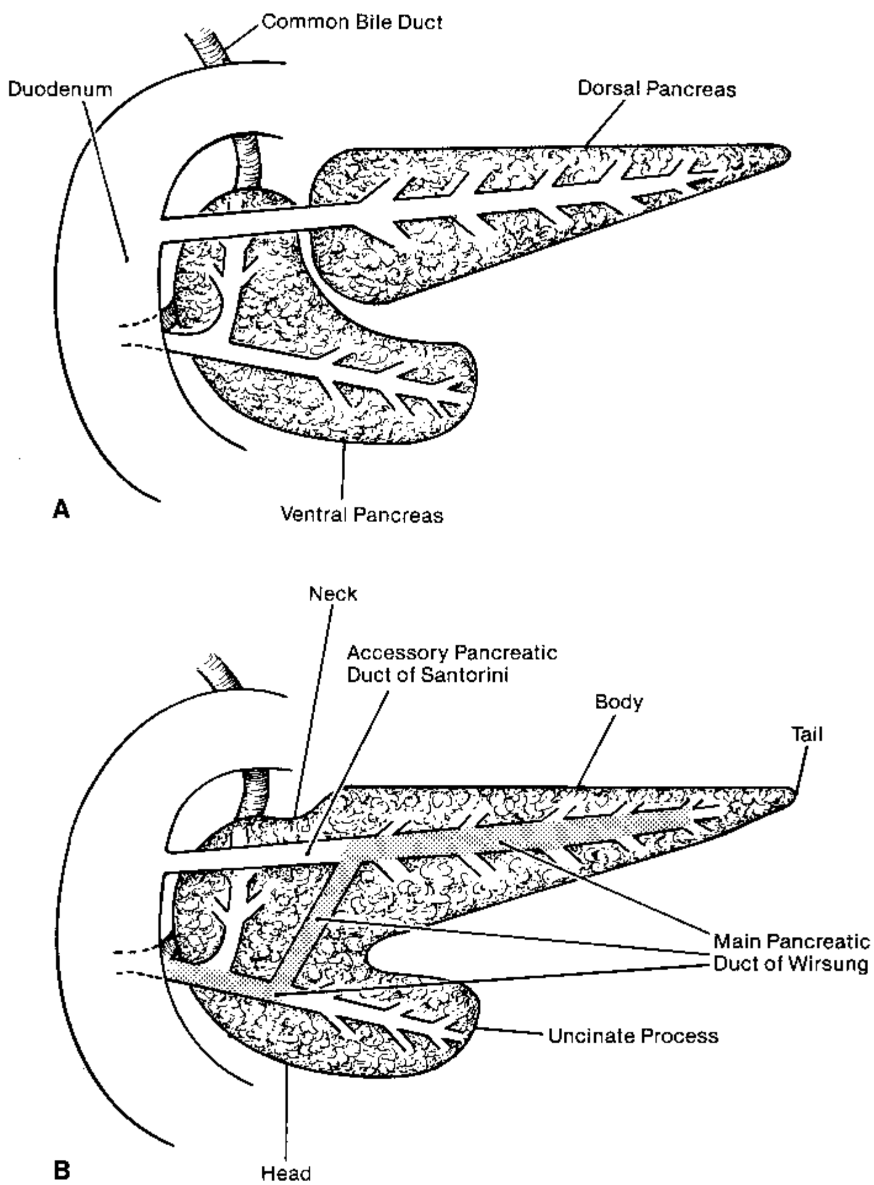


Figure 5–23. *A*, Anterior view of embryonic dorsal and ventral pancreata at a stage prior to their fusion. *B*, The final state of pancreatic form resulting from fusion of this organ's embryonic components.

As the ventral and dorsal pancreata fuse, a new segment of duct forms to bridge between the ventral and dorsal ducts (see Fig. 5-23*B*). The ventral duct, this new bridging segment, and all the dorsal duct to the left of the bridging segment comprise the **main pancreatic duct (of Wirsung)**. It pierces the wall of the second part of the duodenum along with the common bile duct, and joins it to form a very short common "hepatopancreatic" duct that empties into the duodenal lumen (at the junction of the superior two thirds with the inferior third of the second part). The "hepatopancreatic" duct has a dilation called the **ampulla of Vater**, and its opening into the duodenum is surrounded by a circular smooth muscle called the **sphincter of Oddi**. The thickness of the sphincter muscle causes a bump in the mucosal lining of the duodenum marking the site of entry of the "hepatopancreatic" duct. The bump is called the **major duodenal papilla**.

That part of the dorsal pancreatic duct lying to the right of the bridging segment usually persists as a patent structure that empties into the lesser curvature of the second part of the duodenum a couple of centimeters superior to the major papilla (see Fig. 5-23*B*). This part of the dorsal duct is called the **accessory pancreatic duct (of Santorini)**. The bump on the duodenal mucosa where the accessory duct empties is called the **minor duodenal papilla**. Sometimes the connection between the accessory duct and the duodenum is lost, in which case the part of the dorsal duct that would have become the accessory duct remains simply as a tributary of the main duct.

Midgut

The midgut is that portion of the gut tube to which the vitelline duct attaches. It lies immediately caudal to the hepatopancreatic diverticulum. Its artery is the superior mesenteric. The midgut will become that part of the duodenum caudal to the opening of the common bile duct, the entire jejunum (which is two fifths of the nonduodenal small intestine) and ileum (three fifths of the nonduodenal small intestine), the cecum (with appendix), ascending colon, and most of the transverse colon. All the events that lead to these structures occur simultaneously with what has been just described for the foregut.

The duodenal portion of the midgut becomes retroperitoneal, as does that segment of the duodenum derived from the foregut. Smooth muscle fibers migrate from the fourth part of the duodenum into the connective tissue behind it, eventually forming a fibromuscular band that runs from this part of the duodenum up to the perivascular connective tissue at the origins of the celiac and superior mesenteric arteries. This band, which is viewed by surgeons as marking the boundary between the duodenum and jejunum, is called the **suspensory muscle of the duodenum, or the ligament of Treitz**.

The most notable developmental change in the postduodenal midgut is its tremendous growth in length. This growth is so rapid that there is insufficient space within the abdominal cavity to accommodate both the midgut and the expanding liver. As a result, the midgut forms a large loop that passes into the extraembryonic part of the peritoneal cavity residing in the umbilical cord (Fig. 5-24). This represents a physiological (i.e., normal) umbilical herniation of the midgut. That portion of the loop which runs from the foregut out of the abdomen to the site where the vitelline duct attaches is called the **cranial limb of the midgut loop**. That portion which runs from the site of the vitelline duct back into the abdomen to join the hindgut is called the **caudal limb of the midgut loop**. The superior mesenteric artery runs toward the site of origin of the vitelline duct and thus must itself elongate as the midgut herniates (see Fig. 5-24). The root of the midgut mesentery is very short, extending along the front of the aorta from a site just above the origin of the superior mesenteric artery to a site just below it. From this short root the mesentery must fan out tremendously to cover the whole length of the growing midgut (see Fig. 5-24).

In the caudal limb of the midgut loop, not far from the vitelline duct, an outpocketing develops that marks the **cecum** (see Fig. 5-25). The cranial loop and the prececal part of the caudal loop continue an unabated growth which throws them into many subsidiary loops (see Fig. 5-25). The postcecal part of the caudal loop obviously gets bigger, but its growth is slow enough that it remains essentially straight.

Simultaneously with these growth changes, the midgut loop begins a rotation using the superior mesenteric artery as an axis. The cranial limb swings first to the right of the caudal limb, and then caudal to it (Fig. 5-26). The two limbs cross near the umbilicus. After the rotation, the limbs of the midgut loop don't change their names, but, within the extraembryonic coelom, they have exactly the opposite relationship to one another than that implied by their names

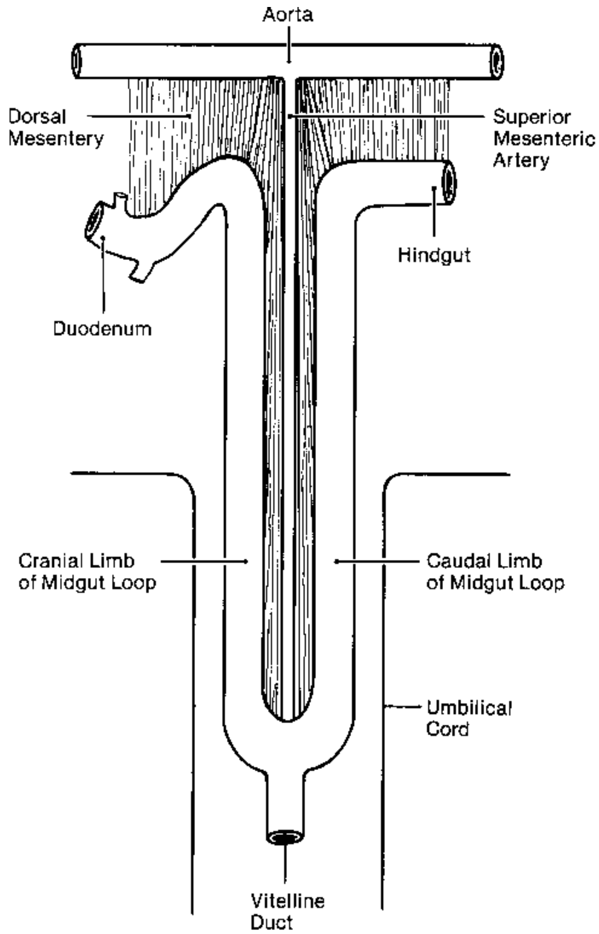


Figure 5–24. Left lateral view of embryonic midgut loop having herniated into the umbilical cord.

When the abdominal cavity has increased sufficiently in size to accommodate both the midgut and the liver, the twisted convoluted midgut returns to the abdominal cavity. Those regions of the midgut closest to umbilicus return first, and they move into the upper left quadrant of the abdominal cavity, near the stomach (Fig. 5-27). The cecum and prececal part of the caudal limb return last, and occupy the right iliac fossa. The liver is still very big and because its lower pole extends into the right iliac fossa, the cecum abuts the liver (see Fig. 5-27). That part of the colon derived from the midgut runs from the right iliac fossa obliquely upward and to the left, toward the spleen. It forms an "oblique" colon. With subsequent enlargement of the abdominal cavity and "retreat" of the liver cranially, **ascending and transverse colons** differentiate from this "oblique" colon (Fig. 5-28). The bend at the junction between the ascending and transverse colons is called the **right (or hepatic) flexure of the colon**.

One must keep in mind that throughout all the events described above the root of the midgut mesentery stayed confined to a short region centered at the origin of the superior mesenteric artery (Fig. 5-29), which itself runs from its origin on the aorta posterior to the body of the pancreas, downward and to the right between the layers of the midgut mesentery. After the ascending colon differentiates, it and its mesentery "fall" against the posterior abdominal wall on the right side. The visceral peritoneum on the back surface of the ascending colon and the triangular mesentery of the ascending colon fuse with the parietal peritoneum. This has three rather interesting consequences. First, the ascending colon becomes secondarily retroperitoneal. Second, the root of the mesentery for the small intestine now becomes a linear structure that runs from the origin of superior mesenteric artery downward and to the right (Fig. 5-30), ending on the anterior surface of the right psoas major below the iliac crest. The superior mesenteric artery itself lies in the new root; together they cross a number of important retroperitoneal structures (see

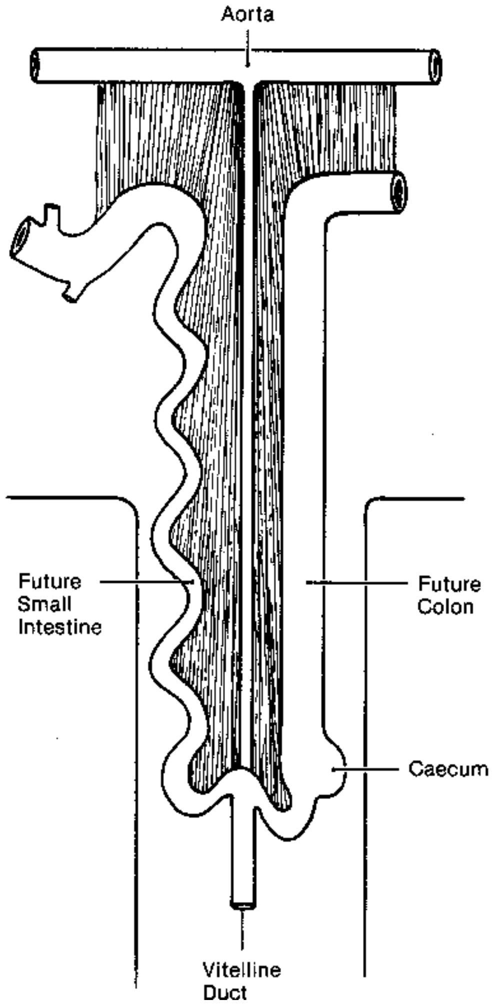


Figure 5-25. Left lateral view of embryonic midgut at a stage subsequent to that depicted on Figure 5-24. The future small intestine and colon can be identified.

further on). Third, the mesentery of the right half of the transverse colon gains a new linear root that runs from the origin of the superior mesenteric artery across the anterior surfaces of the pancreatic head and second part of the duodenum toward the hepatic flexure (see Fig. 5-30).

After return of the midgut to the abdominal cavity, the vitelline duct usually degenerates, leaving no clue to its site of origin. In a small percentage of cases, this degeneration is incomplete. Then a narrow tubular outpocketing (**Meckel's diverticulum**) of the ileum can be found on its antimesenteric border approximately 2 feet from the ileocecal junction. Even more rarely, a child may be born in whom the diverticulum extends all the way to the umbilicus, where it opens up onto the surface of the skin as an **umbilico-ileal fistula**.

Hindgut

The hindgut becomes the last few inches of the transverse colon, the descending colon, sigmoid colon, and rectum. In the embryo, all but the rectum are originally suspended by a dorsal mesentery. The hindgut does not grow nearly so much as the midgut and does not herniate through the umbilicus. When

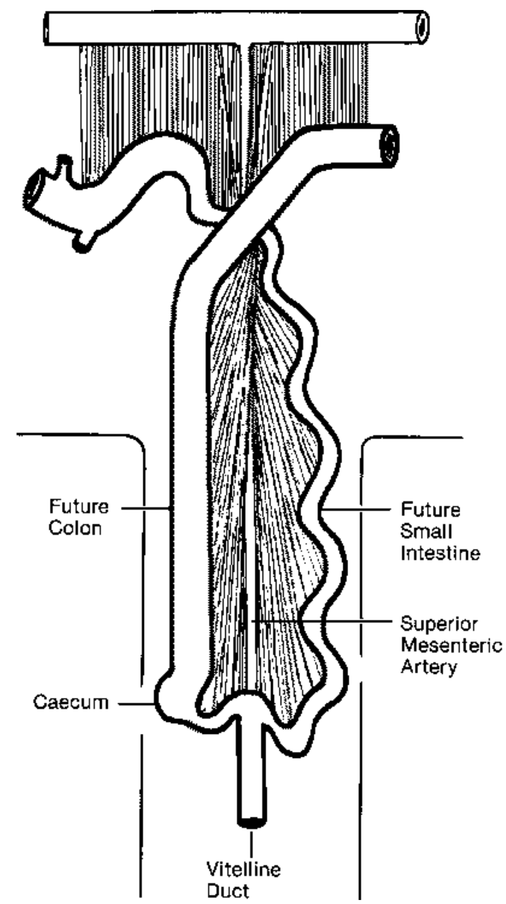


Figure 5-26. Left lateral view of embryonic midgut at a stage in development subsequent to that depicted in Figure 5-25. The midgut loop has undergone a rotation around an axis coinciding with the superior mesenteric artery.

the midgut loop begins its re-entry into the abdominal cavity, it pushes to the hindgut against the left posterior abdominal wall. Just as the ascending colon became retroperitoneal and its triangular mesentery fused with the parietal peritoneum, so does most of the hindgut and its rectangular mesentery (see Fig. 5-30). The secondarily retroperitoneal portion of the hindgut is called the **descending colon**. Between it and the rectum is a part of the hindgut that keeps a mesentery; this is the **sigmoid colon**. The bend at the junction of the transverse colon with the descending colon is called the **left (or splenic) flexure**. The bend at the junction of the descending colon with the sigmoid colon is called the **sigmoid flexure**.

One result of the descending colon having become retroperitoneal is that mesentery of the left half of the transverse colon gains a new linear root that runs from the origin of the superior mesenteric artery along the lower border of the pancreas toward the splenic flexure. Another result is that the mesentery of the sigmoid colon gains a new root that runs from the left psoas major, across the iliac vessels, and toward the vertebral column opposite S3, where the rectum begins. The root of the sigmoid mesocolon is not exactly straight but tends to take a curved course upward and then back down to S3.

The Last Change in the Mesenteries

We have reached a state in which all the mesenteries except the lower mesogastrium and the mesentery of the transverse colon (i.e., **transverse mesocolon**) have achieved their adult condition. The lower mesogastrium arises from the lower border of the body of the pancreas, loops down toward the pelvis, and returns back up to that part of the greater curvature that faces inferiorly. The left half of the transverse mesocolon arises just inferior to the root of the lower mesogastrium and passes directly to the transverse colon. Obviously, the posterior sheet of the lower mesogastrium is in close proximity to the transverse colon and mesocolon (Fig. 5-31). Where they contact one another, the lower mesogastrium fuses to the transverse mesocolon and to the visceral peritoneum on the anterior surface of the transverse

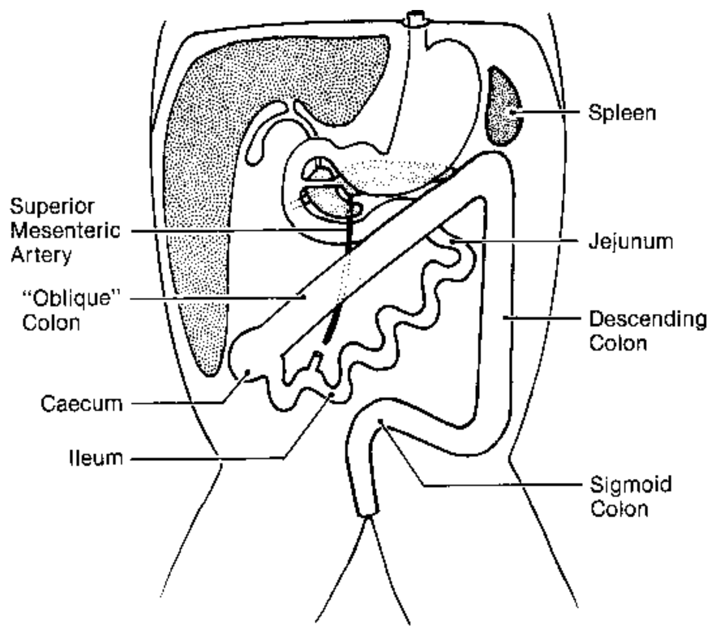


Figure 5–27. Schematic anterior view of embryonic abdominal cavity immediately following return of the midgut into this cavity (mesenteries not drawn).

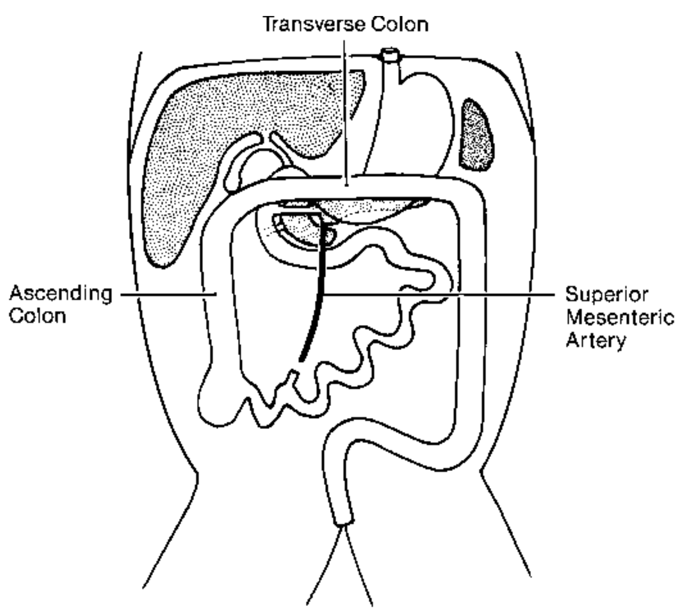


Figure 5–28. Schematic anterior view of embryonic abdominal cavity at a stage subsequent to the development of the definitive ascending and transverse colons (mesenteries not drawn).

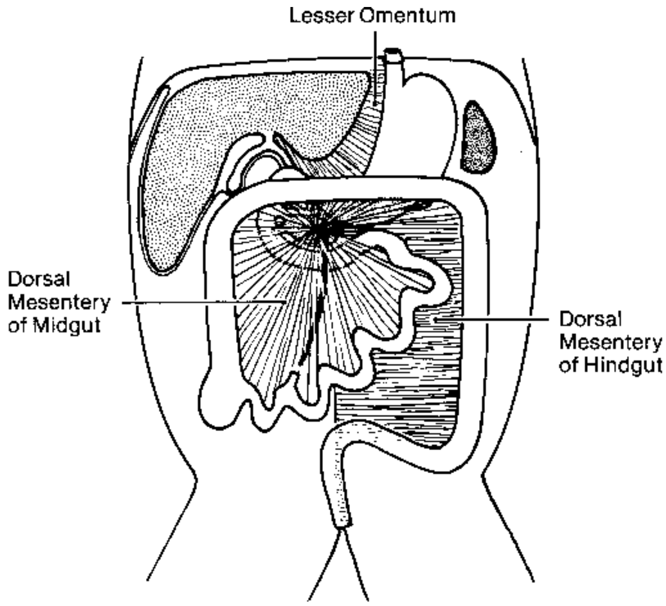


Figure 5–29. Schematic anterior view of embryonic abdominal cavity at same stage as depicted in Figure 5–28, but with lesser omentum, mesentery of midgut, and mesentery of hindgut drawn (mesogastrium not drawn). At this stage, neither the ascending nor descending colons have become secondarily retroperitoneal.

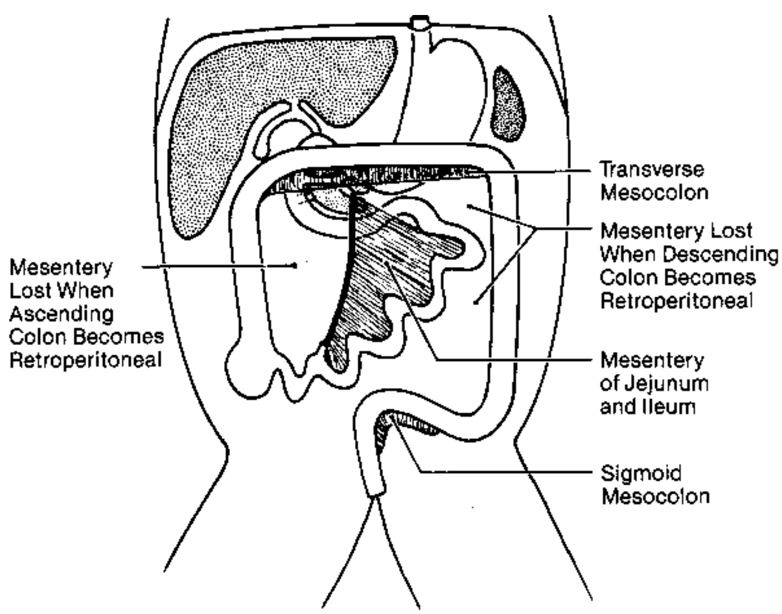


Figure 5–30. Schematic anterior view of embryonic abdominal cavity at a stage in development subsequent to that depicted in Figure 5–29 (mesogastrium not drawn). The ascending and descending colons have become secondarily retroperitoneal. Consequently, the mesentery of the jejunum and ileum, the transverse mesocolon, and the sigmoid mesocolon all gain new roots.

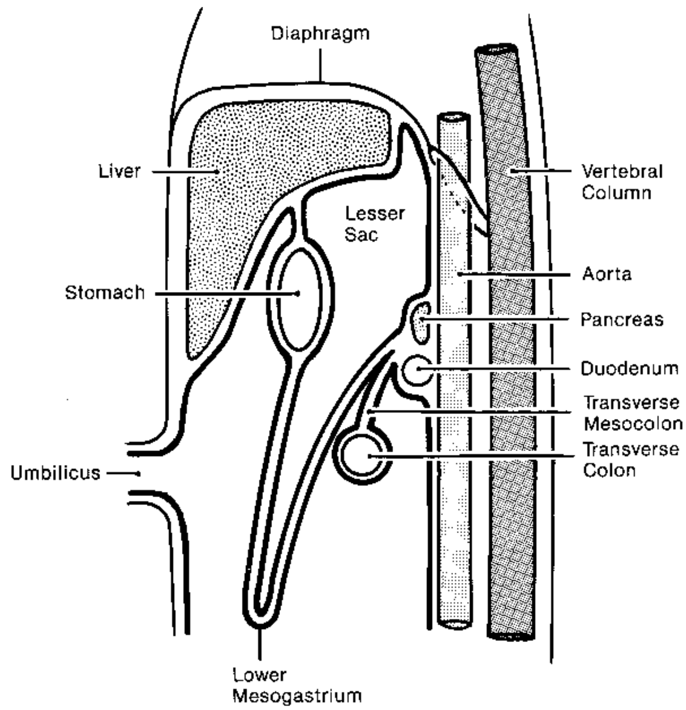


Figure 5–31. Schematic median sagittal section of embryonic abdomen showing relationships of transverse colon and transverse mesocolon to the lower mesogastrium.

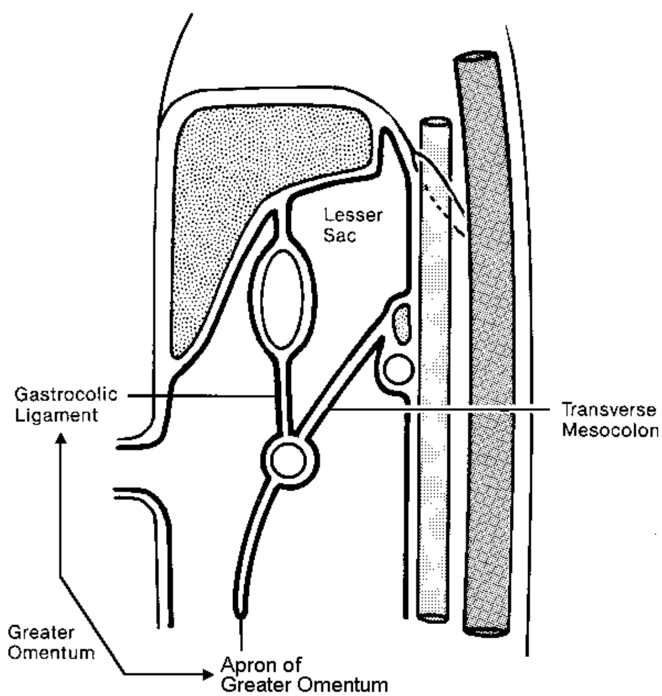


Figure 5–32. Schematic median sagittal section of embryonic abdomen at a stage in development subsequent to that depicted in Figure 5–31. The transverse mesocolon has fused to the superior portion of the lower mesogastrium, and most of the inferior recess of the lesser sac has become obliterated by fusion of the anterior and posterior sheets of the lower mesogastrium.

colon (Fig. 5-32). The fusion of lower mesogastrium with transverse mesocolon produces a single bilayer of mesentery that retains the name of transverse mesocolon. The remainder of the posterior sheet of the lower mesogastrium now takes origin from the visceral peritoneum of the transverse colon and descends toward the pelvis. This part of the posterior sheet then fuses with the anterior sheet of the lower mesogastrium, obliterating most of the lower recess of the lesser sac (see Fig. 5-32). Above the zone of fusion, the anterior sheet continues from the visceral peritoneum of the transverse colon up to the greater curvature of the stomach. The entire mesenteric structure that hangs down from the stomach is called the greater omentum. The upper part of the greater omentum, running between stomach and transverse colon, is called the **gastrocolic ligament**. The lower part, extending inferior to the transverse colon, is called the **apron of the greater omentum**.

IDENTIFICATION OF BOWEL SEGMENTS UPON SURGICAL ENTRANCE TO GREATER SAC

Upon entering the peritoneal cavity via an anterior abdominal incision, any mesenteric portion of the bowel may be encountered first. Thus, the surgeon is confronted with deciding whether a particular loop of bowel might be jejunum, ileum, transverse colon, or sigmoid colon. The first clue in making this decision is that colon is characterized by two or three longitudinal bands of smooth muscle, each band called a **taenia coli**, that are readily seen beneath the visceral peritoneum. (By definition, the rectum begins when the taeniae coli of the sigmoid colon fan out to become a uniform sleeve around the bowel.) The second clue is that the external surface of the colon is characterized by little fatty protuberances that cause outpocketings of its visceral peritoneum. These peritoneum-covered fatty protuberances are called **appendices epiploicae**. If the mesenteric loop of bowel you are looking at doesn't have taenia and doesn’t have appendices epiploicae, then it must be part of the small intestine.

If you have identified a loop of bowel as small intestine, whether it is jejunum or ileum can usually be determined by an assessment of the amount of fat within the mesentery. Fat deposition is greater in the meso-ileum. In all but very thin persons, the fat in the meso-ileum extends right up to the wall of the bowel, even overlapping it, so that one cannot clearly distinguish the mesenteric edge of the ileum. The mesojejunum has less fat, thus the mesenteric edge of the jejunum is easily seen. In fact, the mesojejunum is usually characterized by fat-free patches near the bowel wall. Thus, one can actually see through the mesentery to the opposite side, and can also visualize the vessels to and from the jejunum.

If the bowel segment presents with appendices epiploicae, and thus can be identified as colon, it is only necessary that one count the number of mesenteries attached to it. The sigmoid colon has only the sigmoid mesocolon attached along one edge. The transverse colon has the gastrocolic ligament, the greater omentum and the transverse mesocolon running to it.

ARTERIES TO THE GUT AND TO ITS ASSOCIATED STRUCTURES

Celiac Artery (Celiac Trunk)

The celiac artery is for supply of the abdominal foregut, its derivatives and their mesenteries. It also supplies the spleen, which we know develops in the upper mesogastrium.

The celiac artery comes off the ventral surface of the aorta immediately below the superior edge of L1. This coincides with the upper border of the body of the pancreas (Fig. 5-33). The celiac artery is rarely more than 2 to 3 cm long, often less. It trifurcates almost immediately into its three major branches: the **splenic, common hepatic, and left gastric arteries**.

Splenic Artery

The splenic artery runs toward the left (retroperitoneally) along the superior edge of the body of the pancreas (see Fig. 5-33), to which it gives branches. It follows the tail of the pancreas into the lienorenal ligament, and therein to the spleen. Just prior to entering the spleen, the splenic artery gives off two or three **short gastric arteries** and a **left gastroepiploic artery**, all of which continue in the gastrosplenic part of the mesogastrium to reach the greater curvature of the stomach. The short gastric arteries run to the fundus. The left gastro-epiploic turns downward to enter the gastrocolic ligament, where it sends a large branch inferiorly to feed the greater omentum, and continues as a small artery that follows the greater curvature of the stomach about a centimeter from the stomach wall. The continuation of the left gastro-epiploic sends branches up to the stomach and down to the greater omentum, but it ends rather quickly by connecting up the right gastro-epiploic artery (see further on).

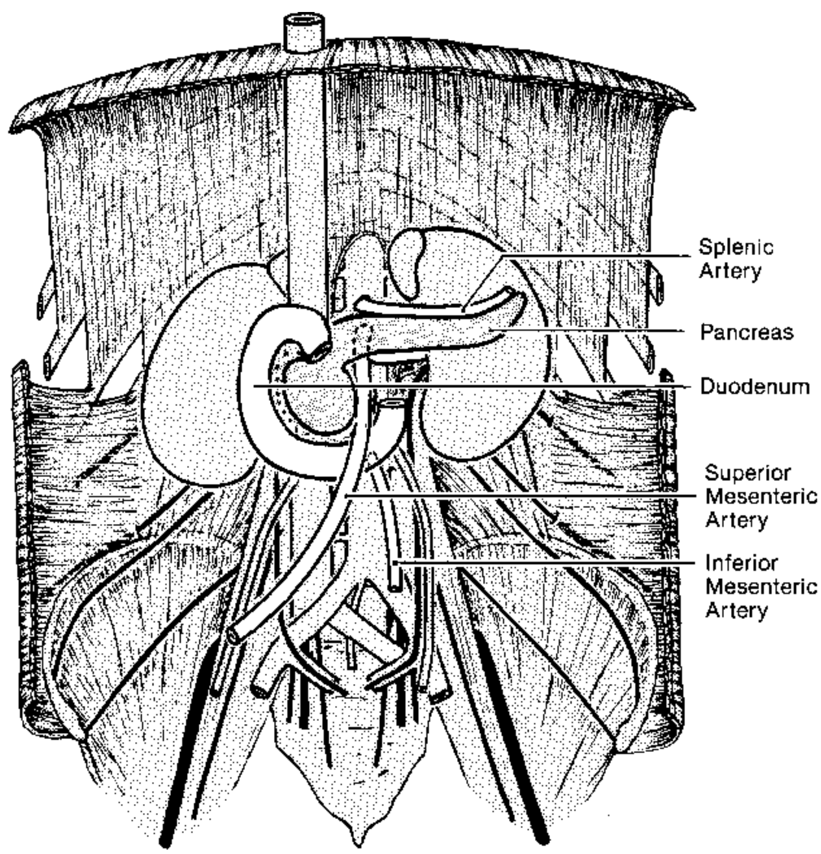


Figure 5-33. The positions of the pancreas, duodenum, splenic artery (from the celiac trunk), superior mesenteric artery, and inferior mesenteric artery in relation to other retroperitoneal structures of the abdomen.

Common Hepatic Artery

The common hepatic artery runs toward the right side (retroperitoneally) along the superior edge of the neck of the pancreas until the vessel reaches the back surface of the first part of the duodenum. At this point the common hepatic artery bifurcates into its **proper hepatic** and **gastroduodenal** branches.

The **proper hepatic artery** turns cranially, enters the hepatoduodenal ligament, and, lying to the left of the common bile duct, is carried by this mesentery to the liver. While in the hepatoduodenal ligament, the proper hepatic artery gives off a small **right gastric artery**, and then divides into **right and left hepatic arteries**. The right gastric artery turns inferiorly and heads back in the hepatogastric ligament toward the lesser curvature of the stomach near the pylorus. Upon reaching the stomach, the vessel follows the lesser curvature of the antrum, supplying branches to it. The right gastric artery doesn't go very far before it meets up with the left gastric artery (see further on).

Although the left lobe of the liver is only that part to the left of the left sagittal fissure, the left hepatic artery supplies not only this small portion of the liver, but also the caudate and quadrate lobes. The right hepatic artery supplies the liver to the right of the major portal scissura. **Surgeons recognize the physiological division of the liver by using the term "left lobe" to include the caudate and quadrate lobes along with the anatomists' left lobe.**

Before the right hepatic artery enters the liver it gives off a small **cystic artery** that follows the cystic duct to the gallbladder. The exact site of origin of the cystic artery is highly variable, and a surgeon setting out to perform removal of the gallbladder must trace any presumed cystic artery to make certain of its identity. Otherwise, there is the risk of tying off a hepatic artery by mistake.

The **gastroduodenal artery**, arising behind the first part of the duodenum, turns inferiorly toward the head of the pancreas. Almost immediately after its origin, the gastroduodenal artery gives off a tiny **supraduodenal branch**, which supplies the superior wall of the first part of the duodenum. While still behind the first part of the duodenum, the gastroduodenal gives off **retroduodenal branches** to the back wall of this structure. When the gastroduodenal reaches the upper edge of the pancreas it gives off a **posterior superior pancreaticoduodenal artery** that passes onto the posterior surface of the pancreas to supply its head and neck, and also the second part of the duodenum. The gastroduodenal itself moves onto the anterior surface of the pancreas and so bifurcates into **anterior superior pancreaticoduodenal and right gastro-epiploic arteries**. The former runs on the anterior surface of the pancreatic head, paralleling the lesser curvature of the duodenum, and supplying it and the pancreas. The right gastro-epiploic artery enters the gastrocolic ligament and runs in it toward the left side, paralleling the greater curvature of the stomach a centimeter or so from its wall. The right gastro-epiploic artery supplies gastric branches to the stomach and epiploic branches that travel inferiorly to supply the greater omentum. The right gastro-epiploic artery ends by joining the left gastro-epiploic artery, forming a gastro-epiploic arcade.

Left Gastric Artery

The left gastric artery follows a retroperitoneal course superiorly toward the esophagogastric junction where the lesser omentum and mesogastrium converge. Here the vessel gives off branches to the abdominal part of the esophagus, then runs inferiorly in the hepatogastric ligament parallel the lesser curvature of the stomach, supplying its body and some of its antrum.

Superior Mesenteric Artery, SMA

The superior mesenteric artery is for supply of the midgut and its mesentery. It arises from the front of the aorta opposite the lower half of L1. Thus, the origin lies behind the body of the pancreas and only a centimeter or so below that of the celiac artery (see Fig. 5-33).

The SMA runs a course downward and to the right (see Fig. 5-33). Early in its course, while it is still behind the body of the pancreas, the vessel gives off small branches (and occasionally a large one) to the pancreas. This early part of the superior mesenteric artery lies anterior to the left renal vein, which is crossing the aorta on its way to the inferior vena cava (see Fig. 5-33).

As the superior mesenteric artery emerges from under cover of the body of the pancreas, the vessel encounters the beginning of the root of the small bowel mesentery where this intersects the root of the transverse mesocolon. Here the superior mesenteric artery gives off **middle colic** and **inferior**

pancreaticoduodenal arteries. The middle colic artery passes into the transverse mesocolon to reach the transverse colon, where it divides into right and left branches. The inferior pancreaticoduodenal artery (which may instead arise from the first jejunal branch of the SMA) runs toward the right (retroperitoneally), supplying the head of the pancreas and the third part of the duodenum. Its anterior and posterior branches join the respective superior pancreaticoduodenal arteries to form anterior and posterior pancreaticoduodenal arterial arcades.

The remainder of the SMA follows a course in the root of the small bowel mesentery, crossing the third part of the duodenum, sometimes the aorta, and the inferior vena cava. Eventually it moves onto the anterior surface of the right psoas major (see Fig. 5-33), where it runs (crossing anterior to the right ureter and gonadal vessels[17]) to below the iliac crest, terminating in branches to the distal ileum.

As the SMA follows its course in the root of the small-bowel mesentery, the vessel gives off from its left side a whole series of **intestinal arteries** that enter this mesentery. The early members of the series are destined for the jejunum, those given off later on are for the ileum. As these intestinal arteries approach the wall of the bowel they bifurcate and each of the resulting branches connects with those of the next higher or next lower intestinal artery. As a result, a series of primary **arterial arcades** are formed. From these, primary arcades branches are sent toward the wall of the bowel, and these too bifurcate and anastomose to form a secondary series of arcades. The jejunal arteries usually form only two such arcades, but as one progresses to lower and lower intestinal arteries up to four series of arcades may be formed. From the arcade closest to the bowel, straight arteries called **vasa recta** proceed directly to the bowel wall. Where there are fewer arcades (jejunum) the vasa recta are longer than where there are many arcades (distal ileum). In a very thin person in whom the mesenteric blood vessels of both the ileum and jejunum can be visualized, one may be guided in identifying regions of the small intestine by the knowledge that the number of arcades in the jejunum does not exceed two, whereas this increases to three and four as one progresses down the ileum.

We have considered the branches of the SMA to the small intestine and the transverse colon, but this vessel, being the artery of the midgut, also must supply the cecum, appendix, and ascending colon. Since these structures have become secondarily retroperitoneal, the branches to them are also retroperitoneal. From the right side of the SMA, at about the middle of its path down the mesenteric root, comes the **ileocolic artery**, which runs a pretty straight retroperitoneal course toward the cecum in the right iliac fossa. About half the time, the first branch of this ileocolic artery is the **right colic**, which travels directly toward the right to reach the middle of the ascending colon, where it divides into a superior and inferior branch. If not arising from the ileocolic, the right colic either comes of the SMA further proximally, or is absent. As the ileocolic artery nears the cecum it gives off **branches to the cecum, appendix, and terminal ileum**.

Inferior Mesenteric Artery, IMA

The inferior mesenteric artery is for the hindgut. Since the mesentery to the left colon has fused with the parietal peritoneum, the inferior mesenteric artery and its branch to the descending colon are retroperitoneal. Its branches to the sigmoid colon start out as retroperitoneal, but obviously must enter the sigmoid mesocolon at its root. The rectal branch of the inferior mesenteric artery maintains a retroperitoneal course throughout.

The IMA arises from the front of the aorta opposite the body of L3 and deep to the third part of the duodenum (see Fig. 5-33). It travels downward, anterior to the left edge of the aorta. The IMA has a course medial to, and almost paralleling, the left ureter (see Fig. 5-33).

---

[17] One could have deduced that the superior mesenteric artery would cross *anterior* to the ureter and gonadal vessels because the latter two structures are primarily retroperitoneal, whereas the superior mesenteric comes to this position secondarily.

The first branch of the inferior mesenteric artery is the **left colic artery**, which either takes a course directly toward the left to reach the descending colon, or passes upward and to the left toward the splenic flexure. The left colic artery crosses anterior to the ureter and gonadal vessels, and upon reaching the colon, the artery divides into a superior and inferior branch.

Further along its course, the inferior mesenteric artery gives off a few **sigmoidal arteries** that descend obliquely downward and toward the left to reach the root of the sigmoid mesocolon, enter it, and supply the sigmoid colon. The sigmoidal arteries participate in an arcade formation similar to that of the jejunal arteries.

As the inferior mesenteric crosses the left common iliac artery, it bifurcates into its last sigmoidal artery and the **superior rectal artery**. The latter passes into the pelvis behind the rectum, which it supplies.

Arterial Anastomoses

The arteries to the bowel have extensive anastomoses with one another. These are of considerable clinical importance, because they allow blood to reach segments that would otherwise be deprived of blood by virtue of arteriosclerotic occlusive disease of a main trunk, or by the necessity to tie off certain vessels during resection of bowel segments. Since **anastomoses between two arteries occur at sites where their areas of supply overlap or abut**, one can generally deduce which vessels are involved based solely on a knowledge of arterial distribution. The anastomotic connections of arteries for the bowel fall into two categories, those between branches of the same main trunk off the aorta, and those between branches of different trunks off the aorta. Don't memorize the lists presented below; try to think how you could have deduced them

Between Branches of the Same Trunk

The important anastomoses between branches of the celiac artery are:

4. Right gastric with left gastric, along the lesser curvature of stomach
5. Right gastro-epiploic with left gastro-epiploic, along the greater curvature of stomach
6. All the branches that supply the stomach, within its wall

The important anastomoses between branches of the SMA are:

.

1. The intestinal branches with one another, via the arcades within the mesentery
2. The ileocolic with the last intestinal, via arcades.
3. An ascending branch of the ileocolic with the inferior branch of the right colic.
4. The right branch of the middle colic with the superior branch of the right colic, near the hepatic flexure. If the right colic is absent, the right branch of the middle colic anastomoses with the ascending branch of the ileocolic.

The important anastomoses between branches of the IMA are:

1. The inferior branch of the left colic with an ascending branch of the first sigmoidal.
2. The sigmoidal arteries with each other, via the arcades in the sigmoid mesocolon.
3. A tenuous anastomosis of the last sigmoidal artery with the superior rectal, via an arcade within the sigmoid mesocolon.

Between Branches of Different Trunks

The esophageal branches of the left gastric and short gastric arteries anastomose with esophageal arteries from the thoracic aorta.

The important anastomoses between the celiac artery and the SMA are:

1 Superior pancreaticoduodenal with inferior pancreaticoduodenal.
2. Pancreatic branches of the splenic artery with those of the SMA.
3. The epiploic branches of the gastro-epiploic arteries with the middle colic artery, over the surface of the transverse colon.

The important anastomoses between the SMA and IMA are:

1. The left branch of the middle colic with the superior branch of the left colic (said to be tenuous).
2. Occasionally there is a rather substantial vessel that arises either from the root of the middle colic artery, or from the superior mesenteric artery near the origin of the middle colic, and arches to the left and downward to meet the left colic artery; this vessel lies retroperitoneally about two inches away from the margin of the descending colon; it is called the **Arc of Riolan**.

The various anastomoses between the different colic arteries creates a long arterial channel that lies near the inner margin of the large intestine. This anastomotic channel is called the **marginal artery of Drummond**.

Variations in Arteries to the Gut

The arterial supply to the gut is so variable that one does not often find a person with the exact pattern just described. The most frequent variations are:

1. About 25% of the time the right hepatic artery comes from SMA, rather than from proper hepatic. This is not so surprising given the proximity of the hepatopancreatic diverticulum to the midgut.
2. The left gastric artery may come from the left hepatic, or vice versa
3. The right colic artery may come directly from the SMA just above the origin of the ileocolic, or be entirely absent.
4. The left colic artery may be absent or may come off an Arc of Riolan that has no connection to the IMA.

In general, one must be mentally prepared to find arteries coming from surprising places.

VENOUS DRAINAGE FROM THE GUT AND FROM ITS ASSOCIATED STRUCTURES

Near each of the aforementioned arteries, with the exception of the gastroduodenal and hepatic arteries, is a vein carrying blood in the opposite direction. However, the venous blood from the gut, pancreas, and spleen does not enter the inferior vena cava directly, as one might have thought, but instead is sent first to the liver (where metabolites are exchanged) and only then to the inferior vena cava.

Superior Mesenteric, Splenic, and Portal Veins

The superior mesenteric vein lies on the right side of its companion artery in the root of the mesentery (Fig. 5-34). After it crosses the uncinate process of the pancreas, the superior mesenteric vein passes behind the neck of the pancreas where it joins with the splenic vein to create the portal vein. The splenic vein reaches the posterior surface of the pancreatic neck by running a course on the posterior surface of the body of the pancreas (see Fig. 5-34). This course takes the splenic vein anterior to the origin of the SMA.

The portal vein, formed posterior to the pancreatic neck just to the right of the midline, passes upward behind the first part of the duodenum to enter the hepatoduodenal ligament posterior to the proper hepatic artery. Just before the liver is reached the portal vein divides into left and right branches,

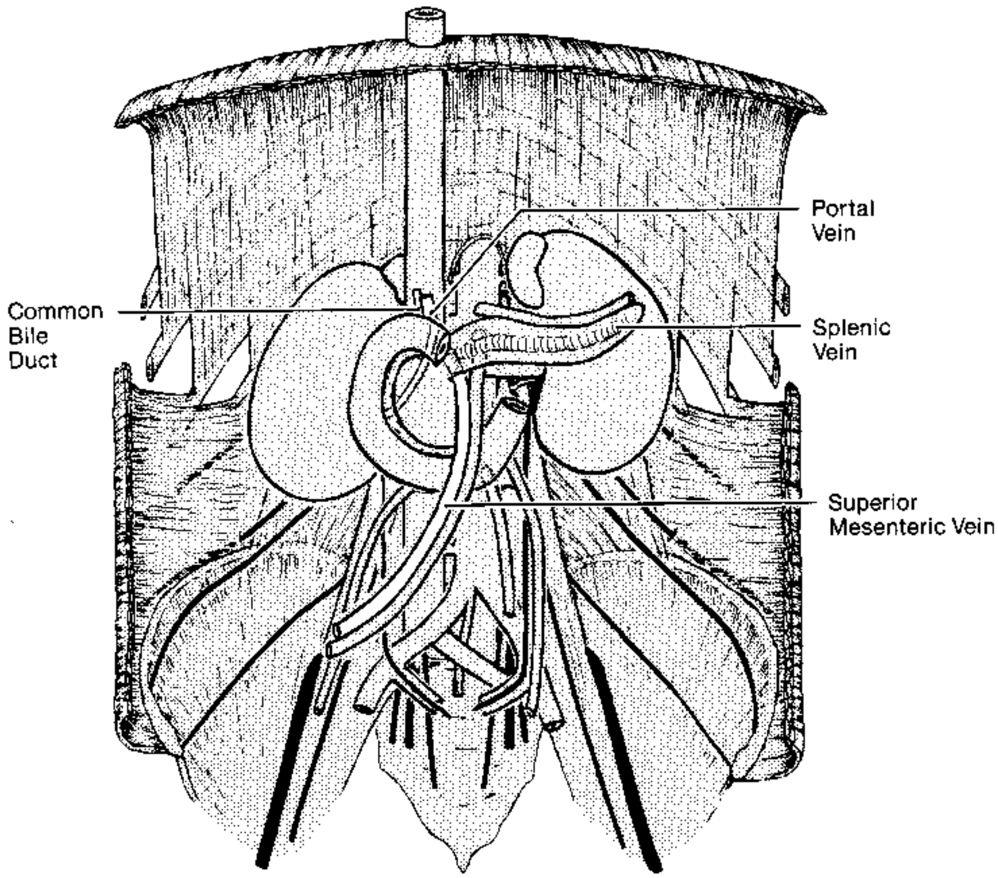


Figure 5-34. The positions of the superior mesenteric vein, splenic vein, portal vein, and common bile duct in relation to other abdominal structures.

which accompany the right and left hepatic arteries and bile ducts to the surgeon's right and left lobes of the liver.

Inferior Mesenteric Vein

The inferior mesenteric vein runs upward on the left side of its companion artery. The vein and artery diverge as they ascend, so that vein follows a more or less vertical course to the left of the midline, reaching the deep surface of the body of the pancreas, and terminating here in the splenic vein. Sometimes, the inferior mesenteric vein follows the IMA posterior to the third part of the duodenum and empties either into the terminal part of the superior mesenteric vein or into the site of formation of the portal vein behind the pancreatic neck.

Left Gastric, Right Gastric, and Cystic Veins

The left gastric vein follows its arterial counterpart down to its origin from the celiac artery. At this site the vein can either turn right to empty into the portal vein or proceed straight to empty into the splenic vein.

The right gastric vein joins the portal vein as it runs to the liver in the hepatoduodenal ligament.

The cystic vein empties into the right branch of the portal vein just before the latter enters the liver.

Why Are There No Hepatic and Gastroduodenal Veins Accompanying Hepatic and Gastroduodenal Arteries?

Within the liver the portal vein branches repeatedly (along with the arteries and bile ducts), eventually forming a venous capillary network called the **hepatic sinusoids**. These sinusoids not only receive blood from the portal vein but also drain venous blood from the capillary network of the hepatic arteries. In turn, the hepatic sinusoids empty into a second set of veins within the liver called **hepatic veins**. Small hepatic veins coalesce into two or three large hepatic veins that leave the liver to empty into the inferior vena cava as it lies in the vena caval fossa.

The liver receives blood from two sources: the hepatic arteries and the portal vein. Although venous blood is relatively deprived of oxygen, the volume of blood carried by the portal vein is so much greater than carried by the hepatic arteries that 50% or more of the liver's oxygen is provided by the portal vein. A liver can survive inadvertent hepatic artery ligation if the portal flow is normal and the liver is not otherwise diseased.

The veins that accompany the superior pancreaticoduodenal and right gastro-epiploic arteries do not join to form a gastroduodenal vein. Instead, they drain directly into the terminal part of the superior mesenteric vein.

SURGICAL ENTRANCE TO THE LESSER SAC

Now that we know something about the locations of vessels that supply the bowel, we can consider the impact of these locations on a particularly important surgical procedure in the abdomen. The lesser sac is a space that is hidden from view when the peritoneal cavity is entered by an anterior abdominal incision. Thus, diseases of the posterior wall of the stomach, the pancreas, or the left suprarenal gland will not be visible unless surgical entry is made into the lesser sac.

One of the most common problems requiring surgical entry into the lesser sac is an ulcer of the posterior wall of the stomach. If such an ulcer perforates, stomach contents are spilled into the lesser sac, producing a peritonitis and, often, a lesser sac abscess. This peritonitis may spread to the greater sac when contents of the lesser sac ooze out through the epiploic foramen. To drain a lesser sac abscess and to repair an ulcer of the posterior wall of the stomach, one must find a way to gain entry to the lesser sac. The only natural entrance is through the epiploic foramen, but obviously this is too small a hole through which to work. By incising one of the mesenteries that bound the sac, the surgeon can gain more working space. But these mesenteries are not equally suitable as sites for such an incision. Let us consider their candidacy one by one.

1. Lesser Omentum--One might cut through the lesser omentum to enter the lesser sac, but the incision could not include the hepatoduodenal ligament because the common bile duct, proper hepatic artery, and portal vein run within it. An incision through the hepatogastric part of the lesser omentum provides neither a sufficient view nor sufficient mobilization of the stomach.

2. Lienorenal Ligament--Incision of the lienorenal ligament is contraindicated by the fact that the tail of the pancreas and splenic vessels run in this ligament perpendicular to the path of the incision.

3. Gastrosplenic Ligament--Entrance to the lesser sac by cutting through the gastrosplenic ligament is contraindicated by the fact that the short gastric and left gastro-epiploic vessels run in this ligament perpendicular to the path of the incision.

4. Transverse Mesocolon--Making a transverse incision in the transverse mesocolon would allow wide access to the lesser sac but, more importantly, would cut through the middle colic vessels and, thus, is unacceptable.

5. Gastrocolic Ligament-- A transverse incision through the gastrocolic ligament is the preferred method of entry to the lesser sac. Within this ligament run the gastro-epiploic vessels, *but* they course parallel to the incision, not perpendicular to it. Some surgeons choose to incise the gastrocolic ligament between the gastro-epiploic vessels and the greater curvature of the stomach; others choose an incision between the gastro-epiploic vessels and the transverse colon. In the first case, one is forced to cut gastric branches of the gastro-epiploic arcade; in the second case, one is forced to cut epiploic branches. The arterial anastomoses in the wall of the stomach are so extensive that incision of the gastric branches of the gastro-epiploic arcade is well tolerated. Those persons who choose this approach believe it actually produces less bleeding than cutting the extensive epiploic branches.

GENERAL TERMINOLOGY OF THE TRUE PELVIS

As mentioned earlier, the part of the trunk below the pelvic brim is called the true pelvis, or often simply the pelvis. It is divided by a muscular diaphragm into two parts (see Fig. 5-2). The part above the **pelvic diaphragm** is the **pelvic cavity** with its walls and contents. The pelvic cavity is much smaller than the abdominal cavity but is in open communication with it at the pelvic brim. The part of the pelvis below the pelvic diaphragm is the **perineum**.

By virtue of the fact that the lower wall of the peritoneal sac coincides with a transverse plane between the end of the sacrum and the pubic crests (see Fig. 5-2), the peritoneal cavity extends downward into the pelvic cavity. Since the pelvic diaphragm is inferior to the lower boundary of the peritoneum by a significant amount, there is an extraperitoneal space between the peritoneal sac and pelvic diaphragm. This space is occupied by connective tissue and by certain organs that will develop within it. If we can call the extraperitoneal space posterior to the peritoneal cavity the "retroperitoneal" space, then the extraperitoneal space below the peritoneal cavity is the **"subperitoneal"** space.

WALLS OF THE PELVIC CAVITY

Posterior, Anterolateral, and Anterior Walls

The pelvic cavity has no superior wall; it opens into the abdominal cavity. The posterior wall of the pelvic cavity is formed by the sacrum and by the piriformis muscle, which arises from the ventral surface of the sacrum. The anterolateral walls of the pelvic cavity are formed by the portion of each os coxae below its terminal line, and by a muscle (the obturator internus) that arises from the inner surface of the os coxae in the vicinity of the obturator foramen. The front wall of the pelvic cavity is formed by the bodies of the two pubic bones and the intervening pubic symphysis.

Inferior Wall--The Pelvic Diaphragm

The inferior wall of the pelvic cavity is the pelvic diaphragm. Like its abdominal counterpart, the pelvic diaphragm is a thin muscle that stretches completely from side to side and from front to back. Unlike its abdominal counterpart, the pelvic diaphragm is convex downward, not upward (Fig. 5-35*A*). It is markedly curved from side to side (see Fig. 5-41). The pelvic diaphragm has holes in it for passage of structures from the pelvic cavity into the perineum, or vice versa (Fig. 5-35*B*). Whereas the fascia on the

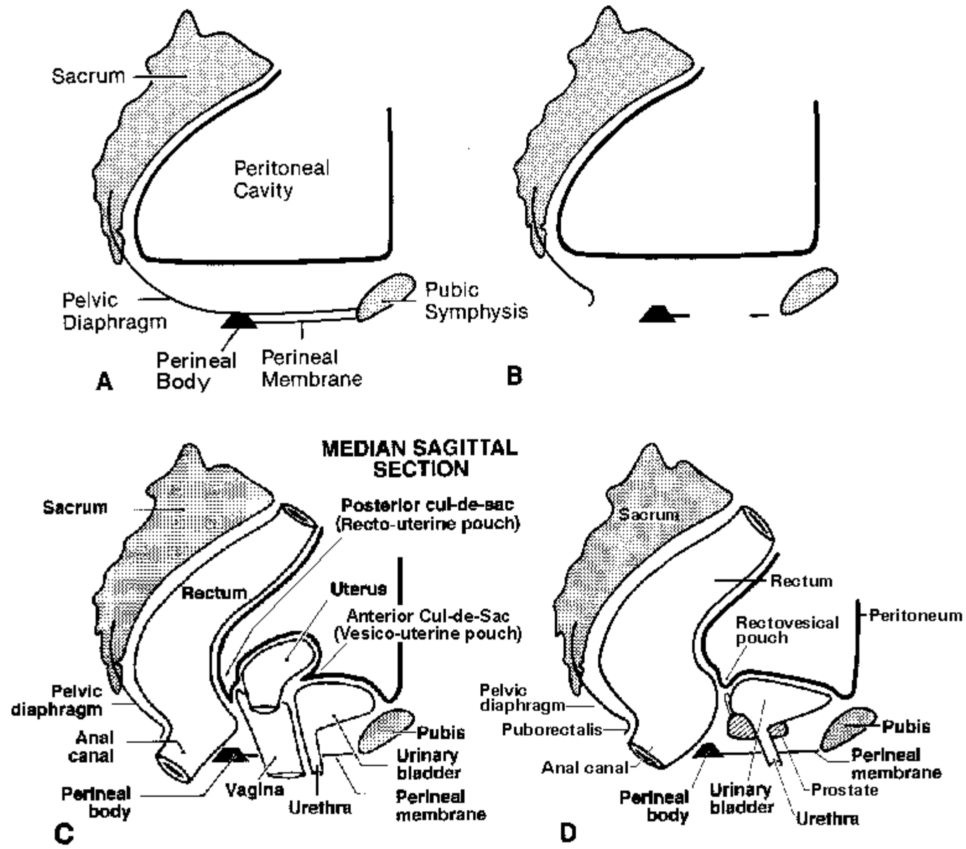


Figure 5-35. Schematic median sagittal sections of the pelvic cavity. *A*, Pelvic diaphragm and perineal membrane (urogenital diaphragm), drawn as if they had no holes. *B*, Pelvic diaphragm and perineal membrane with the midline holes actually found within them. *C*, Pelvic organs of a female passing through holes in the pelvic diaphragm and perineal membrane. *D*, Pelvic organs of a male passing through holes in the pelvic diaphragm and perineal membrane.

upper surface of the abdominal diaphragm is called endothoracic fascia, and that on its lower surface is called transversalis fascia, the comparable fascial layers on the upper and lower surfaces of the pelvic diaphragm are simply called the **superior and inferior fascias of the pelvic diaphragm**. The superior fascia is continuous with the transversalis fascia.

The pelvic diaphragm differs from the abdominal diaphragm in a few ways. First, as already mentioned, it is convex downward, not upward. Second, the pelvic diaphragm, though being a single sheet, is composed of two distinct muscles (Fig. 5-36*B*). One is the **levator ani**, the other is the **coccygeus**. The levator ani, like the abdominal diaphragm, has a central tendon. However, this central tendon is not a broad structure on which muscle fibers converge from all sides (see Fig. 5-36*A*). Rather, it is a short and narrow linear band running anteroposteriorly and receiving muscle fibers from either side (see Fig. 5-36*B*). The coccygeus was a muscle of the tail in our distant ancestors. In humans, the tail bones have been consolidated into the sacrum and coccyx. The coccygeus loses its function as a mover of the tail and, instead, joins the levator ani to form the pelvic diaphragm. The levator ani and coccygeus are derived from the hypaxial parts of the 3rd and 4th sacral dermomyotomes. Thus, they are innervated by the third and fourth sacral ventral rami. The pelvic diaphragm functions primarily to enable increase in intra-abdominal pressure by resisting downward displacement.

*Levator Ani (see Fig. 5-36*B*)*

The levator ani of each side begins its origin from the inner surface of the pubic body next to the lower margin of the symphysis. The origin then passes posterolaterally from the pubic bone onto the fascia covering the obturator internus muscle, extending along this fascia all the way back to the spine of the ischium. The obturator fascia is thickened where it gives origin to the levator ani (just as the fascias of the psoas major and quadratus lumborum were thickened where they gave origin to the abdominal diaphragm). This thickened ridge of obturator fascia is called the **arcus tendineus** (tendinous arch). The fibers of each levator ani pass from their origin to insert on a median linear **anococcygeal raphe** that starts just behind the anal canal (the part of the rectum below the pelvic diaphragm) and runs back to the coccyx. For a substantial distance posterior to the pubic symphysis is a gap between the left and right levators ani. The muscle fibers that arise from the pubis and insert onto the anococcygeal raphe form the margins of this gap, just as the crura of the abdominal diaphragm form the margins of the gap for the

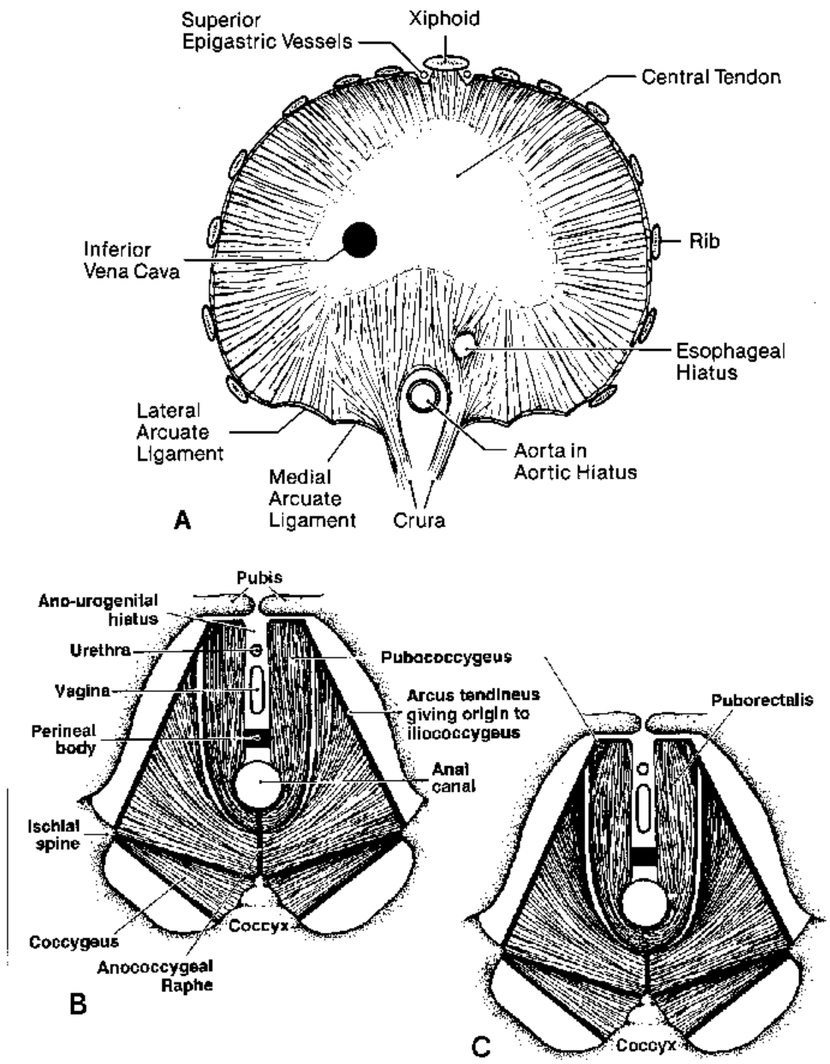


Figure 5–36. *A*, Inferior view of a flattened-out abdominal diaphragm showing major holes for passage of structures between the thoracic and abdominal cavities. *B*, Inferior view of a flattened-out pelvic diaphragm showing its named muscular components and the major holes for passage of structures from the pelvic cavity to the perineum. The pubococcygeus and iliococcygeus together constitute the levator ani. The other muscle of the pelvic diaphragm is the coccygeus. The gap between the left and right pubococcygei is called the ano-urogenital hiatus. *C*, The puborectalis is applied to the undersurface of the puborectalis and considered by some authors to be a part of the levator ani and pelvic diaphragm.

aorta (see Fig. 5-36*A*). The gap at the back of the abdominal diaphragm is called the aortic hiatus. The gap at the front of the pelvic diaphragm is for passage of the urethra, vagina (if you have one), and anal canal; it is called the **ano-urogenital hiatus**. In front of the anal canal, bridging across the hiatus between the inner edges of the left and right levators ani is a pyramidal chunk of connective tissue called the **perineal body** (or, **central tendon of the perineum)** (fig. 5-36B).

The levator ani is commonly divided by anatomists into separate regions. The fibers that arise from the pubis, pass around the ano-urogenital hiatus, and insert onto the anterior part of the anococcygeal raphe are said to constitute a **pubococcygeus muscle**. Fibers that arise a bit more laterally from the pubis, and from the anterior limit of the arcus tendineus, insert into the rest of the anococcygeal raphe and constitute the **iliococcygeus muscle**. This is the thinnest portion of the levator ani, sometimes appearing to be as much fibrous as muscular.

Coccygeus (Ischiococcygeus) (see Fig. 5-36*B*)

The coccygeus arises from the spine of the ischium (at the posterior end of the arcus tendineus) and passes medially, fanning out, to insert onto the coccyx and end of the sacrum. It is the most posterior part of the pelvic diaphragm and lies on a coronal plane (see Fig. 5-35).

Since the coccygeus runs between two essentially immobile structures, it could serve its role as a component of the pelvic diaphragm just as well if it were a ligament rather than a muscle. In fact, the superficial fibers of the coccygeus have regressed to become ligamentous. They form the **sacrospinous ligament**. Sometimes it is even difficult to identify muscle fibers on the deep surface of the sacrospinous ligament.

Puborectalis (Considered by Some Persons to be a Third Part of Levator Ani) (see Fig. 5-36*C*)

Applied to the inferior edge of each pubococcygeus muscle, and not clearly separable from it, are muscle fibers that arise from the pubic body and sweep posteriorly to meet their contralateral partners behind the anal canal. Because they don't insert on the anococcygeal raphe, I adopt the view (espoused by others) that they deserve to be given a separate name - **puborectalis** - and are not strictly part of the pelvic diaphragm The right and left puborectalis muscles form a **puborectal sling**, which is constantly active to pull the back wall of the anal canal forward and thereby assist in fecal continence. The puborectal sling is relaxed during defecation.

Another Hole in the Pelvic Diaphragm--The Greater Sciatic Foramen

The ano-urogenital hiatus has already been described. Superior to the sacrospinous ligament (on each side) is the other major gap in the pelvic diaphragm. This is the **greater sciatic foramen** (see Fig. 10-19). The sacrospinous ligament is its inferior border. Laterally and superiorly it is bounded by the greater sciatic notch of the ilium. The medial boundary would be the sacrum if it were not for the fact that a powerful ligament, the sacrotuberous ligament, attaches to the sacrum here and closes off the most medial part of the foramen. Thus, the lateral edge of the sacrotuberous ligament is considered to be the medial boundary of the greater sciatic foramen.

Through the greater sciatic foramen passes the piriformis muscle on its way from its origin on the sacrum to its insertion on the greater trochanter of the femur. But, although the piriformis is the largest structure passing through the greater sciatic foramen, it is not the most important. It is accompanied by nerves and vessels destined for either the lower limb (the sciatic nerve, the superior gluteal vessels and nerve, the inferior gluteal vessels and nerve, the posterior cutaneous nerve of the thigh, the nerve to the obturator internus, and the nerve to the quadratus femoris) or the perineum (the internal pudendal vessels and pudendal nerve). Once these nerves and vessels leave the pelvic cavity, they never return.

INTERNAL ORGANS OF THE PELVIS

Of the internal organs that lie within the pelvic cavity, two--the rectum and urinary bladder--occur in both sexes. The vagina, uterus, oviducts, and ovaries are found only in females; the vas deferens, seminal vesicles, and prostate gland occur only in males.

Urinary Bladder, Urethra, and Prostate

The urinary bladder is a subperitoneal organ immediately posterior to the pubic symphysis (see Fig. 5-35*C*,*D*). During embryonic life, the anterosuperior edge of the bladder was joined to a tubular duct that ran upward in the anterior extraperitoneal space to reach the umbilical cord. This duct, called the urachus, degenerates into a ligament called the **median umbilical ligament**. It can be seen running from the bladder toward the umbilicus in the anterior extraperitoneal space deep to the linea alba. It raises a fold of peritoneum called the **median umbilical fold**.

In females the urinary bladder rests on the anterior part of the pelvic diaphragm and its ano-urogenital hiatus (see Fig. 5-35*C*). The female urethra exits the pelvic cavity by passing through the hiatus. In males, the beginning of the urethra is surrounded by the prostate gland, which, therefore, lies just superior to the ano-urogenital hiatus and overlaps laterally onto the pubococcygeus (see Fig. 5-35*D*). The part of the male urethra surrounded by prostate gland is called the **prostatic urethra**. Its back wall is pushed forward into the urethral lumen by a lobule of the prostate gland. The ridge produced on the back wall of the prostatic urethra is called the **urethral crest**. It is widest in the middle of its course, to produce the so-called **seminal colliculus**. The prostate adds its secretion to seminal fluid via numerous tiny ducts that open into the urethra on either side of the seminal colliculus. From the peak of the colliculus itself, the epithelium of the urethra evaginates into the prostate gland to form a small tubular pouch called the **prostatic utricle**. Many authors believe that the prostatic utricle is the male homologue of the vagina. Thus, the entire urethra of the female would represent an elongated version of the proximal half of the male prostatic urethra.

Ductus Deferens and Seminal Vesicles

The **ductus deferens (vas deferens)** enters the abdominal cavity at the deep inguinal ring (a finger's breadth above the midpoint of the inguinal ligament). In the abdominal cavity, the ductus deferens takes a postero-inferior course across the medial surfaces of the external iliac vessels and pelvic brim to enter the lateral extraperitoneal space of the pelvic cavity. Here it runs toward the posterolateral corner of the urinary bladder (crossing medial to the obturator nerve and obturator vessels on the inner surface of the obturator internus muscle). When the ductus deferens nears the back of the bladder, it turns medially into the subperitoneal space and runs along the superior border of the back wall of the bladder (crossing superior to the ureter) toward the midline. The two ducti deferentes meet in the midline of the posterior wall of the bladder and then turn downward toward the prostate gland. Each ductus expands to form the **ampulla of the ductus deferens**. Just lateral to each ampulla, on the back wall of the bladder is a **seminal vesicle**. On the upper surface of the prostate, the seminal vesicle joins the ampulla of the vas deferens to form the **ejaculatory duct**. The two ejaculatory ducts pierce the prostate and runs obliquely through it to open up on the seminal colliculus to either side of the prostatic utricle.

Rectum

The rectum is said to begin where the taeniae coli of the sigmoid mesocolon end, on the front of the third sacral vertebra. The rectum lies retroperitoneally as far as the end of the sacrum and then gently turns forward, subperitoneally, along the upper surface of the pelvic diaphragm (see Fig. 5-35*C,D*). Because the rectum is usually filled with fecal matter, its retroperitoneal portion creates a bulge in the parietal peritoneum covering its anterior surface. On either side of this midline bulge the peritoneal cavity is said to form a **pararectal fossa**.

In the male, the subperitoneal portion of the rectum runs forward to contact the back of the urinary bladder (see Fig. 5-35*D*), with the seminal vesicles and ampullae of the vasa deferentes interposed. The rectum then makes a gentle turn inferiorly to pass through the ano-urogenital hiatus of the pelvic diaphragm. That part of the rectum below the pelvic diaphragm is named the **anal canal**. It heads downward and backward to open up onto the skin, at the anus, well below the tip of the coccyx. As the inferior wall of peritoneal sac reflects from the front surface of the rectum onto the upper surface of the bladder, it tends to dip down a bit between these two organs. The small extension of the peritoneal cavity between the front of the rectum and back of the bladder is called the **rectovesical fossa** (see Fig. 5-35*D*).

Vagina, Uterus, and Oviducts (Fig. 5-37)

Of course, females have no prostate glands, ducti deferentes, or seminal vesicles. But absence of these structures is not the crucial difference between the pelvic contents of men and women. In women, interposed between the urinary bladder in front and the rectum behind is the upper end of the **vagina** and the **uterus**.

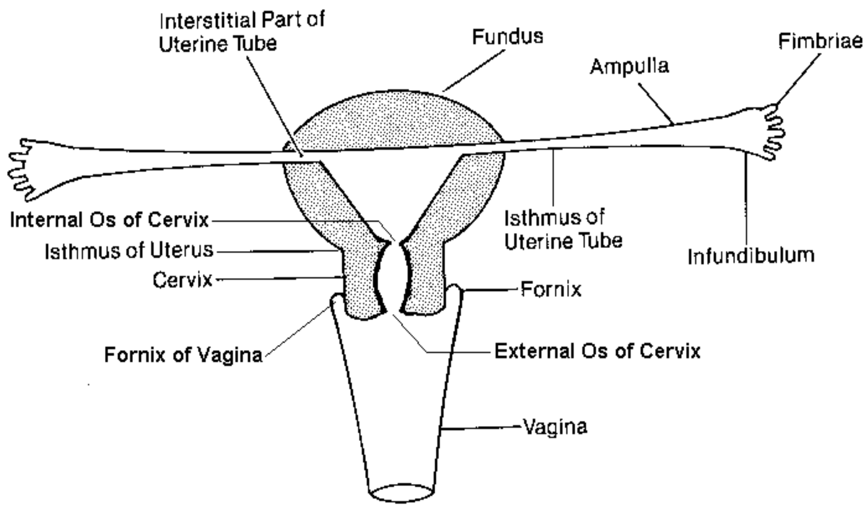


Figure 5–37. Schematic coronal section of vagina, uterus, and oviducts.

The uterus is a hollow organ with thick fibromuscular walls. Its inferior portion, or **cervix**, is narrower than its superior part, called the **body**. The site where the body joins the cervix is called the **uterine isthmus**. There is a bend at the isthmus so that the body lies more anterior than the cervix (see Fig. 5-35*C*). This is called uterine **anteflexion**, and its degree varies from woman to woman. The cavity of the uterine body is triangular (with its base superiorly and its apex pointing downward) and is continuous at the isthmus with the narrow cavity of the cervix. The upper end of the cervical lumen is called the **internal uterine os**. The lumen of the cervix opens inferiorly, at what is called the **external uterine os**, into the vagina. The lower end of the cervix is invaginated into the upper end of the vagina, so that the vaginal lumen not only lies below the cervix but also surrounds its lower end. The part of the vaginal lumen that envelops the cervix is called the **fornix**; it is circular in shape but may be arbitrarily divided into an anterior, two lateral, and a posterior fornix.

From the superolateral corners of the uterine body emerge the **uterine tubes (oviducts)**. Between the origins of the uterine tubes, the upper wall of the uterus is rounded to form the so-called **fundus** (the actual uterine cavity has a more or less straight upper border, thus, the fundus is due entirely to the shape of the wall).

Each uterine tube can be divided into four regions. The lumen of the tube passes through the thick uterine wall to connect up with the uterine cavity. This segment is referred to as the **interstitial** part of the uterine tube. Of that portion outside the uterus, the medial half has a very narrow cavity and is thus called the **isthmus**. Lateral to its midpoint, the uterine tube gets gradually wider as it moves away from the uterus, and is called the **ampulla**. A more dramatic widening just before the lumen of the tube opens up into the peritoneal cavity is called the **infundibulum**. The opening itself is known (somewhat erroneously) as the **abdominal ostium** of the uterine tube. Numerous feather-like projects of infundibular wall surround the margin of the ostium and are called **fimbriae**. These are partly erectile and sort of "grasp" the ovary at the time of ovulation.

Ligaments of the Uterus and Ovaries (Fig. 5-38)

Although the embryonic formation of the uterus and uterine tubes is rather complex, the final result is as if these structures developed in the subperitoneal space between the urinary bladder and

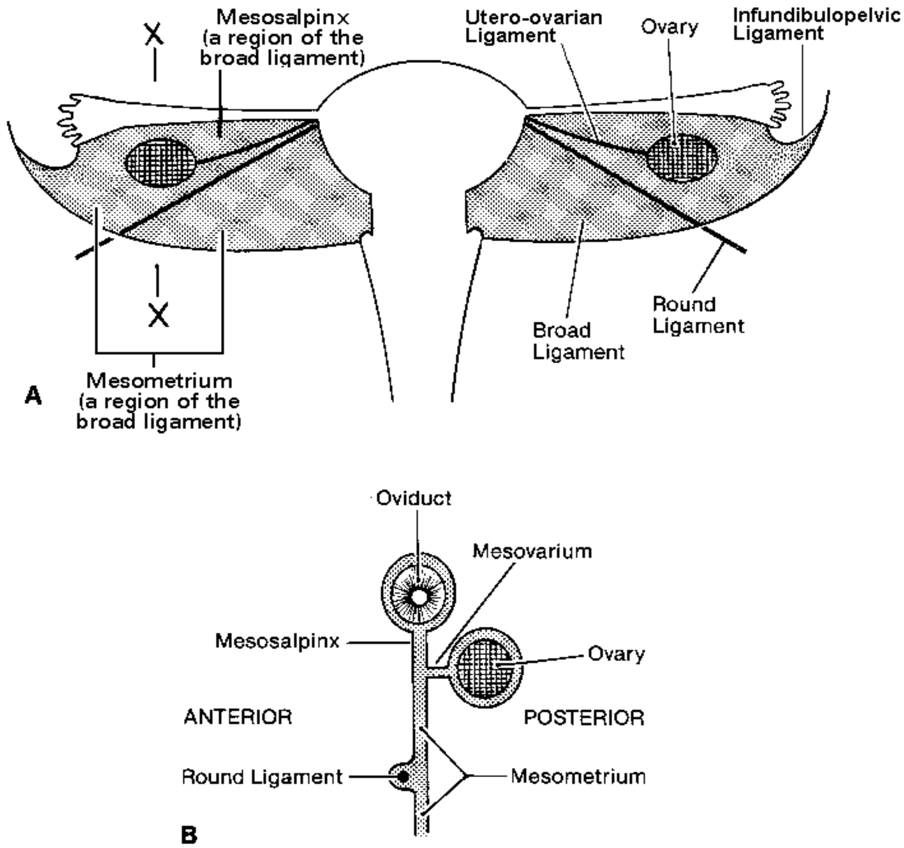


Figure 5–38. *A*, Schematic anterior view of uterus, broad ligament, and the ligaments passing between the layers of the broad ligament. *B*, Schematic sagittal section of the broad ligament through the plane X-X indicated in *A*.

rectum, then grew upward, pushing parietal peritoneum ahead of them. If one views the development of the uterus and uterine tubes in this way (although it is not true), it is easy to visualize how upward protrusion of the uterus and its two laterally projecting uterine tubes would cause them to be covered on their front, top, and back surfaces by an adherent layer of peritoneum that is quite analogous to the visceral peritoneum that came to cover the bowel as it pushed into the abdominal cavity from the back. Thus, the uterine tubes and the body of the uterus are covered by visceral peritoneum. The visceral peritoneum on their posterior surface meets the visceral peritoneum on their anterior surface along the inferior borders of the uterine tubes and lateral borders of the uterine body. From these borders, a peritoneal bilayer extends downward to the parietal peritoneum at the floor of the peritoneal cavity, and outward to the parietal peritoneum along the lateral pelvic wall. This bilayer is just like a mesentery (but a bit thicker) and the sites where it merges with parietal peritoneum is just like the root of a mesentery. The bilayer is called the **broad ligament of the uterus**, and its root is called its **root**.

As the uterus grows it encroaches on the path that the gubernaculum takes to reach the future ovary. The developing uterus breaks across the gubernaculum, dividing it into two segments. One of these runs from the skin of the labium majus to the uterine body just inferior to the origin of the uterine tubes. It is called the **round ligament of the uterus**. It follows a path rather similar to that of the vas deferens, but after entering the pelvic cavity it passes through the root of the broad ligament and runs between its layers to reach the uterus. As it travels within the broad ligament, the round ligament raises a fold in its anterior layer.

The second segment of the gubernaculum also attaches to the uterus just below the origin of the uterine tube. It runs laterally between the two layers of broad ligament, parallel but inferior to the uterine tube. In the embryo, this segment of the gubernaculum passes into the lateral extraperitoneal space of the pelvis and then up to the ovary. When it contracts, this segment of the gubernaculum pulls the ovary downward into the lateral extraperitoneal space of the pelvis and then through lateral the root of the broad ligament into a position between its layers just inferior to the ampulla of the uterine tube.

Henceforth, this part of the gubernaculum will be known as the **utero-ovarian ligament** (**proper ligament of the ovary**). It raises a ridge in the posterior layer of the broad ligament.

Once in position between the layers of the broad ligament, the ovary grows and bulges out the posterior layer of the broad ligament, thus creating a visceral peritoneum of the ovary. This protrusion is so complete that, along the anterior border of the ovary, visceral peritoneum on its superior surface meets visceral peritoneum from its inferior surface to form a bilayer which runs a short course anteriorly to merge with the posterior layer of the broad ligament. This bilayer is the **mesovarium**.

All these changes allow anatomists to assign two new names to parts of the broad ligament. The part that runs from the uterine tube down to the root of the mesovarium and the proper ovarian ligament is called the **mesosalpinx**. The part inferior to the root of the mesovarium and the proper ovarian ligament is called the **mesometrium**.

On either side, the connective tissue at the root of the broad ligament is said by some gynecologists to form a thickened **cardinal** (= **transverse cervical**) **ligament** that connects the uterus to the lateral wall of the pelvic cavity. The uterine artery is said to run in the cardinal ligament, and the ureter is said to pierce it. I am cautious about describing this structure because careful anatomical studies have not revealed its distinct presence, and I know some gynecologic surgeons who also doubt its existence. On the other hand, no-one doubts the existence of the **uterosacral ligaments** (right and left), which run from the uterus (at the site of the internal os of the cervix) to the sacrum at S2 or S3. Each uterosacral ligament courses lateral to the rectum and raises a visible ridge in the parietal peritoneum.

Anterior and Posterior Cul-de-Sacs (Vesico-uterine and Recto-uterine Pouches) (see Fig. 5-35*C*)

At the site of the uterine isthmus, the visceral peritoneum on the anterior surface of the uterine body turns forward to become the parietal peritoneum over the upper surface of the bladder. It dips down a little between the two organs and thereby is created a small extension of the peritoneal cavity called the **anterior cul-de-sac (vesico-uterine pouch)**. Nonetheless, most of the anterior surface of the uterine cervix is not covered by peritoneum and is separated from the back of the bladder only by subperitoneal connective tissue.

The visceral peritoneum on the posterior surface of the uterus continues further downward; it covers the back of the cervix and even the posterior fornix of the vagina before turning backward as parietal peritoneum on the anterior surface of the rectum. Thus, a substantial pouch of peritoneal cavity extends downward between the rectum, in back, and the uterus and vagina, in front. This is the **posterior cul-de-sac** (**recto-uterine pouch of Douglas**).

> Being the both the most inferior and posterior point of the peritoneal cavity in females, the posterior cul-de-sac is the repository for any free-floating abnormal contents of the peritoneal cavity. Examples of such abnormal peritoneal contents are blood, pus, and desquamated cancer cells. This takes on special significance, because a physician may easily sample the contents of the posterior cul-de-sac by passing a hypodermic needle through the posterior fornix of the vagina and the peritoneum on its surface. Such a procedure is called a **culdecentesis**. There is no comparably easy way to enter the rectovesical pouch of males.

Path of the Ovum

By giving a false embryology of the female reproductive system, I have failed to explain how it is that the lumen of the uterine tube opens into the peritoneal cavity of the pelvis. The reader may want to refer to an embryology text for the true cause of this connection, but the simple fact of the matter is that the visceral peritoneum on the outer surface of the uterine tube is continuous with the epithelial lining of the uterine tube lumen. As a result it is possible for things to pass from the peritoneal cavity into the uterine tube lumen and then to the uterine cavity. Just what sort of things are we talking about? After all, the peritoneal cavity is normally filled only with a thin layer of fluid. But this is not precisely true in females. The outer layer of the ovary is its visceral peritoneum. When the Graafian follicle ruptures through the outer layer of the ovary, it spills its contents through a hole in the visceral peritoneum and, thus, into the peritoneal cavity. To prevent the ovum from aimlessly floating throughout the peritoneal cavity and eventually degenerating, the fimbriae of the uterine tube "clasp" the ovary, sequestering a tiny portion of the peritoneal cavity between the abdominal ostium of the uterine tube and the ovarian surface. Thus, the journey of the ovum is through this tiny sequestered part of the peritoneal cavity directly into the uterine tube.

Of course, if something can pass from the peritoneal cavity into the uterine tube, and thence to the uterus, so may the opposite route be followed. Infections of the uterus may travel out the uterine tubes into the peritoneal cavity. An ovum fertilized normally in the uterine tube may (rarely) turn around and exit the uterine tube to enter the peritoneal cavity. Once within the peritoneal cavity, the blastocyst may implant on the ovary, broad ligament, uterus, mesentery, bowel, and so on. Finally, the physician, realizing that it should be possible for something to pass from the uterus to the peritoneal cavity, may inject radio-opaque dye or radiolucent gas into the uterus, with the full expectation that if uterine tubes are normal the injected material will reach the peritoneal cavity. If it does not, there is an obstruction in the lumen of the uterine tube.

VENTRAL RAMI WITHIN THE PELVIC CAVITY

Obturator Nerve

We have already seen how one branch of the lumbar plexus, the obturator nerve (L2, 3, 4), enters the pelvic cavity to reach the obturator groove, which leads into the medial part of the thigh. During its intrapelvic course in the lateral extraperitoneal space, the obturator nerve lies on the inner surface of the obturator internus just below the pelvic brim. Interestingly, the obturator nerve does not supply the obturator internus, nor any other structure within the pelvic cavity.

Sacral Plexus (see Fig. 10-6)

The lumbar plexus gives rise to a few nerves for the lower limb, however, these are not nearly sufficient to innervate the entire lower limb, which contains cells not only from lumbar dermomyotomes 2-4, but also from the 5th lumbar through the 3rd sacral hypaxial dermomyotomes. The 5th lumbar ventral ramus (joined by a small twig from L4) joins with the 1st-3rd sacral ventral rami to form a sacral plexus of nerves, the terminal branches of which are also destined for the lower limb.

As just mentioned, a nerve bundle called the lumbosacral trunk is formed by a small branch of the 4th lumbar ventral ramus joining the 5th lumbar ventral ramus just superior to the pelvic brim on the cranial surface of the sacral ala (see Fig. 5-9). This **lumbosacral trunk** crosses the sacral part of the pelvic brim to enter the retroperitoneal space of the pelvic cavity. Here it joins the 1st sacral ventral ramus, which has entered the pelvic cavity through the 1st ventral sacral foramen. Together they cross onto the ventral surface of the piriformis, where they form a plexus with the 2nd and 3rd sacral ventral rami. From the interweaving of nerve fibers on the ventral surface of the piriformis emerge a series of nerves that exit the greater sciatic foramen with the piriformis and distribute to the lower limb structures not innervated by the lumbar plexus. Exiting above the upper border of the piriformis is the **superior gluteal nerve**. Exiting below the lower border of the piriformis are the **sciatic nerve, inferior gluteal nerve, nerve to the obturator internus, nerve to the quadratus femoris, and the posterior cutaneous nerve of the thigh**. These nerves are discussed in Chapter 10. The piriformis itself gets a branch from the sacral plexus that is composed of axons from S1 and S2.

Other Branches of Sacral Ventral Rami

Not all the cells from the hypaxial portions of the 2nd and 3rd sacral hypaxial dermomyotomes enter the lower limb. Some join with cells from the 4th sacral hypaxial dermomyotomes to form the pelvic diaphragm and muscles of the perineum. Thus, very soon after their emergence from the ventral sacral foramina, the 2nd-4th sacral ventral rami give off branches destined for these structures.

Nerves to the Pelvic Diaphragm and Puborectalis

The 3rd and 4th sacral ventral rami give off branches to the pelvic diaphragm and puborectalis. These branches have no occasion to leave the pelvic cavity.

Pudendal Nerve (for Muscles of the Perineum and Most of Its Skin)

The 2nd-4th sacral ventral rami give off early branches that join together to form the **pudendal nerve**, destined to supply muscles and skin of the perineum. Since the perineum is below the pelvic diaphragm, the pudendal nerve must somehow exit the pelvic cavity. It does this by leaving through the greater sciatic foramen below the lower border of piriformis, but rather more medially than any of the other nerves with this relationship. The pudendal nerve immediately crosses onto the dorsal surface of the sacrospinous ligament and, upon reaching its lower border, passes downward through the lesser sciatic foramen (see Chapter 10) to reach the inner surface of obturator internus inferior to the arcus tendineus. At this point it is in the perineum. Its further course will be discussed subsequently.

Pelvic Splanchnic Nerves (Parasympathetic Preganglionic From S3 and S4)

The 3rd-4th (and occasionally also either the 2nd or 5th) sacral ventral rami give off early branches that contain the parasympathetic preganglionic axons whose cell bodies lie in the sacral segments of the spinal cord. These branches comprise the pelvic splanchnic nerves. They provide the preganglionic parasympathetic innervation for the smooth muscle and glands of the hindgut (from approximately the left colic flexure downward). They also provide the preganglionic parasympathetic innervation to smooth muscle and glands for all the internal organs of the pelvis. (Even abdominal parts of the ureters may receive some innervation originating in the pelvic splanchnic nerves.)

Coccygeal Plexus

The ventral rami of S5 and Co (joined by a small twig from S4) unite to form a coccygeal plexus. Since the 5th sacral and 1st coccygeal somites do not give rise to muscle, the coccygeal plexus is just for supply of the skin near the coccyx.

ARTERIES OF THE PELVIS

The superior rectal artery, median sacral artery, ovarian artery, and the pubic branch of the inferior epigastric artery (all previously described) originate outside the pelvis but enter it to supply pelvic organs. The other arteries in the pelvis are branches of the internal iliac artery.

Internal Iliac Artery

The internal iliac artery arises as a branch of the common iliac on the medial surface of the psoas major opposite the L5/S1 intervertebral disc (see Fig. 5-10). The internal iliac artery immediately crosses the pelvic brim into the lateral extraperitoneal space of the pelvis. Although the internal iliac artery gives off several constant named branches, the sequence in which they are given off is notoriously variable. It or its branches also give off tiny unnamed arteries to the pelvic part of the ureter. These participate in a linear anastomosis with ureteric branches from the renal artery. Often, the first thing the internal iliac artery does is to bifurcate into **posterior and anterior trunks**.

Posterior Trunk of the Internal Iliac Artery--Its Iliolumbar, Lateral Sacral, and Superior Gluteal Branches

Very soon after its origin, the posterior trunk gives off the **iliolumbar artery**, which is destined to supply the posterior abdominal wall. To do this, it travels superiorly across the pelvic brim out of the pelvis and into the abdominal cavity. Upon reaching the psoas major, the iliolumbar artery bifurcates into its iliac and lumbar branches. The former travels laterally behind the psoas to reach the iliacus, which it supplies. The lumbar branch travels superiorly behind the psoas, supplying it and the quadratus lumborum. It also sends a branch through the intervertebral foramen between L5 and S1 for supply of the spinal cord.

After giving off the iliolumbar artery, the posterior trunk of the internal iliac heads toward the greater sciatic foramen. Along the way it gives off the **lateral sacral artery**, which courses *medially* toward the sacrum. The lateral sacral artery gives off a branch that enters the 1st ventral sacral foramen[18] and then turns inferiorly to run on the pelvic surface of the sacrum just medial to the lower ventral foramina. During its descent, the lateral sacral artery gives off branches that enter these foramina. All the branches that enter ventral sacral foramina give off spinal branches, and then exit via the dorsal sacral foramina to supply the epaxial region of the trunk.

After the lateral sacral is given off, the continuation of the posterior trunk of the internal iliac is called the **superior gluteal artery**. This large vessel first passes between the lumbosacral trunk and 1st sacral ventral ramus (usually), and then goes out the greater sciatic foramen above the upper border of piriformis. It is an artery of the lower limb whose further course will be described in Chapter 10.

Anterior Trunk of the Internal Iliac Artery--Its Umbilical, Obturator, Inferior Gluteal, Internal Pudendal, Middle Rectal, and Sex-Dependent Branches

Very shortly after it arises, the anterior trunk of the internal iliac gives off an **umbilical artery**. The umbilical artery runs toward the anterior abdominal wall along the superior surface of the urinary bladder near its lateral edge. Along the way, the vessel gives off **superior vesical** branches to the bladder and then loses its lumen to take on the name of **lateral umbilical ligament**. The lateral umbilical ligament turns upward in the anterior extraperitoneal space and takes an oblique course toward the umbilicus. It raises a longitudinal fold--the **lateral umbilical fold** of parietal peritoneum--that lies between the fold raised by the median umbilical ligament (obliterated urachus) and that raised by the inferior epigastric artery.

After the origin of the umbilical artery, the branches of the anterior trunk of the internal iliac can come off in almost any imaginable sequence and must be traced to find out what they are. These branches consist, in both sexes, of obturator, internal pudendal, inferior gluteal, and (it is said) middle rectal arteries.

The **obturator artery** runs on the inner surface of the obturator internus toward the obturator groove, where it meets the obturator nerve and exits the pelvic cavity to enter the thigh. Within the pelvis, the obturator artery supplies the obturator internus. It anastomoses with the pubic branch of the inferior epigastric artery. In fact, sometimes the internal iliac artery does not give off an obturator branch. In such cases, the obturator artery that goes to the lower limb is merely a continuation of the pubic branch of the inferior epigastric artery. This vessel and its continuation are then said to constitute an **aberrant obturator artery**.

Within the pelvis, the **internal pudendal and inferior gluteal arteries** run fairly close to one another; they often have a common stem. Where they are separate, the inferior gluteal is more posterior of the two. Both vessels head toward the greater sciatic foramen, through they pass inferior to piriformis. The inferior gluteal artery is a vessel of the lower limb and will be described further in Chapter 10. The internal pudendal artery crosses the tip of the ischial spine and passes with the pudendal nerve through the lesser sciatic foramen to take up a position on the inner surface of the obturator internus below the

---

[18] This vessel may arise independently from the posterior division of the internal iliac artery.

arcus tendineus, thus in the perineum. Its course and branches within the perineum are discussed later in this chapter.

Most texts describe a **middle rectal artery** that simply goes to the rectum. I've only seen such a structure once or twice. My surgeon friends say they never look for it.

Sex-Dependent Branches of the Anterior Trunk--Inferior Vesicle Artery in Males and Uterine Artery in Females. In males, the anterior trunk of the internal iliac artery (or one of its branches already mentioned) gives off an **inferior vesical artery** that runs toward the inferior part of the posterior surface of the bladder. Upon reaching this location it gives off a branch to the ductus deferens (the **deferential artery**) and then ramifies on the bladder, seminal vesicles, and prostate. The deferential artery supplies the ductus deferens and travels with it through the spermatic cord into the scrotum.

In females, the artery corresponding to the inferior vesical is the **uterine**. It is much larger than its male counterpart. It runs in the root of the broad ligament toward the uterine cervix. During its path the uterine artery crosses anterosuperior to the ureter ("bridge over water"), which is following a subperitoneal course toward the bladder. Upon reaching the cervix just above the lateral fornix of the vagina, the uterine artery gives off a **vaginal artery** that descends along the vagina, supplying it and the inferior part of the urinary bladder[19]. The uterine artery itself turns superiorly to run within the broad ligament near the lateral border of the uterine cervix and body, suppling the uterus along the way. At the site of attachment of the utero-ovarian ligament, the uterine artery trifurcates, sending a tubal branch out along the lower border of the uterine tube, an ovarian branch out along the utero-ovarian ligament, and a ligamentous branch out along the round ligament. It is estimated that 25% of the blood supply to the ovary derives from the ovarian branch of the uterine artery.

VEINS OF THE PELVIC CAVITY

All the branches of the internal iliac artery are accompanied by veins that run along side them and, quite logically, drain to the internal iliac vein.

The vesical, uterine, vaginal, and rectal veins each form by the coalescence of smaller, freely anastomosing vessels that lie in the outer connective coverings of their respective organs. Thus, in the male there is a **prostatic plexus of veins** all around the prostate gland and lower part of the bladder that gives rise to the inferior vesical vein. In the female there is a **uterovaginal plexus** draining to the uterine vein. In both sexes there is a **vesical plexus of veins** around the upper part of the bladder that gives rise to the superior vesical vein, and a **rectal plexus** draining to rectal veins. Each plexus anastomoses with nearby ones.

Three intrapelvic veins do not drain to the internal iliac. The **ovarian vein** runs with the ovarian artery into the abdominal cavity. The right ovarian vein empties into the inferior vena cava; the left ovarian vein empties into the left renal vein. The **median sacral vein** runs out of the pelvis (with its artery) to drain to the left common iliac vein. The superior rectal veins run up out of the pelvis alongside the superior rectal artery. The **superior rectal veins** contribute to the formation of the inferior mesenteric vein.

PERINEUM

The perineum is that part of the trunk inferior to the pelvic diaphragm. Its lateral boundaries make the shape of a diamond (Fig. 5-39*A*), but it is better to view it as two triangles, an anterior and a posterior, joined at their bases (Fig. 5-39*B*). The anterior, or urogenital triangle, lies in a transverse plane; the posterior, or anal triangle, lies between a transverse and a coronal plane. Their conjoined base runs from side to side between the anterior limits of the ischial tuberosities (see Fig. 5-39*B*).

---

[19] The vaginal artery may arise independently from the anterior division of the internal iliac.

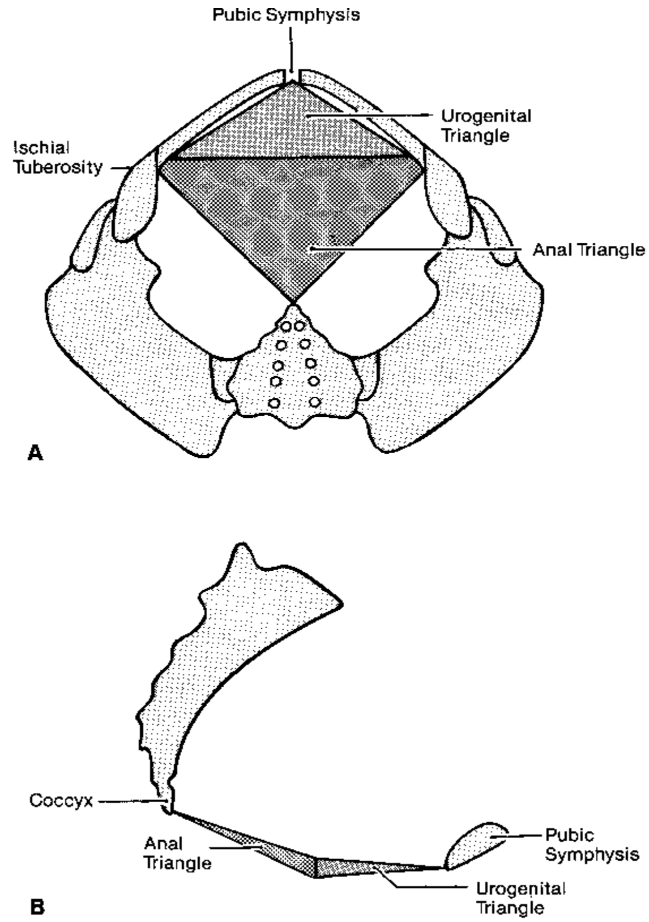


Figure 5-39. *A*, Inferior view of the bony pelvis showing the diamond-shaped boundary of the perineum and the regions defined as urogenital and anal triangles. *B*, Median sagittal section of bony pelvis illustrating positions of urogenital and anal triangles.

Urogenital Triangle

The lateral walls of the urogenital triangle are formed by the ischiopubic rami and that part of each obturator internus that lies below the arcus tendineus. The apex of the urogenital triangle is formed by the **arcuate ligament of the pubis**, which runs from one pubic bone to the other along the inferior edge of the pubic symphysis.

Contents of the Urogenital Triangle

Perineal Membrane. A major structure within the urogenital triangle is the perineal membrane. It is a flat fibrous sheet that stretches between the right and left ischiopubic rami (Fig. 5-40; see Fig. 5-35). It is as if the periosteum of one ischiopubic ramus bridges across to merge with the periosteum of the other ramus. The old view of the perineal membrane was that it was merely the thickened inferior fascia of a muscular urogenital diaphragm. This is incorrect[20]. No muscular urogenital diaphragm exists. If one wishes to retain the term **urogenital diaphragm**, it becomes synonymous with perineal membrane.

[20] Oelrich, TM: The urethral sphincter muscle in the male. Am J Anat 158:229 - 264, 1980. Oelrich, TM: The striated urogenital sphincter muscle in the female. Anat Rec 205:223 - 232, 1983.

The perineal membrane, viewed inferiorly, is itself triangular (see Fig. 5-40). The long posterior edge of the perineal membrane stretches between the anterior limits of the ischial tuberosities. Its apex has been cut off so that the perineal membrane does not reach the pubic symphysis. Its short anterior edge runs between the ischiopubic rami just behind the pubic symphysis. This edge is also called the **transverse ligament of the pelvis**, and there is a gap between it and the arcuate pubic ligament.

The ano-urogenital hiatus of the pelvic diaphragm overlies the middle of the perineal membrane (Fig. 5-41). The urethra and vagina, which pass through the ano-urogenital hiatus, would be stopped by the perineal membrane if the latter did not contain a hole for their passage. It does (see Fig. 5-40), and thus the urethra and vagina eventually are able to reach the skin. The perineal body is fused to the middle of the posterior edge of the perineal membrane.

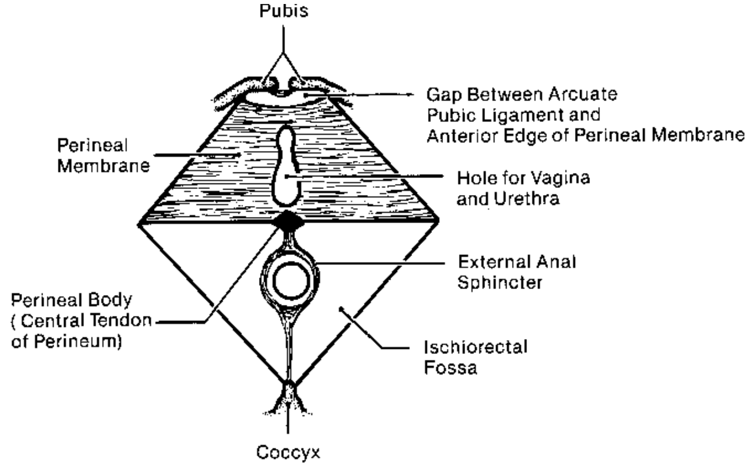


Figure 5-40. Inferior view of perineal membrane and anal triangle.

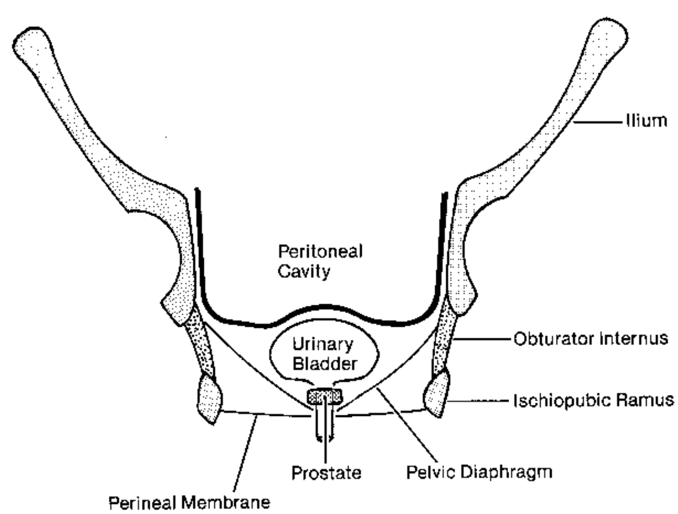


Figure 5-41. Schematic coronal section through bony pelvis and urogenital triangle in a male, showing relationship of pelvic diaphragm to urinary bladder, prostate, and perineal membrane.

Perineal Muscles Superior to the Perineal Membrane--Sphincter Urethrae (Both Sexes), Deep Transverse Perineus (Males), Sphincter Urethrovaginalis (Females), Compressor Urethrae (Females). In both sexes, the part of the urethra above the pelvic diaphragm and passing through the ano-urogenital hiatus is surrounded by a circular **sphincter urethrae muscle**. In the male, this muscle becomes thicker below the ano-urogenital hiatus, as it lies on the superior surface of the perineal membrane (Fig. 5-42*A*). Embedded in the muscle here are the **bulbo-urethral glands**, which send their ducts through the perineal membrane eventually to join up with the urethra. Additionally, on the superior surface of the perineal membrane in males are some muscle fibers that arise on each side from the anterior limit of the ischial tuberosity and pass directly medially to insert on the perineal body (with some fibers interdigitating with the back of the sphincter urethrae). These fibers compose the **deep transverse perineus** muscles.

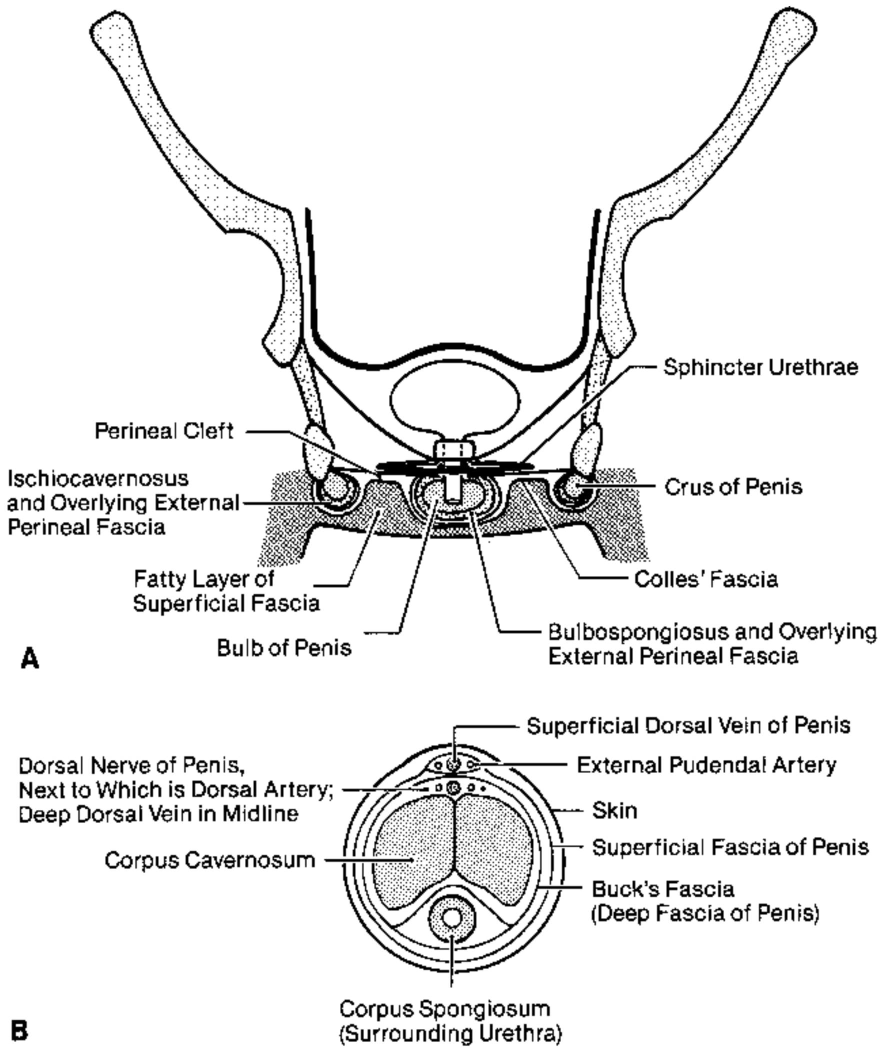


Figure 5–42. *A*, Schematic coronal section through bony pelvis and urogenital triangle of a male (as in Fig. 5–41), to which has been added the sphincter urethrae and the structures that lie inferior to the perineal membrane. *B*, Transverse section of the shaft of the penis.

In females, once the sphincter urethrae has passed through the ano-urogenital hiatus, but while it is still above the perineal membrane, it enlarges to encircle both the urethra and vagina. Thus, at this site it is called the **sphincter urethrovaginalis**. The existence in females of deep transverse perineus muscles is debatable. However, there are apparently muscles that arise from the same sites but, rather than passing posterior to the sphincter urethrovaginalis to reach the perineal body, instead proceed to blend with the most anterior fibers of that muscle. The fibers on the right, together with those on the left, form an arch that, upon contraction, compresses the anterior urethral wall against the posterior urethral wall. Thus, the muscle is called the **compressor urethrae**. The thickness of the sphincter urethrae in males may make such a muscle unnecessary.

Genital Structures Opposed to the Inferior Surface of the Perineal Membrane--Crura of Phallus, Bulb of Penis (Males), Bulb of Vestibule (Females) (see Fig. 5-42*A*). Attached to the inner surface of each ischiopubic ramus, just inferior to the lateral margin of the perineal membrane, is a highly vascular erectile tube surrounded by a tough fibrous envelope. This is the **crus of the phallus (penis or clitoris)** with its fibrous **tunica albuginea**. Of course, there are two crura, one on either side.

The crura of the penis meet one another at the anterior border of the perineal membrane and together pass forward into the free shaft of the penis. Within the penile shaft they are called the **corpora cavernosa**, and where their tunicae albugineae contact each other, they fuse to form the **septum of the penis**. At certain sites the septum is perforated, allowing the vascular spaces of one side to communicate with those of the other. The existence of these communications causes some authors to view the corpora cavernosa as constituting a single **corpus cavernosum**.

The crura of the clitoris differ from those of the penis only in size. They are of smaller diameter and the shaft of the clitoris is comparatively short. Within the clitoral shaft the adherent crura are said to constitute a **corpus clitoridis**.

In males, there is another highly vascular erectile organ, with its own fibrous tunica albuginea, located on the undersurface of the perineal membrane in the midline. This is the **bulb of the penis**. As the bulb of the penis nears the anterior border of perineal membrane, it narrows into a cylindrical structure that passes into the free shaft of the penis ventral to the septum penis. This cylindrical erectile structure is called the **corpus spongiosum** of the penis. It is longer than the corpus cavernosum, and when it reaches their distal ends, the corpus spongiosum expands dorsally to form a cap over them. This cap is the **glans penis**.

The bulb of the penis lies on the inferior surface of the perineal membrane right where the urethra pierces this membrane. The urethra passes through the tunica albuginea of the bulb to become surrounded by erectile tissue. Immediately after it enters the bulb, the urethra undergoes a small dilatation and then, after narrowing again, makes a right angle turn to run through the middle of the corpus spongiosum up to the tip of the glans. Here it opens on the skin by means of a small dilatation called the **fossa navicularis**.

The reader will recall that the part of the urethra surrounded by the prostate gland is called the **prostatic urethra**. The part of the urethra within the bulb is called the **bulbar urethra**; the part within the corpus spongiosum is called the **penile urethra**. Between the prostatic urethra and the penile urethra is the segment that actually passes through the ano-urogenital hiatus and perineal membrane; this is the **membranous urethra**.

There is no single bulb of the clitoris. After the vagina and urethra pierce the perineal membrane they immediately open up onto the skin between the labia minora. This space between the labia minora is called the **vestibule of the vagina**. At the root of each minor labium, on the inferior surface of the perineal membrane, is a flattened oval erectile body called the **bulb of the vestibule**. From the anterior pole of each bulb comes a slender extension onto the ventral surface of the corpus clitoridis. The two slender extensions from each side meet and then expand to form a small **glans clitoris**.

Adjacent to the posterior ends of each vestibular bulb is a **greater vestibular gland (of Bartholin)** that sends its duct to open into the vestibule lateral to the posterior half of the vaginal orifice. (Gynecologists refer to the openings of Bartholin ducts as being at the 5 o'clock and 7 o'clock position relative to the vaginal orifice.)

Muscles Associated with the Crura and Bulbs--Ischiocavernosus and Bulbospongiosus (see Fig. 5-42*A*). Arising from the ischiopubic ramus, covering the inferior and medial surfaces of each crus, and inserting onto the tunica albuginea of the crus just before it turns to join the penis or clitoris is an **ischiocavernosus muscle**. The ischiocavernosi of the two sexes differ only in size. By contraction, these muscles elevate pressure within the relevant erectile tissues to a level substantially above the systolic blood pressure.

Arising from the perineal membrane and nearby fibrous tissues are muscle fibers that sweep around the sides of the bulb and proximal corpus spongiosum to insert on a midline raphe that runs from the perineal body forward along the inferior surface of the bulb and the proximal corpus spongiosum. This is the **bulbospongiosus muscle**. It seems to be involved as a sphincter acting on the urethra to assist in ejaculation and urination.

In females, a bulbospongiosus muscle lies on the lateral surface of each bulb of the vestibule. The fibers arise from the perineal body and run forward. The function of the bulbospongiosus in females is unknown. It would seem to have the ability to narrow the vestibule.

In both males and females there is yet another muscle on the inferior surface of the perineal membrane, but this muscle is unrelated to the erectile bodies. It is called the **superficial transverse perineus**. On each side it arises from the anterior limit of the ischial tuberosity and passes medially to insert on the perineal body.

Fascia of the Urogenital Triangle (see Fig. 5-42). The description that follows applies to the condition in males, for which a knowledge of urogenital fascia is of considerable clinical significance.

The epimysium on the external surfaces of the ischiocavernosus and bulbospongiosus is bilaminar. The thicker outer layer is called the **deep (external) perineal fascia**. It is continuous anteriorly with a deep fascial sleeve around the erectile bodies of the of the penis. This sleeve is called **Buck's fascia**. Not only does Buck's fascia encircle the entire shaft of the penis just external to the tunicae albugineae of the corpora, but it also sends a septum from side to side between the corpus spongiosum and the corpus cavernosum. It ends anteriorly by blending with the tunica albuginea of the glans. At the root of the penile shaft, Buck's fascia sends a connection from the dorsal surface of penis to the anterior surface of the symphysis pubis. This connecting band constitutes the **suspensory ligament of the penis**.

As elsewhere in the body, superficial to the most external layer of deep fascia is the subcutaneous layer. The subcutaneous layer of the urogenital triangle is special in the same way as is that of the lower abdominal wall. It has a deep fibrous lamina overlain by a more fatty loose connective tissue. The deep fibrous layer in the abdomen was called Scarpa's fascia; the fatty layer was called Camper's fascia. In the urogenital triangle the deep fibrous lamina is called **Colle's fascia**. The fatty layer has no name. Colle's fascia is continuous anteriorly with Scarpa's fascia, the tunica dartos of the scrotum, and the superficial fascia of the penis. However, Colle's fascia ends laterally by attaching to the periosteum of the ischiopubic rami, and it ends posteriorly by attaching to the back edge of the perineal membrane. It also has a midline attachment to the raphe of the bulbospongiosus, which attachment is continuous anteriorly with the attachment of the scrotal septum (a derivative of the tunica dartos) to this raphe. The fatty layer of the superficial fascia of the perineum is continuous with Camper's fascia, the tunica dartos of the scrotum, the superficial fascia of the penis, the subcutaneous layer of the medial thigh, and the subcutaneous layer of the anal triangle.

Perineal Pouches and the Perineal Cleft (see Fig. 5-42). When anatomists believed that there was a true muscular urogenital diaphragm with its own superior and inferior fascias, they decided to call the space between these "fascial layers" the "deep perineal pouch." It was said to be occupied by the muscle fibers of the "urogenital diaphragm," the bulbourethral glands, and some vessels and nerves that run on the superior surface of the perineal membrane. We now know that there is no "deep perineal pouch", although there certainly are structures that lie on the upper surface of the perineal membrane.

One may say that between the perineal membrane and the deep perineal fascia there is a trilobular space occupied laterally by the crura and ischiocavernosi, and in the midline by the bulb and bulbospongiosus. Some authors, including myself, choose to refer to this trilobular space as constituting a **superficial perineal pouch**. It is continuous with the space deep to Buck's fascia in the penis.

Between the deep perineal fascia and Colle's fascia is a thin fluid-filled space that many authors, including myself, choose to call the **perineal cleft**. It lies between deep and superficial fascia. It is continuous with the space between deep and superficial fascia in other regions of the body: (1) the space within the scrotum between the external spermatic fascia and the tunica dartos (2) the space between

Buck's fascia and the superficial fascia of the penis, and (3) the space between the deep fascia on the outer surface of the external abdominal oblique and Scarpa's fascia. The attachment of Colle's fascia to the back of the perineal membrane and to the ischiopubic rami prevents the perineal cleft from having continuity with the space between deep and superficial fascias of the anal triangle or the medial side of the thigh.

The perineal cleft has considerable clinical significance. This is so because trauma to the perineum in males, or an improperly performed urethral catheterization, can lead to tearing of the urethra and deep fascia just below the perineal membrane. As a result, urine (often mixed with blood) gains access to the perineal cleft. Once within the perineal cleft, urine spreads anteriorly into (1) the scrotum between external spermatic fascia and tunica dartos, (2) the shaft of the penis between Buck's fascia and the superficial fascia of the penis, and (3) the anterior abdominal wall between the deep fascia of the external abdominal oblique and Scarpa's fascia. If the rupture into the cleft is unilateral, urine will first fill one side of the perineum and one scrotal sac. However, because the anterosuperior edge of the scrotal septum is free, urine always passes to the other scrotal sac. In the abdomen and penis also, the plane between deep and superficial fascias is continuous across the midline. You might think that any urine that has reached the anterior abdominal wall could travel downward into the thigh, or posteriorly into the back. Such spread is in fact prevented by attachment of Scarpa's fascia to (1) the fascia lata just below the inguinal ligament, (2) the iliac crest, and (3) the thoracolumbar fascia.

There are also cases in which bloody urine can get into the space between the tunica albuginea of the bulb of the penis and the deep perineal fascia. (Ordinarily this space is occupied only by the bulbospongiosus muscle.) As a consequence of a careless catheterization of the male urethra, the tip of the catheter may be driven through the wall of the urethra at the site of the bulbar dilatation. If the rupture goes no further, urine will simply spread throughout the blood-filled sinuses of the bulb and corpus spongiosum. If the catheter also pierces the tunica albuginea of the bulb, bloody urine will enter the space between deep perineal fascia and the tunica albuginea but will still be confined to the middle of the perineum and ventral surface of the penis. Subsequent infection may then cause breakdown of the external perineal fascia and entry of urine into the perineal cleft. This entire process may also result from primary untreated infection of the penile urethra.

Because the female urethra is straight and opens onto the surface almost immediately after it pierces the perineal membrane, it is not subject to the same trauma as may occur in the male.

Anal Triangle

Each lateral boundary of the anal triangle is formed anteriorly by the inner surface of the ischial tuberosity and the portion of the obturator internus arising from it (see Fig. 5-39*A*). Behind the ischial tuberosities, the lateral wall of the anal triangle is formed by the sacrotuberous ligament, which runs from the inner edge of the tuberosity upward and backward to the coccyx, sacrum, and posterior ilium (see Fig. 10-19). External to the sacrotuberous ligament is the gluteus maximus muscle, which, therefore, also contributes to the lateral wall of the anal triangle. The apex of the anal triangle is the tip of the coccyx.

Contents of the Anal Triangle

The contents of the anal triangle are far less numerous than those of the urogenital triangle. Its major occupant is the **anal canal**, which is that portion of the rectum below the pelvic diaphragm. The anal canal passes just posterior to the perineal membrane on its way to the anus (see Figs. 5-35*C,D*, 5-40). It is surrounded by a striated muscle that arises from the central tendon of the perineum, then sends fibers around the sides of the anal canal to converge on a tendon that goes to the coccyx (see Fig. 5-40).

This is the voluntary **external anal sphincter** that constricts the anal canal and enables us to be continent. Within the wall of the anal canal is a smooth muscle sphincter (the **internal anal sphincter**), which relaxes reflexly upon parasympathetic stimulation when the rectum fills with fecal matter.

The anal canal is surrounded on all sides by fatty connective tissue, which allows it to expand easily as fecal matter enters it. This fatty tissue fills up the perineum in the region of the anal triangle. On each side, the space occupied by this fat is called the **ischiorectal fossa**, because part of it is bounded laterally by the ischial tuberosities and medially by the rectum. The two ischiorectal fossae are continuous with one another both in front of and behind the anal canal. The fat within each ischiorectal fossa also extends forward between the upper surface of the perineal membrane and lower surface of the pelvic diaphragm on the lateral sides of the sphincter urethrae. These spaces are said to comprise anterior recesses of the ischiorectal fossa.

EPISIOTOMY

During childbirth it used to be very common for the physician to incise the posterior wall of the vagina, and the skin adjacent to it, in order to prevent ragged tearing of these tissues. Most obstetricians prefer to make the incision in the midline, through the fourchette of minor labia (i.e., where they meet posterior to the vagina) and then through the perineal body. The greatest risk of this approach is carrying the incision too far, into the external anal sphincter or even anal canal. In order to avoid this risk, some obstetricians start the incision to one side of the perineal body, and attempt to direct it posterolaterally. Although entailing less risk to the rectum, such an incision produces more bleeding and is slower to heal. Episiotomy is losing favor with the obstetricians I know.

Nerves of the Perineum

The perineum, including the phallus and the back of the scrotum or posterior regions of the labia, is innervated by the **pudendal nerve** (S2, S3, and S4). It will be recalled that this nerve, after crossing the external surface of the sacrospinous ligament, enters the perineum through the lesser sciatic foramen. It comes immediately into contact with the fascia on the medial surface of the obturator internus below the arcus tendineus. The nerve embeds itself within this fascia and runs inferiorly toward the posterolateral corner of the perineal membrane (which is at the anterior limit of the ischial tuberosity). The space within the obturator fascia occupied by the pudendal nerve is called **Alcock's canal (pudendal canal)**.

Shortly before entering Alcock's canal, the pudendal nerve gives off the **inferior rectal nerve**. This nerve passes medially through the fat of the ischiorectal fossa toward the anal canal. It supplies the external anal sphincter and the skin around the anus.

While the pudendal nerve is within Alcock's canal, it bifurcates into its two terminal branches: the **perineal nerve** and the **dorsal nerve of the phallus** (**clitoris** or **penis**, as the case may be). The perineal nerve passes superficial to the perineal membrane and gives off branches for supply of the structures within the superficial pouch, the skin of the perineum, and the skin on the back surface of the scrotum or posterior regions of the labia. The dorsal nerve of the phallus passes on the superior surface of the perineal membrane, supplying whatever perineal muscles are found there (variously sphincter urethrovaginalis, sphincter urethra, compressor urethrae, deep transverse perineus), and then pierces the perineal membrane near its anterior edge to enter the phallus. It runs on the dorsal surface of the phallus (see Fig. 5-42*B*), beneath its deep fascia, supplying the skin and fascia of the phallus. (Some skin at the root of the phallus is innervated by the anterior scrotal or anterior labial branches of the ilioinguinal nerve.) The erectile bodies of the phallus are not supplied by its dorsal nerve, but by branches of the pelvic plexus (see further on) that pierce the pelvic diaphragm and perineal membrane.

Arteries of the Perineum

The artery for perineal structures is the **internal pudendal** branch of the internal iliac artery. After crossing the tip of the ischial spine just lateral to the pudendal nerve, the internal pudendal artery enters Alcock's canal along with the nerve. The artery has three main branches (**inferior rectal, perineal, and the artery to the clitoris or penis**) that run with the three main branches of the pudendal nerve (inferior rectal, perineal, and dorsal nerve of the clitoris or penis). Each artery supplies blood to the same tissues that the nerves innervate. The only difference is that its the artery to the phallus has two additional named branches above and beyond the dorsal artery to the phallus.

The two other branches of the artery of the phallus arise during its path superior to the perineal membrane. They are the **artery to the bulb**, which pierces the perineal membrane and feeds the bulb of the penis or vestibule, then a bit further along its course a **deep artery of the penis or clitoris**, which pierces the perineal membrane and runs within the crus and corpus cavernosum or corpus clitoridis for their whole lengths. After the deep artery of the phallus is given off, the continuation of the parent vessel is the **dorsal artery of the penis or clitoris**, which travels with the dorsal nerve, but more toward the midline (see Fig. 5-42*B*).

Why, you may ask, is the artery that accompanies the pudendal nerve not simply called the pudendal artery, instead of the more specific name of internal pudendal artery? The answer is that there is an additional artery that goes to the labia and clitoris or scrotum and penis that is distinguished as the **external pudendal artery**. This is a branch of the common femoral artery just below the inguinal ligament. It travels medially within the superficial fascia of the thigh and crosses the round ligament or spermatic cord to feed the skin of the anterior labia or scrotum, and then continues in the superficial fascia on the dorsal surface of the phallus toward its glans (see Fig. 5-42*B*).

Veins of the Perineum

Accompanying most of the branches of the internal pudendal artery are veins draining to an internal pudendal vein, which runs through Alcock's canal to exit the perineum through the lesser sciatic foramen and enter the pelvis through the greater sciatic foramen, finally emptying into the internal iliac vein.

The venous drainage of the penis and clitoris deserve special mention. Instead of there being paired dorsal veins of the phallus accompanying the dorsal arteries, there is a single **deep dorsal vein** that lies in the midline between these arteries beneath Buck's fascia (see Fig. 5-42*B*). This deep dorsal vein passes backward along the dorsal surface of the phallus toward the perineal membrane. When it gets there, it passes through the gap between the perineal membrane and arcuate pubic ligament to reach the ano-urogenital hiatus of the pelvic diaphragm. Passing through this hiatus, the deep dorsal vein reaches the prostatic or uterovaginal plexus of veins. Additionally, there is a **superficial dorsal vein of the phallus** that lies within the superficial fascia of the penis or clitoris along its dorsal midline, bracketed by the external pudendal arteries (see Fig. 5-42*B*). This vein also passes toward the root of the phallus, and when it gets there it bifurcates into two vessels which are the right and left **external pudendal veins**. These receive the anterior scrotal or labial veins and pass to the great saphenous vein of the thigh.

ANASTOMOTIC CONNECTIONS OF THE INTERNAL ILIAC ARTERY

Now that all the arteries of the abdomen and pelvis have been described, it is possible to consider the clinically relevant fact that there are extensive anastomotic connections between branches of the internal iliac artery and other vessels of the region. Such anastomoses, as elsewhere in the body, occur wherever the region of supply of one vessel overlaps or abuts that of another. **Therefore, a consideration of anastomoses is also a review of arterial distribution.** In the pelvis, they are particularly relevant because surgery for cancer of pelvic organs may require such extensive removal of structures that the internal iliac artery, or its anterior trunk, must be ligated. The pelvic structures that remain, and which are ordinarily supplied by this artery, are forced to rely for their blood supply on anastomoses between smaller branches of the internal iliac and branches of some other artery:

1. The lateral sacral artery from the internal iliac anastomoses with the median sacral from the aorta.
2. The iliolumbar artery from the internal iliac anastomoses with the lumbar arteries from the aorta and the deep circumflex iliac artery from the external iliac.
3. The obturator artery from the internal iliac anastomoses with the pubic branch of the inferior epigastric artery from the external iliac.
4. The internal pudendal artery from the internal iliac anastomoses through (a) its inferior rectal branches with the superior rectal artery from the IMA, and (b) through its perineal and phallic branches with the external pudendal artery from the common femoral.
6. The uterine artery from the internal iliac anastomoses with the ovarian artery from the aorta
7. The deferential branch of the inferior vesical artery anastomoses with the cremasteric branch of the inferior epigastric artery and with the testicular artery from the aorta. A comparable anastomosis between the ligamentous branch of the uterine and the artery to the round ligament occurs in women.
8. Outside the pelvis, the inferior gluteal and obturator branches of the internal iliac anastomoses with branches of the common femoral artery (these will be described in Chapter 10).

PORTACAVAL VENOUS ANASTOMOSES

Now that the venous drainage of the abdomen and pelvis has been described, it is possible to consider one of the most important sets of venous anastomoses in the body. I am speaking of those between tributaries of the portal vein and tributaries of the vena cavae. Cirrhosis of the liver, or disseminated cancer in the liver, may lead to such thorough disruption of the hepatic sinusoids that great resistance is offered to flow of blood from the portal vein through hepatic sinusoids to reach the hepatic veins. This is called **portal hypertension**. When it occurs, venous blood from the gut and its related organs must find another route back to the heart. The routes that are followed are those permitted by the four portacaval anastomoses:

1. Veins within the wall of esophagus near its entrance to the stomach drain both downward to the left gastric vein (portal system) and upward to the azygos and hemiazygos veins (superior vena cava)
2. Veins within the wall of the rectum drain upward to superior rectal veins (portal system) and downward to inferior rectal veins (inferior vena cava).
3. Small para-umbilical veins, alongside the ligamentum teres of the abdomen within the falciform ligament, drain both upward to the left branch of the portal vein (at the porta hepatis) and downward to subcutaneous veins in the vicinity of the umbilicus.
4. Small anastomotic venous channels connect the secondarily retroperitoneal mesenteric veins with the primarily retroperitoneal veins of the posterior abdominal wall.

When venous blood flow is blocked at hepatic sinusoids and must be diverted to these four areas of anastomosis, the latter dilate greatly to accommodate the unaccustomed flow. Dilatation of the posterior abdominal anastomoses is not visible, nor does it lead to detectable symptoms. By contrast, dilatation of the other three anastomotic channels is clinically significant.

1. Dilatation of veins in the wall of the lower esophagus is called **esophageal varices.** . The dilated veins bulge into the lumen of the esophagus and can “explode”, leading to significant (and sometimes fatal) hemorrhage. Blood accumulates in the stomach and is often vomited. Vomiting blood is called **hematemesis**. Thus, hematemesis may be a symptom of portal hypertension.
2. Dilatation of veins in the wall of the rectum is called **rectal varices**. Like esophageal varices, they may rupture, although this is less common and less often

life-threatening. Fresh blood in the stool is another potential symptom of portal hypertension.

3. Dilatation of the thoraco-epigastric veins is asymptomatic but visible. Whereas blockage of one or the other vena cavae produces dilated veins that run a vertical course within the subcutaneous tissue of the abdomen, portal hypertension yields a pattern of dilated veins that radiate in all directions from the umbilicus. To some clinician long ago these radiating engorged and tortuous superficial veins looked like the snakes that comprise the hair of Medusa. Thus, they were said to form a **caput medusae**. Caput medusae is a sign of portal hypertension.

INNERVATION OF THE INTERNAL ORGANS OF THE ABDOMEN AND PELVIS

Sympathetic Innervation

The Subdiaphragmatic Sympathetic Ganglia

The sympathetic axons to all the internal organs of the abdomen and pelvis derive from ganglia (some large, some minute) that lie along the anterior surface of the abdominal aorta and, below the aortic bifurcation, within the retroperitoneal and subperitoneal space of the pelvis. These are the **subdiaphragmatic sympathetic ganglia**.

Ganglia surrounding the origin of the celiac artery are said to constitute **celiac ganglia**. Around the origins of the superior mesenteric and inferior mesenteric arteries are so-called **superior mesenteric and inferior mesenteric ganglia**. Between the superior and inferior mesenteric plexuses are minute **intermesenteric ganglia**. Below the inferior mesenteric artery, extending along the front of the aorta and vertebral column as far down as the 1st or 2nd sacral vertebra, are minute **superior hypogastric ganglia**. On either side of the rectum are minute **inferior hypogastric ganglia**. Finally, bilaterally in the subperitoneal space are **pelvic sympathetic ganglia**. Another name for the subdiaphragmatic ganglia that lie on the anterior surface of the abdominal aorta is **pre-aortic ganglia**. Inferior to the aorta, the ganglia are said to be **prevertebral**.

Postganglionic sympathetic fibers are sent from the pre-aortic ganglia out along the celiac, superior mesenteric, inferior mesenteric, suprarenal, renal, and gonadal arteries to distribute to the internal organs supplied by these vessels. Postganglionics from the inferior hypogastric and pelvic ganglia travel directly to pelvic organs.

Preganglionic Sympathetic Input to Subdiaphragmatic Sympathetic Ganglia

All the preganglionic axons to the subdiaphragmatic sympathetic ganglia originate from cells lying in the intermediolateral columns of the spinal cord from the 5th thoracic to the 2nd lumbar segments. The axons travel out a ventral root, join the spinal nerve, enter its ventral ramus, and then leave the ventral ramus in a white ramus communicans to reach the paravertebral ganglion of the corresponding segment. Such axons either pass right through that ganglion to exit from its ventral surface or descend in the sympathetic chain to reach a lower paravertebral ganglion, which is also passed through and exited.

The nerve bundles containing preganglionic sympathetic axons that leave the chain are called **splanchnic nerves**. The precise name of a splanchnic nerve depends on the paravertebral ganglia from which it exits. On each side, bundles from the 5th thoracic to the 9th thoracic ganglia eventually join to form a **greater splanchnic nerve**. Bundles from the 10th and 11th ganglia may join the form the **lesser splanchnic nerve**. The bundle from the 12th thoracic ganglion is said to constitute the **least splanchnic nerve**. These thoracic splanchnic nerves are formed within the thorax and run downward toward the abdomen along the sides of the vertebral bodies. The thoracic splanchnic nerves must pass through the abdominal diaphragm to reach the subdiaphragmatic ganglia in which they synapse. They do this by piercing the crura of the diaphragm.

Splanchnic nerves emanating from lumbar sympathetic ganglia are called **lumbar splanchnic nerves**. They are variable in number. All the preganglionic sympathetic axons within lumbar splanchnic nerves derive from spinal cord levels T12-L2. One thing, however, must be obvious: any splanchnic nerve exiting from a lumbar ganglion below the 2nd must contain preganglionic axons that have descended in the sympathetic chain from higher ganglia.

The greater splanchnic nerve tends to feed the celiac ganglia; the lesser splanchnic feeds the superior mesenteric ganglia; and the least splanchnic and lumbar splanchnics feed the inferior mesenteric ganglia; but there is some overlap. **Thus, the foregut is controlled by spinal segments T5-T9, the midgut by T9-T12, and the hindgut by T12-L2 (note 5 segments go to the foregut, 4 segments to the midgut, and 3 segments to the hindgut)**. Within each region of the gut, structures that are developmentally more cranial receive innervation from more cranial segments of the spinal cord. Thus, the upper end of the stomach is innervated by T5-T6, the second part of the duodenum and its diverticula (such as the gallbladder) by T7-T9, the appendix by T10, the transverse colon by T11-T12, the descending colon by T12-L1, and the rectum by L1-L2. The kidneys and ureters also receive their sympathetic innervation from the T12-L2 segments of the cord.

The hypogastric and pelvic ganglia are fed by lumbar splanchnic nerves deriving from spinal cord segments T12-L2. It has been reported that in females some preganglionic sympathetic axons originating in spinal segments L1 and L2 actually descend within the sympathetic chain all the way down to the sacral sympathetic trunk and leave it as **sacral splanchnic nerves**. These are not found in males.

Although I have described the subdiaphragmatic ganglia as isolated clumps of sympathetic neurons fed by distinct splanchnic nerves, the fact of the matter is that these ganglia are interconnected by preganglionic sympathetic axons passing through one ganglion to get to another. Thus, a **subdiaphragmatic plexus** is formed. The subdiaphragmatic plexus is a highly complicated three-dimensional network of ganglionated nerve strands that can only be arbitrarily divided into regions.[21] One speaks of celiac, superior mesenteric, intermesenteric, inferior mesenteric, superior hypogastric, inferior hypogastric and pelvic plexuses as regions of the subdiaphragmatic plexus in which ganglia of the same name are embedded.

Parasympathetic Supply to Abdominopelvic Organs

The foregut, its derivatives, and the midgut receive their parasympathetic preganglionic input from the **vagus** nerve. The postganglionic cell bodies are located within the organ (e.g., within the bowel wall, within the connective tissue between liver cells, and so on). The vagal fibers enter the abdominal cavity as the anterior and posterior vagal trunks on the surface of the esophagus. These trunks pass onto the surface of the stomach, give direct branches to it, and then follow the left gastric artery back to the upper end of pre-aortic plexus. The vagal preganglionics join in the network of nerves forming the pre-aortic plexus and distribute to the abdominal organs supplied by branches of the celiac and superior mesenteric arteries.

Whether or not there is any parasympathetic supply to the adrenals, kidneys, or gonads is debated. Those who claim there is say they are derived from the vagus. This would make sense for the adrenal and gonad, given their high embryonic origin. However, the kidney arises in the pelvis, and if it receives parasympathetic innervation, such ought to come from pelvic splanchnic nerves (see further on). Indeed, this has also been suggested.

The hindgut and all pelvic organs receive their parasympathetic preganglionic input via the **pelvic splanchnic nerves**. These are early branches primarily of the 3rd and 4th sacral ventral rami. The pelvic splanchnic nerves carry preganglionic parasympathetic axons that have traveled from cell bodies in spinal cord segments S3-S4 out the ventral roots into the spinal nerves and thence to ventral rami. After leaving the ventral rami in the pelvic splanchnic nerves, these axons travel to the pelvic plexuses.

[21] Pick, J: The Autonomic Nervous System. JB Lippincott, Philadelphia, 1970.

Here there are not only small sympathetic ganglia but also tiny parasympathetic ganglia for the pelvic organs. Some of the preganglionic parasympathetic axons synapse in pelvic plexus parasympathetic ganglia, which then send postganglionic axons to pelvic organs. Other preganglionic parasympathetic axons pass through the pelvic plexus to go to postganglionic neurons within the walls of pelvic organs. The pelvic splanchnic nerves have no connection to the sympathetic trunk (but see footnote 4 in Chapter 2).

The axons within pelvic splanchnic nerves must also find a way to get to the descending and sigmoid colons. Branches of the pelvic splanchnic nerves before they join the pelvic plexuses, plus axons that have passed through the pelvic and inferior hypogastric plexuses, travel directly to the descending and sigmoid colons. A few of these may join the perivascular nerves along the inferior mesenteric artery, but apparently most do not.

The pelvic splanchnic nerves are often called **nervi erigentes** (L. *erigo*, to raise), because they carry the preganglionic parasympathetic axons that, upon stimulation, cause the phallus to erect. These particular axons probably synapse in ganglia within the pelvic plexuses. The postganglionic fibers then pass through the urogenital diaphragm and perineal membrane to reach the vasculature of the erectile bodies of the phallus. They are endangered by operations on the prostate, which can damage the part of the pelvic nerve plexus around this gland.

Visceral Pain From Internal Organs of the Abdominopelvic Cavity

Visceral pain from all organs within the abdominopelvic cavity travel back to the spinal cord along precisely the reverse of the pathway that brought sympathetic supply to these organs. Thus, if one knows the nerve bundles that carry sympathetic axons from the spinal cord to such an organ, one also knows the nerve bundles that carry pain from the organ back to the cord. In general, the pain returns to the same segments wherein lie the preganglionic sympathetic neurons for the organ.

An exception to the rule just stated concerns visceral sensation arising as the result of distension of pelvic organs. The axons carrying this sensation do not travel centrally with bundles carrying sympathetic outflow. Instead they travel centrally with bundles carrying parasympathetic outflow. Thus, all such pain fibers reach the S3-S4 (and occasionally either S2 or S5) levels of the cord.

As one example, we can trace pain back to the spinal cord from the gallbladder. The pain fibers travel from the wall of the gallbladder down the perivascular plexus of nerves around the cystic, right hepatic, proper hepatic, and common hepatic arteries to reach the celiac plexus. From here they travel in the greater splanchnic nerve (predominantly the right) up to the 7th-9th thoracic paravertebral ganglia. The pain fibers pass right through these ganglia into the white rami communicantes, and are conducted by them to the 7th-9th thoracic ventral rami. Traveling centrally in the ventral rami they reach the spinal nerves and pass from them into the dorsal roots of T7-T9. The cell bodies of these sensory neurons lie in the dorsal root ganglia, and the central processes of the axons enter the spinal cord at the T7-T9 segments.

True visceral pain from the gallbladder is perceived as a dull, poorly localized ache in the upper abdomen. As is often the case with true visceral pain, there is an accompanying referred somatic pain that is sharp and well localized. The referred pain from disease of the gallbladder starts in the epigastric (i.e., infraxiphoid) region of the anterior body wall (innervated by intercostal nerves 7-9) and radiates backward along the right side of the chest toward the inferior angle of the scapula, thus, along the right 7th-9th intercostal spaces. Occasionally referred pain from gall bladder disease is felt over the right shoulder. This is a typical location for referred pain from the right hemidiaphragm, innervated by spinal nerves C3, 4, and 5 via the phrenic nerve.. One must conclude either that gall bladder disease can somehow irritate the right hemidiaphragm, or that the phrenic sends a branch to the gall bladder.

The fact that referred pain from abdominal organs travels back to the same segments as provide sympathetic outflow explains why referred pain from the appendix (innervated by T10-T11) is localized to the periumbilical area, and why referred pain from the gonads (innervated by T12-L2) radiates mainly along the distribution of the ilioinguinal, iliohypogastric, and genitofemoral nerves.

As a second example of visceral pain pathways, we may trace pain produced by distension of the uterine cervix, as occurs during the first stage of labor. The sensory axons leave this organ to join the pelvic plexuses and then leave them via the pelvic splanchnic nerves. Thus, the sensory axons are carried to the S3 and S4 ventral rami, spinal nerves, and dorsal roots. The sensory cell bodies lie in the dorsal root ganglia and send their central process into the spinal cord segments S3 and S4. Referred pain from the uterine cervical distension is felt chiefly over the back of the sacrum.

The most severe labor pain arises not from cervical distension but from sustained contractions of the uterine body. This pain is carried centrally along the same nerves that bring sympathetic supply to the organ. You should deduce that spinal cord levels T12 - L2 are the source of sympathetic innervation to the uterus, but this is a case where the facts supercede deduction. In truth, the uterus receives it sympathetic supply from the T10 - L1 levels of the spinal cord and it is to these levels that the pain of uterine contraction returns. The pain of delivery is a somatic pain due to perineal stretching and, if performed, episiotomy. This pain is carried by the pudendal nerve (S2-4).

It is possible to eliminate all labor and delivery pain by anesthetizing spinal nerves T10 - S4. Nowadays, the most popular means of producing anesthesia of T10 - S4 is via a lumbar epidural block. One determines if the proper levels have been anesthetized by testing the skin for its ability to respond to touch. The level of insensibility must rise as high as the umbilicus (T10) and as low as the perineum.

LYMPHATICS OF THE ABDOMEN, PELVIS, AND PERINEUM

Nodes That Lie Along Vessels

In general, throughout the body, lymph nodes are gathered into groups that lie along major blood vessels. The lymph nodes of the abdomen, pelvis, and perineum follow this rule. More often than not, groups of nodes take the name of the vessels they lie near to.

Nodes of the Gut and Associated Structures--The Pre-aortic Chain

Lymph nodes lie alongside all the arterial branches that go to bowel, liver, pancreas, and spleen. Some are very close to the organ, and these drain to more central nodes that lie along larger arteries. Where arterial branches lie in a mesentery, so do the nodes. Where the arteries have become secondarily retroperitoneal, so have the nodes. Eventually lymph from the foregut and spleen drains to a few nodes around the origin of the celiac artery; lymph from the midgut drains to a few nodes around the origin of the superior mesenteric artery; lymph from the hindgut drains to a few nodes around the origin of the inferior mesenteric artery. The celiac, superior mesenteric, and inferior mesenteric nodes form a **pre-aortic chain** along the anterior surface of the abdominal aorta. The lower nodes of this chain drain to the higher nodes. It is useful to view all the smaller nodes closer to the gut, liver, pancreas, and spleen as simply outlying members of this pre-aortic chain.

Inguinal Nodes

In the subcutaneous tissue on the front of the thigh, immediately below the inguinal ligament, is a collection of lymph nodes called the **superficial inguinal nodes**. (Sometimes an upper group, lying along the origins of the superficial epigastric and superficial circumflex iliac vessels, and a lower group, lying along the terminal part of the great saphenous vein, are distinguished.) The nodes of the superficial inguinal group are very large. They are palpable even in the absence of disease. The efferents of all these nodes pass through the deep fascia of the thigh either to reach the so-called **deep inguinal nodes** that lie around the upper few inches of the common femoral vein, or to run past these to reach the external iliac nodes.

Iliac Nodes

Along the external iliac, internal iliac, and common iliac vessels are nodes that are called **external iliac, internal iliac, and common iliac nodes**, respectively. The external iliac nodes are obviously a continuation of the deep inguinal nodes and receive lymph from them. Lower iliac nodes drain to the higher ones.

Para-aortic (Lumbar) Nodes

The right common iliac chain of lymph nodes continues superiorly onto the right surface of the aorta, in close contact with the inferior vena cava. These constitute the right **para-aortic nodes**. A comparable extension of the left common iliac chain onto the left side of the aorta comprises the left para-aortic nodes. The para-aortic nodes are the abdominal equivalent of the posterior mediastinal nodes.

Lymphatic Drainage of Specific Structures

Skin and Subcutaneous Tissue

The skin and subcutaneous tissue below a transverse plane through the umbilicus (all the way down to the tips of the toes) drain into the superficial inguinal nodes.

Muscles and Deep Fascia

The deep structures of the body wall send lymphatic vessels centrally alongside the vasculature that supplies blood to these structures. Such lymph vessels drain to the previously mentioned nodes lying along the major vascular trunks to which the smaller ones connect. Thus, lymphatics follow the inferior epigastric and deep circumflex iliac blood vessels back to the external iliac nodes. Other lymphatics follow lumbar vessels back to para-aortic nodes. Lymphatics from deep structures of the perineum follow the internal pudendal vessels back to internal iliac nodes. The principle is really quite simple and there is no need to give additional examples.

Internal Organs

The same pattern just described for abdominopelvic wall structures, holds for the internal organs. Lymphatics follow blood vessels centrally toward the nodes at their origins. Thus, the bowel and its derivatives drain ultimately to the pre-aortic chain (after having passed through all the outlying members of this chain). Primarily retroperitoneal abdominal organs drain to para-aortic nodes. Pelvic organs drain to internal iliac nodes. Remember that the blood supply to the gonads arises from the aorta between the SMA and IMA. Thus, lymph from the gonads returns primarily to para-aortic nodes of this region. Lymph from the fundus of the uterus may also drain to para-aortic nodes. Some lymph from the ovary goes to internal iliac nodes, maybe via a route that follows the uterine artery’s contribution to ovarian blood supply. Finally, if its normal routes of lymphatic drainage are blocked by tumor, the uterus may drain to superficial inguinal nodes. Once tumor is found here, it is generally a sign of advanced disease.

Lumbar Trunks, Intestinal Trunk, Cisterna Chyli, and Thoracic Duct

Efferent lymph vessels from the para-aortic (lumbar) nodes join to form the **lumbar trunks**, one on the right and one on the left. Efferent lymph vessels from the highest pre-aortic nodes join to form the **intestinal trunk**. The lumbar trunks pass onto the L1/L2 intervertebral disc, and here join one another and the intestinal trunk to form the **thoracic duct**. Often the thoracic duct is dilated at its beginning as the so-called **cisterna chyli**. Regardless, the thoracic duct passes superiorly on the anterior surface of the vertebral column through the aortic hiatus of the diaphragm and into the thorax.

TWO IMPORTANT EXCEPTIONS TO THE LYMPH DRAINAGE JUST DESCRIBED

1. The sigmoid colon and upper rectum send lymphatic vessels not only to the inferior mesenteric nodes but also to the left lumbar chain. Thus, metastatic carcinoma from these segments of the bowel is likely to involve both pre- and para-aortic nodes.
2. The bare area of the liver and the cardiac end of the stomach send lymphatic vessels through the diaphragm to the lateral diaphragmatic nodes of the thorax. Thus, metastatic carcinoma from the liver and upper stomach may pass directly into the thoracic nodes.

SURFACE ANATOMY AND RELATIONSHIPS OF ABDOMINOPELVIC ORGANS

As was done for thoracic organs, surface anatomy and relationships of abdominopelvic structures will be presented for the average supine person. Many abdominal organs descend considerably when a person sits or stands, but physical examination, radiographs, and surgery of the abdomen and pelvis are almost always done on supine patients.

Surface Landmarks

Many important surface landmarks of the lower trunk concern bones that can be palpated. At the back, one can feel ribs, spines of vertebrae, and part of the ilium. At the side, ribs and parts the ilium are palpable. On the front, ribs, the sternum, and the parts of the pubic bone can be felt. The ischiopubic rami and ischial tuberosity are palpable in the perineum. In addition there are some observable landmarks unrelated to bones.

Bony Landmarks on the Back of the Abdomen and Pelvis

The 12th rib can usually be palpated lateral to the erector spinae muscle, but since this is not always the case, the 12th rib is not an important landmark. It is far more useful to orient oneself relative to the tip of the **4th lumbar spine**. This can be located because it is crossed by a plane passing between the most superior points on the iliac crests, which lie quite near the back of the ilium. This is the **supracristal (intercristal) plane.**

The level of the 2nd sacral vertebra lies on the same transverse plane as the palpable **posterior superior iliac spine**. Usually there is a dimple in the skin over the posterior superior iliac spine. It will be recalled that S2 marks the end of the dural sac.

The sacral hiatus, formerly an important landmark for epidural anesthesia, is usually palpable, as is the coccyx.

Bony Landmarks on the Side of the Abdomen and Pelvis

The most inferior point on the 10th costal cartilage, the tip of the 11th costal cartilage, and the tip of the 12th costal cartilage all lie more or less on the same transverse plane (**subcostal plane**) that crosses the **3rd lumbar vertebra**. Thus, the rib cage is separated by only one vertebral level from the tops of the iliac crests.

Just behind the anterior superior iliac spine a lateral projection of the iliac crest is called the iliac tubercle (see Chapter 10). A transverse plane passing through the right and left iliac tubercles is called the **intertubercular plane**; it crosses the **5th lumbar vertebra**.

Bony Landmarks on the Front of the Abdomen and Pelvis

As we know, the xiphisternal joint and ribs can be palpated on the front of the trunk. So may be the anterior superior iliac spines. A transverse plane at their level is called the **interspinous plane**. It crosses the **2nd sacral vertebra**.

In the anterior midline the top of pubic symphysis can be felt. Extending laterally are the palpable pubic crests, which end in the pubic tubercles.

One knows that the inguinal ligament runs between the anterior superior iliac spine and the pubic tubercle, but it is only palpable in thin persons.

Bony Landmarks of the Perineum

The ischiopubic rami, ending posteriorly at the ischial tuberosities, can be palpated from below. The ischial spines can be felt through the wall of the rectum by a finger placed through the anus.

Two Important Nonbony Landmarks

The **umbilicus** is an easily observable landmark in the abdomen. It generally lies opposite the **L4 vertebra**, thus on the supracristal plane.

In persons with good muscle development, and who are not too fat, the lateral edge of the rectus abdominis may be seen through the skin. This lateral edge is called the **linea semilunaris**. It crosses the costal margin at the **tip of the 9th costal cartilage**.

The Transpyloric Plane

A very important landmark of the abdomen is not itself palpable or visible, and must be derived from the position of structures that are. The transpyloric plane is defined as a transverse plane positioned halfway between the jugular notch of the manubrium and the top of the pubic symphysis. Since this is sometimes inconvenient to determine, there are three other lines that approximate the location of the transpyloric plane. One is a line joining the medial epicondyles of the humeri when the upper limbs are at the side. A second is a plane about halfway between the umbilicus and the xiphisternal joint. The third approximation is a transverse plane through the point where the linear semilunaris meets the costal margin.

As we position organs within the abdominal cavity the importance of the transpyloric plane will become evident. The following structures lie in the transpyloric plane:

1. L1/L2 intervertebral disc
2. End of spinal cord
3. Beginning of thoracic duct
4. Hili of the kidneys (with the left a bit above the transpyloric plane and the right a bit below it)

5. Superior margins of the renal arteries at their origins

6. Beginning of portal vein (just to the right of midline)
7. Neck of pancreas (anterior to [6])
8. Superior border of pylorus (separated from [7] by the lesser sac)
9. Fundus of gallbladder (deep to tip of right 9th costal cartilage).

Positions of Organs and Structures

Sympathetic Trunk (see Fig. 5-10)

On each side, entering the abdominal cavity behind the medial arcuate ligament, is a lumbar sympathetic trunk. It descends on the anterolateral surfaces of the lumbar vertebral bodies and intervertebral discs, along the anteromedial border of the psoas major. Below the origin of the psoas, the sympathetic trunk passes into the pelvis on the ventral surface of the sacrum medial to the ventral sacral foramina.

Aorta (see Fig. 5-10)

Entering the abdominal cavity by passing through the aortic hiatus of the diaphragm opposite T12, the aorta descends along the anterior surfaces of the lumbar vertebrae immediately to the left of the midline. Opposite the lower half of L4 (supracristal plane, umbilical plane), the aorta bifurcates into the common iliac arteries.

Origins of the Arteries to the Bowel (see Fig. 5-10). The celiac artery arises from the anterior surface of the aorta just below the top of L1. The superior mesenteric artery arises a centimeter or so further inferiorly, just below the middle of L1. The inferior mesenteric artery arises opposite L3 (subcostal plane).

Inferior Vena Cava (see Fig. 5-11)

Forming anterior to the right edge of the 5th lumbar vertebral body (intertubercular plane), the inferior vena cava passes superiorly in front of the right sympathetic trunk as far as the origin of the diaphragm from the medial arcuate ligament. It then follows the undersurface of the diaphragm upward and forward to pierce the central tendon at its dome (opposite T9) to the right of the midline.

Kidneys (see Fig. 5-11)

The hili of the kidneys lie opposite the L1/L2 intervertebral discs (transpyloric plane). More accurately, the left hilum is a bit above this, and the right a bit below. The top of the left kidney lies opposite the top of T12; the bottom of the left kidney lies opposite the middle of L3. The top of the right kidney lies opposite the middle of T12; the bottom of the right kidney lies opposite the bottom of L3. **Thus, the kidneys lie from T12-L3, with the left a bit higher than the right**. Depending on the obliquity of the ribs, the top of the left kidney reaches as high as the 11th rib or 10th intercostal space. The right kidney reaches as high as the 11th intercostal space or 11th rib.

The kidneys lie on the posterior abdominal wall. They nestle up against the lateral surface of the psoas major, their hili facing anteromedially and their “posterior” surfaces facing posteromedially. The lateral surface of the psoas major is oblique and so is the long axis of a kidney, its upper pole being closer to the midline than its lower pole. Above the medial and lateral arcuate ligaments, the posterior surface of the kidney rests on the abdominal diaphragm. Below this level, the relationship is to the psoas major, quadratus lumborum, and transversus abdominis. Since the subcostal, iliohypogastric, and ilioinguinal nerves lie on the anterior surface of the quadratus lumborum below the diaphragm, these nerves are interposed between the kidney and the muscle.

The anterior relationships of the kidneys are very important but cannot be discussed until more of the abdominal organs are put in place.

The renal arteries come off the sides of the aorta immediately below the transpyloric plane. The right renal artery passes behind the inferior vena cava (so as not to compress it). The left renal vein (see

Fig. 5-12) crosses anterior to the aorta (so as not to be compressed by it) to reach the inferior vena cava. In doing this, the left renal vein passes inferior to the origin of the superior mesenteric artery. On their way from the kidneys, the renal veins lie anterior to the renal arteries.

Ureter (Fig. 5-12)

The ureter passes vertically down the abdomen, lying on the anterior surface of the psoas major, in a sagittal plane corresponding, to the tips of the lumbar transverse processes. The ureter is the most posterior of the structures on the psoas surface, being crossed by the gonadal vessels and, on the right side, also by the superior mesenteric vessels (see Fig. 5-33). The inferior mesenteric vessels are medial to the left ureter (see Fig. 5-33), but the left colic artery crosses anterior to it.

The ureter crosses the medial surface of the bifurcation of the common iliac artery and then follows the internal iliac artery into the pelvis. Upon reaching the lower limit of the peritoneal sac, the ureter turns forward and takes an anteromedial course to the bladder. In females, the ureter passes inferior to the uterine artery; in males, it passes inferior to the vas deferens.

Suprarenal Glands (see Fig. 5-12)

The suprarenal glands lie on the upper poles of the kidneys, opposite T12 and L1. Their posterior surfaces lie on the crura of the diaphragm. The right suprarenal is posterior to the inferior vena cava.

Pancreas (see Fig. 5-33)

The neck of the pancreas lies just to the right of the midline in the transpyloric plane. Thus it lies just anterior to the junction of the *left* renal vein with the inferior vena cava. Extending below and to the right of the neck is the head of the pancreas. It lies on the anterior surface of the inferior vena cava at the level of L2. The uncinate process of the pancreas extends toward the left, behind the superior mesenteric vein and occasionally even further, onto the anterior surface of the aorta below the site where it is crossed by the left renal vein.

The body of the pancreas extends from the neck toward the left, crossing the aorta anterior to the origin of the SMA. Past the aorta, the lower border of the pancreas more or less parallels the transpyloric plane. Thus, the body of the pancreas travels retroperitoneally toward the left and then crosses the anterior surface of the left kidney at its hilum. Upon reaching the root of the lienorenal ligament, the pancreas enters between the two layers of this mesentery and travels as the so-called tail of the pancreas to the spleen.

The celiac artery, arising a centimeter or so above the superior mesenteric, is found at the upper border of the pancreas. The splenic branch of the celiac artery runs toward the left along the upper border of the pancreas and accompanies it in the lienorenal ligament to the spleen.

Duodenum (see Fig. 5-33)

The duodenum begins at the pylorus, the upper border of which lies in the transpyloric plane just to the right of the midline. The postpyloric duodenum swings upward as the so-called **duodenal bulb**. The duodenal bulb is not retroperitoneal. From its superior edge comes the hepatoduodenal ligament. The free edge of the hepatoduodenal ligament lies anterior to the inferior vena cava. Between them is the epiploic foramen, which is bounded inferiorly by the duodenum and superiorly by the caudate lobe of the liver. After its short upward course, the duodenum turns posteriorly to become retroperitoneal along the right side of L1, superior to the head of the pancreas. Upon reaching the right kidney, the duodenum turns inferiorly to travel across the right renal vein down to the level of L3, and then turns to the left, crossing sequentially the right psoas major (on which rest the ureter and gonadal vessels), inferior vena cava, and aorta at the origin of the IMA. On the aorta, the duodenum makes another cranial turn and travels along its left side onto the left psoas major anterior to the left sympathetic trunk. This fourth part of the duodenum travels as high as L2, where it turns anteriorly, regains a mesentery, and becomes the jejunum.

Superior Mesenteric Artery (see Fig. 5-33)

The SMA arises behind the body of the pancreas and passes downward, curving gently to the right. Immediately after its origin, the artery crosses anterior to the left renal vein. At the lower border of the pancreas the SMA enters the root of the mesentery and in it crosses the third part of the duodenum, the aorta (sometimes), and the inferior vena cava to reach the anterior surface of the right psoas major. On the surface of the right psoas major, the SMA crosses anterior to the ureter and gonadal vessels, and then terminates below the iliac crest as the last ileal artery.

Superior Mesenteric, Splenic, and Portal Veins (see Fig. 5-34)

The superior mesenteric vein follows the same course as the artery, but on its right side. The splenic vein runs on the posterior surface of the pancreatic body (just inferior to the splenic artery) toward its neck. Behind the neck of the pancreas the superior mesenteric and splenic veins meet to form the portal vein. Thus, the beginning of the portal vein is sandwiched between the neck of the pancreas and the junction of the left renal vein with the inferior vena cava.

From the site of its formation, the portal vein travels superiorly, behind the duodenal cap, to enter the hepatoduodenal ligament. Within this mesenteric sheet, the portal vein lies posterior to the proper hepatic artery. The common bile duct lies in the free edge of the hepatoduodenal ligament to the right of the artery.

Common Bile Duct (Fig. 5-34)

From its location in the free edge of the hepatoduodenal ligament, the common bile duct passes downward behind the duodenal cap and the head of the pancreas (between it and the inferior vena cava) to reach the major duodenal papilla in the second part of the duodenum. It is joined by the main pancreatic duct within the duodenal wall.

Ascending Colon (Fig. 5-43)

The ascending colon begins in the right iliac fossa and takes a short course upward on the transversus abdominis and quadratus lumborum toward the right kidney. On the anterior surface of the lower pole of the right kidney, the ascending colon makes a turn to the left to become the transverse colon. This turn is called the **right (or hepatic) flexure** of the colon.

The iliohypogastric and ilioinguinal nerves, after passing behind the kidney, then pass behind the ascending colon. Lower down, so does the lateral femoral cutaneous nerve.

Descending and Sigmoid Colons (see Fig. 5-43)

The descending colon begins at the **left (or splenic) flexure**, which lies just lateral to the middle of the left kidney. It takes a retroperitoneal course downward (first on the diaphragm, then on the quadratus lumborum and transversus abdominis) into the left iliac fossa. In the left iliac fossa, the descending colon turns toward the right and crosses onto the anterior surface of the psoas major. This turn is called the **sigmoid flexure**, and beyond it lies the sigmoid colon. The sigmoid colon takes a variable course to the beginning of the rectum, which lies in midline on the surface of S3. Often the sigmoid colon loops quite high into the abdominal cavity.

The same nerves that lie posterior to the ascending colon lie behind the descending colon. The sigmoid colon has the left common iliac vessels behind it.

It is said that the left foot is usually larger than the right because pressure of a feces-filled sigmoid colon on the left iliac veins produces a slight physiological "edema" of the left lower limb.

Transverse Colon (see Fig. 5-43)

The transverse colon takes a variable course between the two colic flexures. It may go almost straight across, but more typically it dips down in the middle. Sometimes this dip is so great that the transverse colon extends into the false pelvis. The left most portion of the transverse colon lies on the anterior surface of the lower outer quadrant of the left kidney.

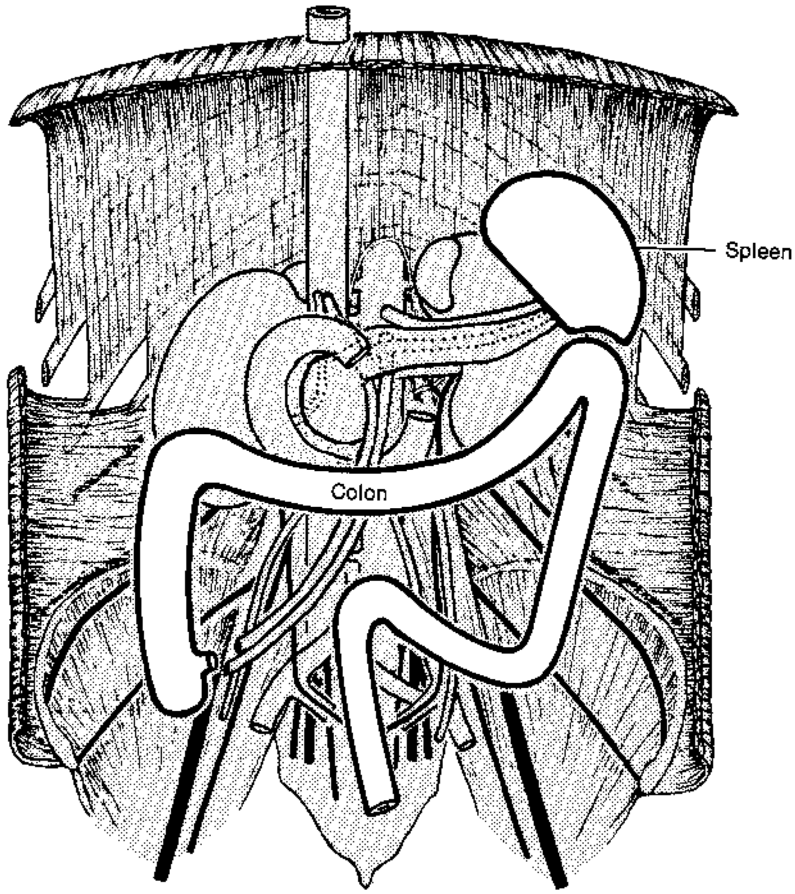


Figure 5–43. The positions of the spleen and colon (in white) in relation to other abdominal structures.

Spleen (see Fig. 5-43)

The spleen is contained within the upper mesogastrium, bulging out that mesentery's left layer. It lies deep to the 9th, 10th, and 11th ribs posterior to left midaxillary line. The rounded lateral surface of the spleen is related to the diaphragm. Its flat posteromedial surface is related to the upper outer quadrant of the left kidney. Its concave anteromedial surface is related to the greater curvature of the stomach (Fig. 5-44). Its lower pole is related to the splenic flexure of the colon. I have specifically used the word "related" in the foregoing descriptions, because the spleen is actually separated from all the named organs by peritoneum and peritoneal cavity.

The tail of the pancreas travels in the lienorenal ligament to the hilum of the spleen.

Esophagus and Stomach (see Fig. 5-44)

The esophagus pierces the muscle of the diaphragm posterior to the central tendon and just to the left of the midline (see Fig. 5-36*A*) opposite T10 (the xiphoid process). It takes a short course and enters

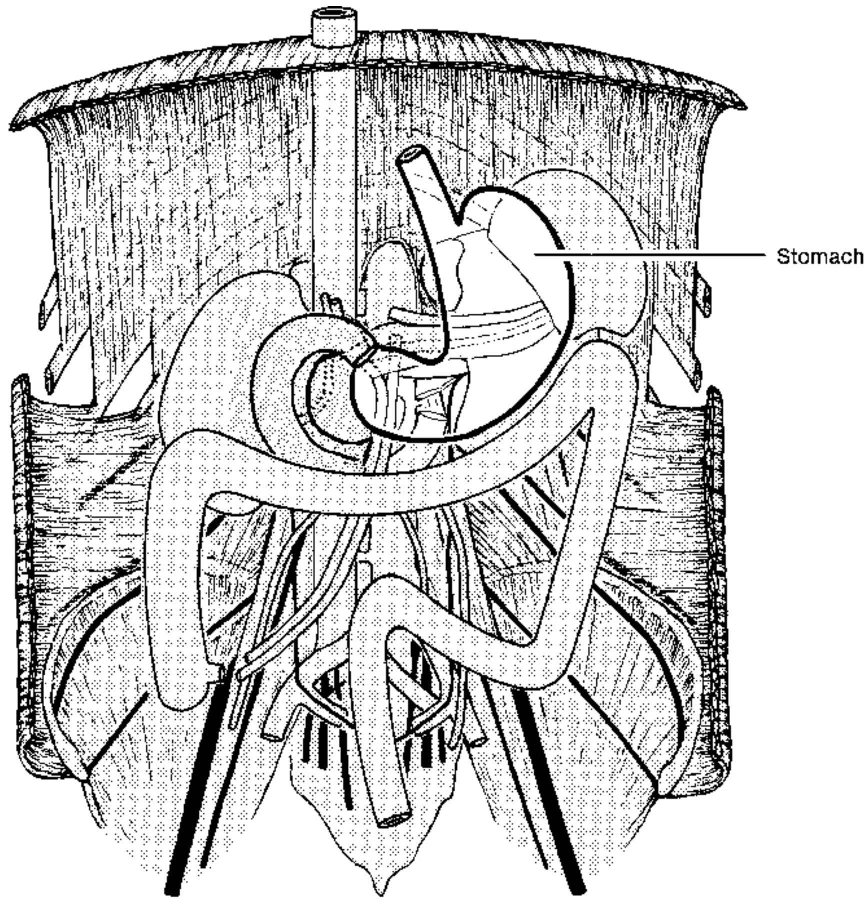


Figure 5-44. The position of the stomach (in white) in relation to other abdominal organs.

the stomach at a site 2 fb to the left of the midline, halfway between the xiphisternal joint and the transpyloric plane. The stomach follows a highly variable course from this point to the pylorus (immediately to the right of the midline, immediately below the transpyloric plane). Its general course is described as J-shaped. The fundus and body lie considerably more posterior than the antrum. The upper part of the greater curvature of the stomach is related to the anteromedial surface of the spleen. The lower part of the greater curvature is related to the transverse colon, and connected to it by the gastrocolic ligament.

The posterior surface of the stomach is separated from retroperitoneal organs by the lesser sac. The body is related to the upper inner pole of the left kidney, the left suprarenal gland, and to the body of the pancreas. The pylorus lies anterior to the neck of the pancreas (separated from it by the lesser sac).

Ulcers of the posterior wall of the stomach, if they perforate, spill their contents into the lesser sac and may lead to an abscess of the lesser sac. They may also adhere to, and cause necrosis of, pancreatic tissue

---

Liver and Gallbladder (Fig. 5-45)

The inferior pole of the liver lies in the right midaxillary line anywhere between the costal margin and the iliac crest. The hepatic flexure of the colon is related to the medial surface of the inferior pole of the liver.

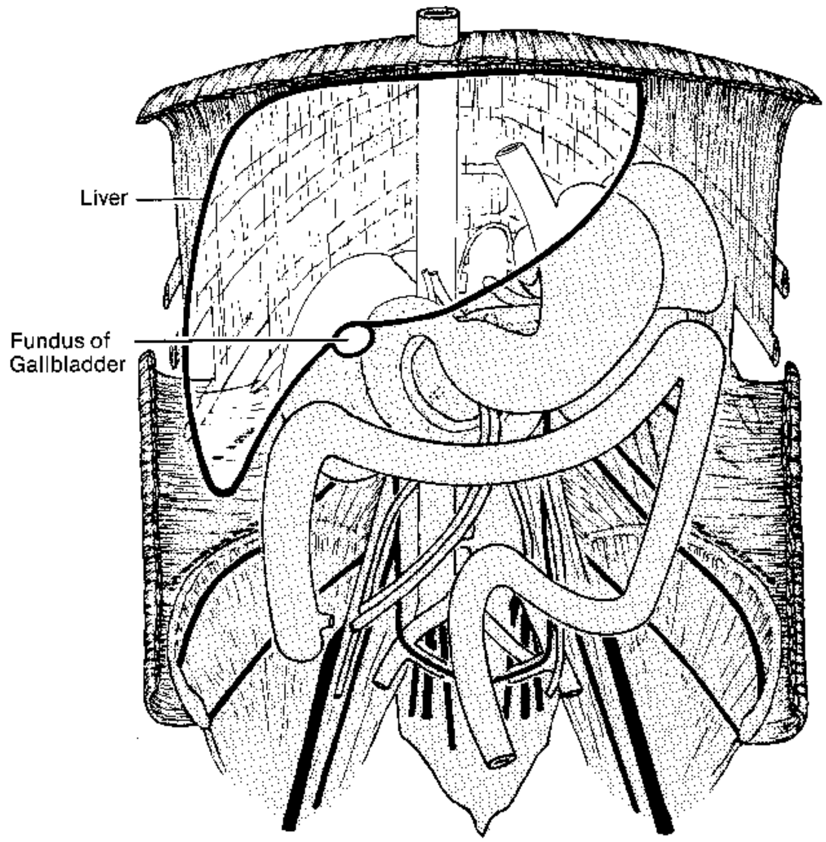


Figure 5-45. The positions of the liver and the fundus of the gallbladder in relation to other abdominal organs.

The right and superior surfaces of the liver follow the undersurface of the diaphragm. The highest point of the superior surface lies in the right midclavicular line at the level of the 5th rib. From this point, the superior limit of the liver sweeps across the xiphisternal joint toward the left 5th intercostal space 1 hb from the midline. This is the furthest leftward extent of the liver. From this site the anterior border follows a more or less oblique course toward the right costal margin, where it intersects the transpyloric plane (also linea semilunaris). This is the site of the fundus of the gallbladder. Below this point the anterior border of the liver follows the costal margin down to the inferior pole. Only the caudate and the right lobes of the liver have a posterior surface. The left lobe has only a posterior edge. The posterior surface of the caudate lobe is related to the diaphragm, separated from it by the superior recess of the lesser sac. The posterior surface of the right lobe is related to the right kidney, separated from it by the so-called **hepatorenal recess** of the peritoneal cavity. This recess is a low point of the peritoneal cavity when one is lying on one's back.

The esophagus is related to the back edge of the liver just to the left of the left sagittal fissure. The inferior surface of the left lobe of the liver is related to the stomach.

Anterior Relations of the Kidneys

In one way or another these have been mentioned previously. The anterior relationships of the left kidney are the suprarenal gland, pancreas, terminal portion of the transverse colon, spleen, and stomach (see Fig. 5-44). The anterior relationships of the right kidney are the suprarenal gland, liver, right colic flexure, and sometimes the second part of the duodenum (see Fig. 5-45).

SOME CLINICALLY SIGNIFICANT FACTS ABOUT THE RELATIONSHIPS AND SURFACE ANATOMY OF ABDOMINAL ORGANS

Obviously, in order to understand how disease of one organ can involve a nearby one, or where one places a hand to palpate any particular abdominal structure, one must know all the relationships and surface anatomy just described. I would like to illustrate this with just a few cases.

1. A tumor of the head of the pancreas will often compress the common bile duct, which lies posterior to it. Compression of the common bile duct leads to jaundice and a palpable, but painless, gall bladder.

2. The superior mesenteric artery's descending course takes it across the anterior surface of the third part of the duodenum. Normally there is sufficient fat in the root of the mesentery to form a cushion between the artery and the duodenum. If a person undergoes dramatic loss of weight (or growth in height without gain in weight) the arterial wall may come into direct contact with the duodenum. Furthermore, in such a person the loss of mesenteric fat tends to allow the small intestine to descend lower in the abdomen during erect posture. This descent pulls the superior mesenteric artery taut across the third part of the duodenum and leads to compression of its lumen. A similar phenomenon may occur in a person whose spine is held in hyperextension by a cast. Afflicted persons may be unable to pass solid food through the third part of the duodenum. Abdominal cramps and vomiting will follow attempts to eat solid food. The patient may have to assume a prone position (which pulls the superior mesenteric artery away from the duodenum) and eat soft foods in order to allow passage of food to the jejunum. If this fails gastrojejunostomy (surgical connection of the stomach to the jejunum) or duodenojejunostomy (surgical connection of a proximal part of the duodenum to the jejunum) may be required to allow food to bypass the area of duodenal occlusion until weight is regained. Another option is to detach the root of the mesentery and the superior mesenteric artery from the posterior abdominal wall and displace the entire duodenum and jejunum to the right side of the abdomen.

3. Normally the spleen is not palpable. When it is greatly enlarged (splenomegaly), it expands anteriorly to the right and also inferiorly. Then it may be palpated (particularly on deep inspiration) emerging under cover of the left costal margin, between this margin and the umbilicus. The enlarged spleen also displaces mobile structures to which it is related. As the spleen expands anteriorly and to the right, the body of the stomach (related to the spleen's anteromedial surface) is shoved in the same direction. This is detectable on radiographs as a displacement of the gastric air lucency to the right. As the spleen expands inferiorly, the splenic flexure of the colon (related to the inferior pole of the spleen) is pushed downward. Again , this is detectable on radiographs as an inferior displacement of the air than usually resides in the splenic flexure.

4. The close relationship of the spleen to the 9th-11th ribs makes this organ particularly susceptible to puncture by a rib fragment consequent upon traumatic injury to the left posterior thorax.

Pelvic Structures

Surface anatomy of pelvic organs is not of much relevance, since they are generally accessible to examination only by palpation through the rectum or vagina. The one major exception is the uterus. By placing two fingers into the vagina up to the uterine cervix, and then pushing the uterus upward, a second hand on the abdomen above the pubis can palpate the uterine fundus. Masses associated with the uterine tubes or ovaries can also be felt.

The close relationship of the urinary bladder to the anterior pelvic brim (see Fig. 5-35*C,D*) is also of significance. When empty, the bladder does not rise out of the pelvis, but when full it may do so. As the bladder roof rises, it takes parietal peritoneum with it. Thus, with the patient's bladder full, one may make a surgical incision above the pubic symphysis and enter the subperitoneal area of the pelvic cavity. If this is desired, the bladder is artificially inflated at the time of surgery by means of a urethral catheter.

Most routine examination of pelvic organs involves placement of a finger (or fingers) in the rectum and, in women, also in the vagina.

In men, a rectal examination enables assessment of the posterior surface of the prostate gland, which is anterior to the rectum. An attempt can be made to feel the seminal vesicles on the back of the bladder (see Fig. 5-35*D*), but this is not often possible.

In women, the rectal examination enables assessment of the organs anterior to the rectum. These are the posterior wall of the vagina (separated from the rectum by the connective tissue of the rectovaginal septum) and the lower uterus (separated from the rectum by the posterior cul-de-sac) (see Fig. 5-35*C*). Normally the posterior wall of the vagina is examined intravaginally. However, if a vaginal examination cannot be performed (such as in a child) a rectal examination can give some information about the back wall of the vagina. Rectal examination in adult women is done primarily to provide information about the posterior cul-de-sac, uterine cervix, and lower uterine body.

A vaginal examination enables assessment not only of the vagina, its fornices, and the lowest part of the cervix, but also of the urethra and base of the bladder, both of which lie anterior to the vagina (Fig. 5-35*C*). Placing one finger in the vagina and the adjacent finger in the rectum allows examination of the rectovaginal septum