CHAPTER 5

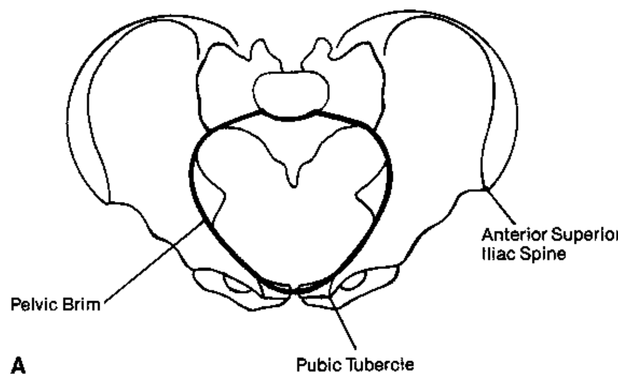
Abdomen

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[15]. 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



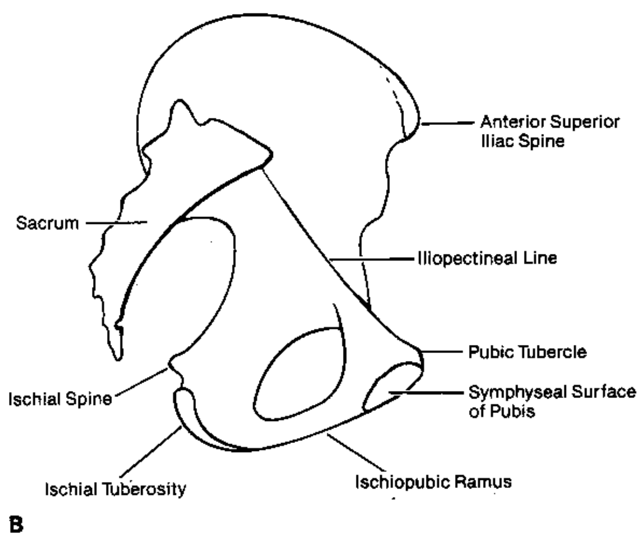


Figure 5-1. *A*, Superior view of bony pelvis. *B*, Medial view of left os coxae and sacrum. The iliopectineal line represents the os coxae's contribution to the pelvic brim.

[15] If the reader is unfamiliar with the basic structure of the innominate bone, he or she should refer to Chapter 12.

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.

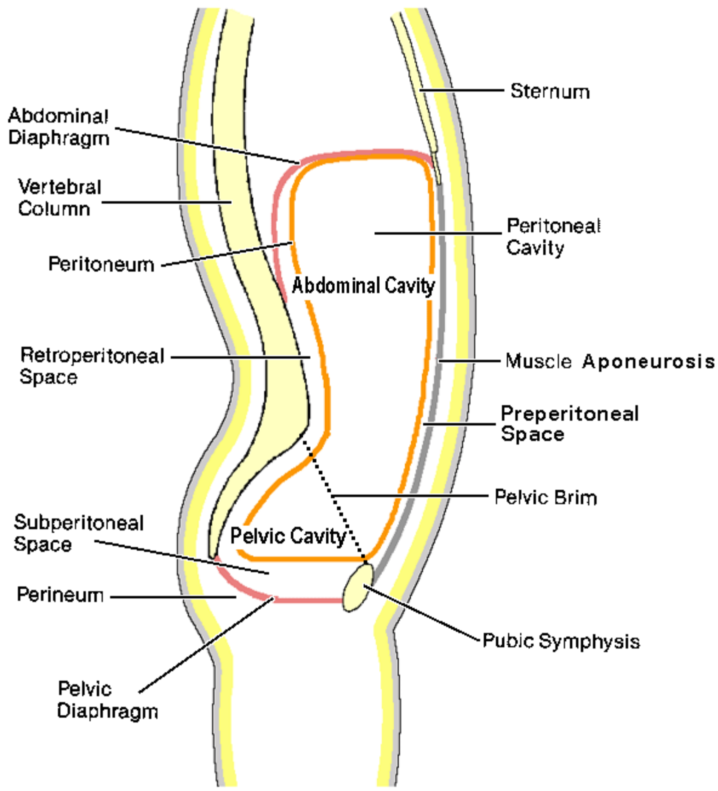


Figure 5-2. Schematic median sagittal section of abdominopelvic cavity. Postero-inferior to the pelvic brim is the lesser (true) pelvis with its cavity. Immediately anterosuperior to the pelvic brim is the greater (false) pelvis, the cavity of which merges without demarcation into that of the abdomen.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

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 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**.

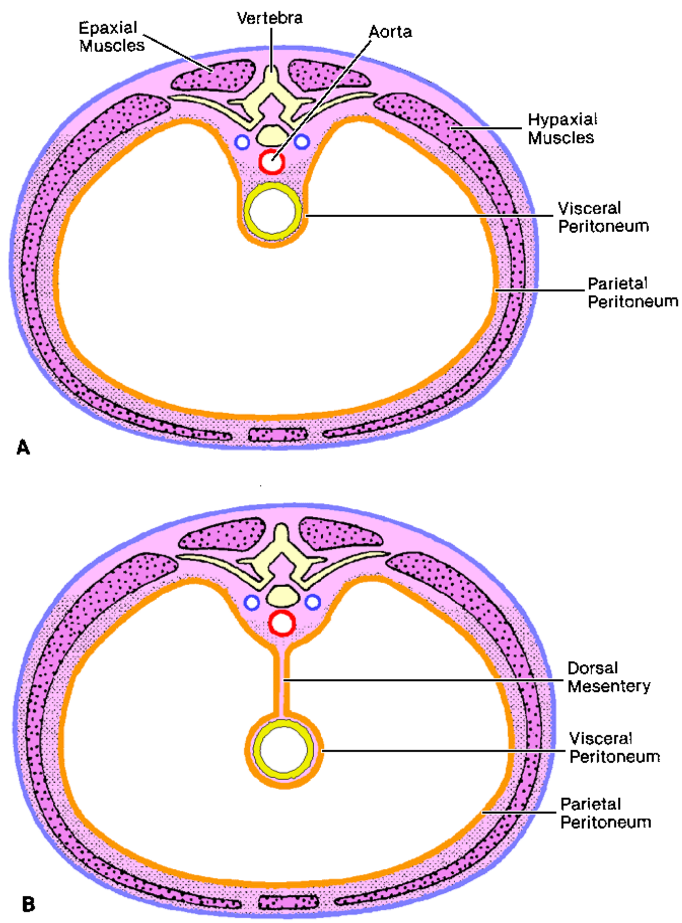


Figure 5–3. Schematic transverse sections through the embryonic abdomen at two sequential stages in development. *A*, A very early stage, in which the gut causes the dorsal wall of the peritoneal sac to deviate around it but in which no actual dorsal mesentery exists. *B*, A slightly later stage, in 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.

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, 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[16]. 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 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.

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** (see Figure 5-4). 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** (see Figure 5-4).

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[16] 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).

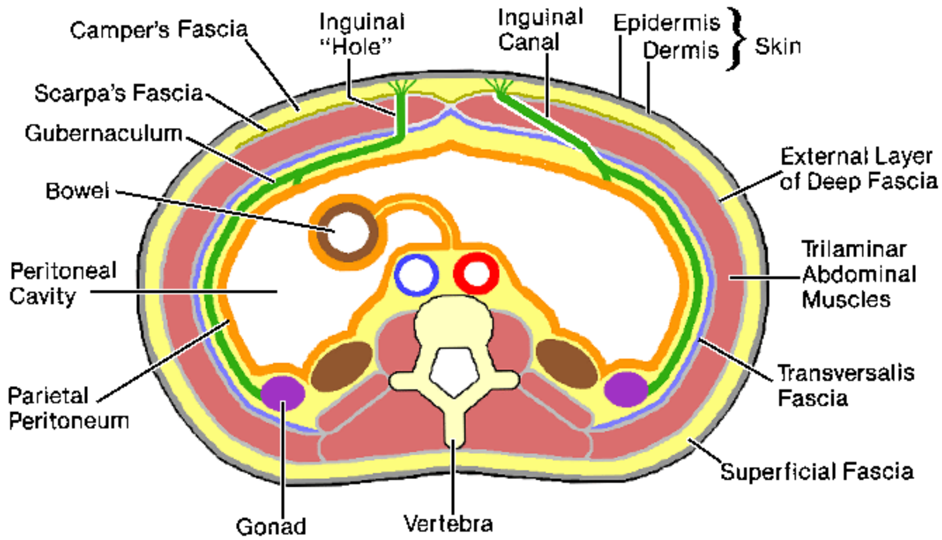


Figure 5-4. Schematic transverse section of the abdomen showing the path of the embryonic gubernaculum. See text for a discussion of why an inguinal canal is far preferable to an inguinal "hole".

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.

Anterolateral Muscles

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.

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. 5-4). 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. 5-4) very near the inferior limit of the anterior abdominal wall.

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 5-4. 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. 5-4). 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. 5-5A). 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.

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 12, p. 526) 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

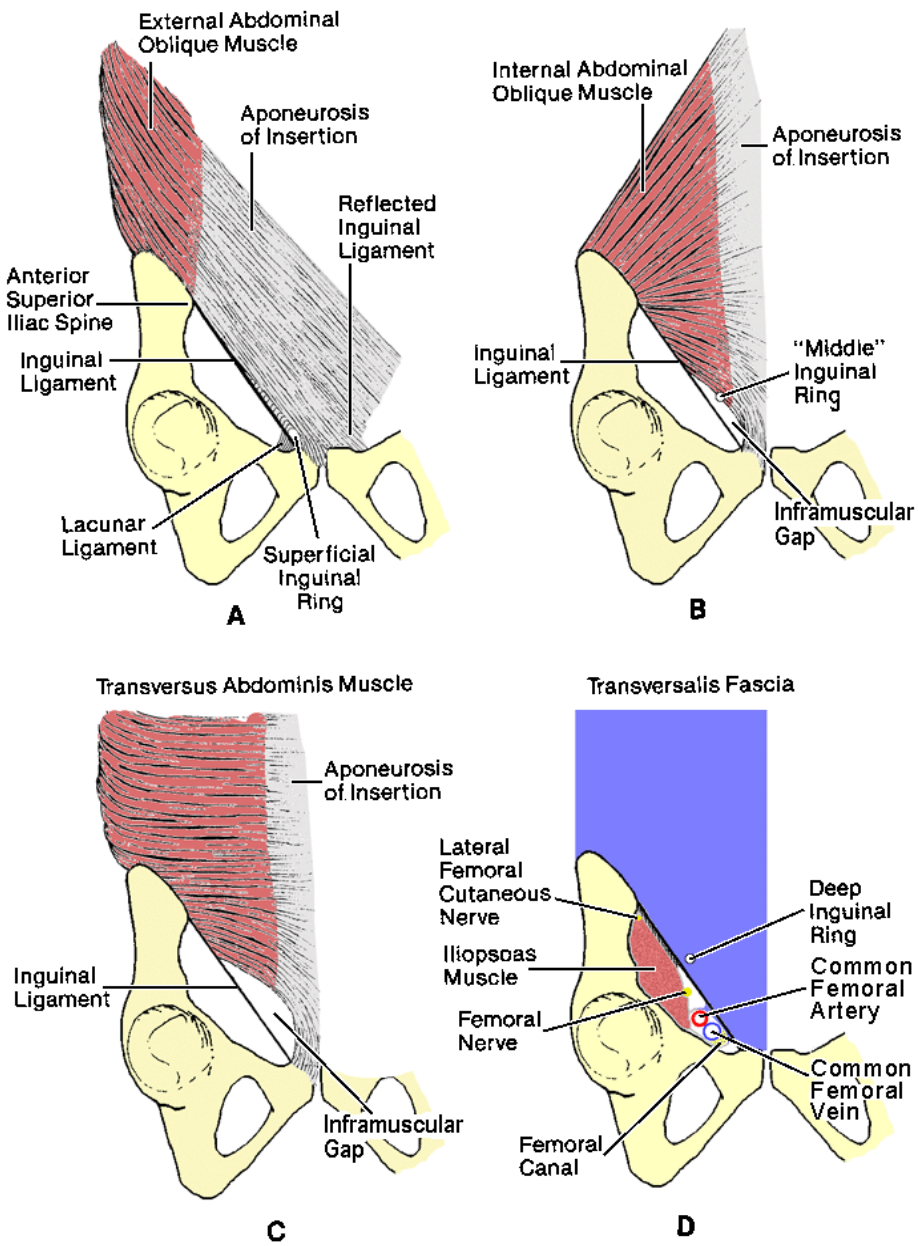


Figure 5-5. The four components of the musculofascial anterior abdominal wall. *A*, External abdominal oblique layer. *B*, Internal abdominal oblique layer. *C*, Transversus abdominis layer. *D*, Transversalis fascia. The last drawing illustrates the structures passing from the abdominal cavity into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

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. 5-5B). 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. 5-5C). 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. 5-32). 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. 5-5*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 (Fig. 5-6A). 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.

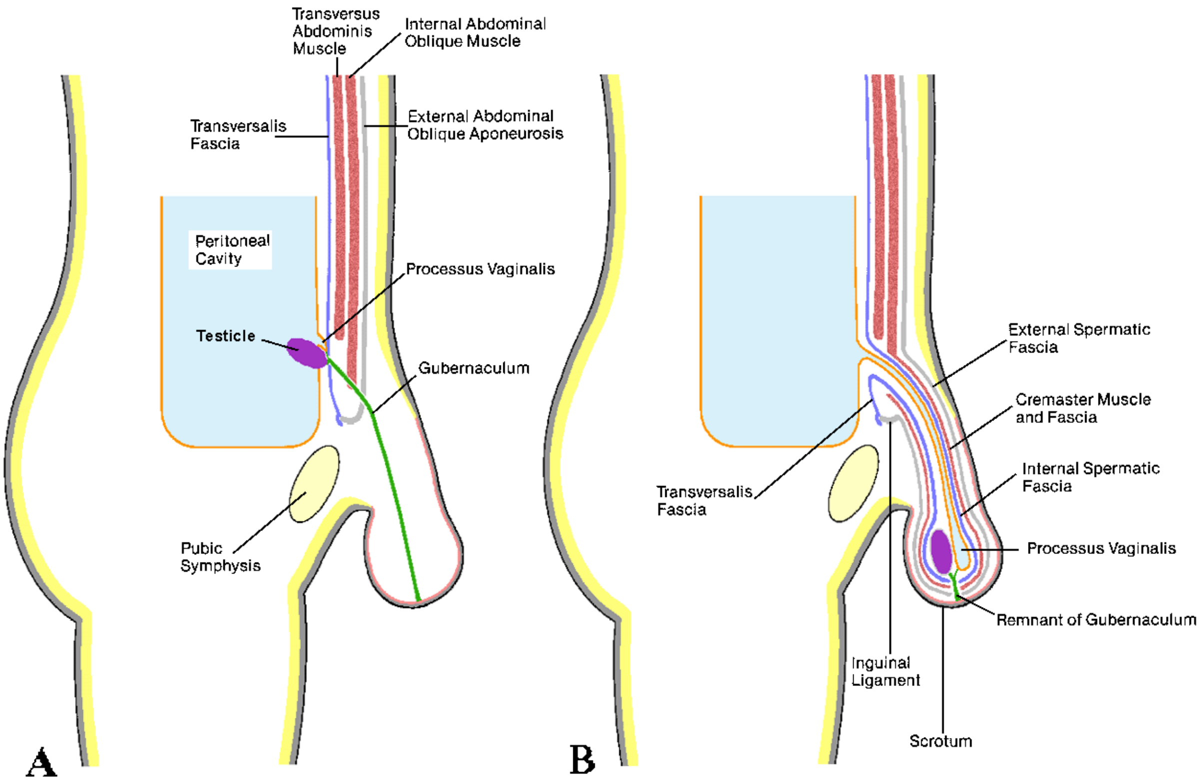


Figure 5-6. Schematic sagittal section through an inguinal canal and spermatic cord of a fetus. **A**, At the very inception of testicular descent. **B**, After testicular descent is complete. Both drawings pretend that a single sagittal section could traverse the entire inguinal canal, which in reality follows an oblique path from depp and lateral to superficial and medial.

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. 5-6B). 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. 5-6B).

The sleeves themselves get new names (see Fig. 5-6B). 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[17].

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. 5-5*D*).

[17] 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.

The lateral half of this "retroligamentous" space is filled in with the iliacus and 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 12, p. 527).

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.

ARTERIES OF THE ANTERIOR ABDOMINAL WALL - Superior Epigastric, Musculophrenic, Inferior Epigastric, Deep Circumflex Iliac, Superficial Epigastric, and Superficial Circumflex Iliac

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 (see Fig. 5-29, p. 165) 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 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. 5-5*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.

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 12, p. 525). 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.

INNERVATION OF THE SKIN, TRILAMINAR MUSCLE BLOCK, AND RECTUS ABDOMINIS

Intercostal Nerves 7 - 11

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.

Subcostal Nerve

The ventral ramus of the T12 spinal nerve is called the subcostal nerve. The proximal portion of the subcostal nerve is seen when one dissects the posterior abdominal wall, hence it is described on page 161. Suffice it to say here that by the time it reaches the lateral abdominal wall the subcostal nerve has entered the plane between the TA and IAO. From this point on, it behaves as do the 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.

Iliohypogastric and Ilioinguinal Nerves

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, its main trunk and collateral branch have separate names - iliohypogastric nerve and ilioinguinal nerve, respectively. The proximal portions of these nerves are seen when one dissects the posterior abdominal wall, hence they are described on page 161. Ultimately, both enter the plane between the TA and IAO, in which they have parallel but different paths as they wrap around toward the front of the body.

When the **iliohypogastric nerve** 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**. 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.

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.

Genitofemoral Nerve (for the Cremaster Muscle)

The cremaster muscle represents stretched-out fibers of the internal abdominal oblique. It is innervated by the genitofemoral nerve. The proximal portion of the genitofemoral nerve is seen when one dissects the posterior abdominal wall, hence it is described on page 162. Eventually it gives rise to two branches - genital and femoral. 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. 5-5D), 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.

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. 5-7). 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. 5-7). 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. 5-7). This gut diverticulum is the remnant of the yolk sac and is called the **vitelline duct**.

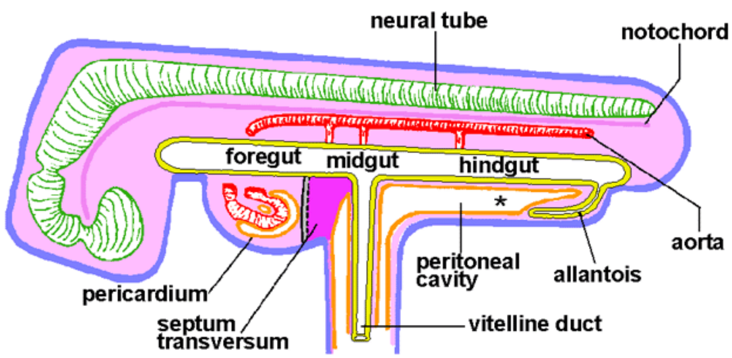


Figure 5-7. Schematic median sagittal section through a fourth-week embryo, illustrating the three different regions of the gut tube. The abdominal portion of the foregut receives the celiac artery from the aorta; the midgut receives the superior mesenteric artery; the hindgut receives the inferior mesenteric 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. 5-7). 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. 5-7). 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. 5-8*A*).

From the foregut arise two diverticula (Fig. 5-9*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. 5-8*B*). This is the **dorsal pancreatic diverticulum**.

The hepatopancreatic diverticulum soon bifurcates into **hepatocystic** and **ventral pancreatic diverticula** (see Fig. 5-9*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. 5-9*B*). The cystic diverticulum stays along the caudal surface of the septum, in contact with the peritoneum (see Fig. 5-9*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. 5-9*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. 5-8*B*), then pass around the sides of the liver and again approach one another between the liver and anterior abdominal wall (Fig. 5-10*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. 5-10*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.

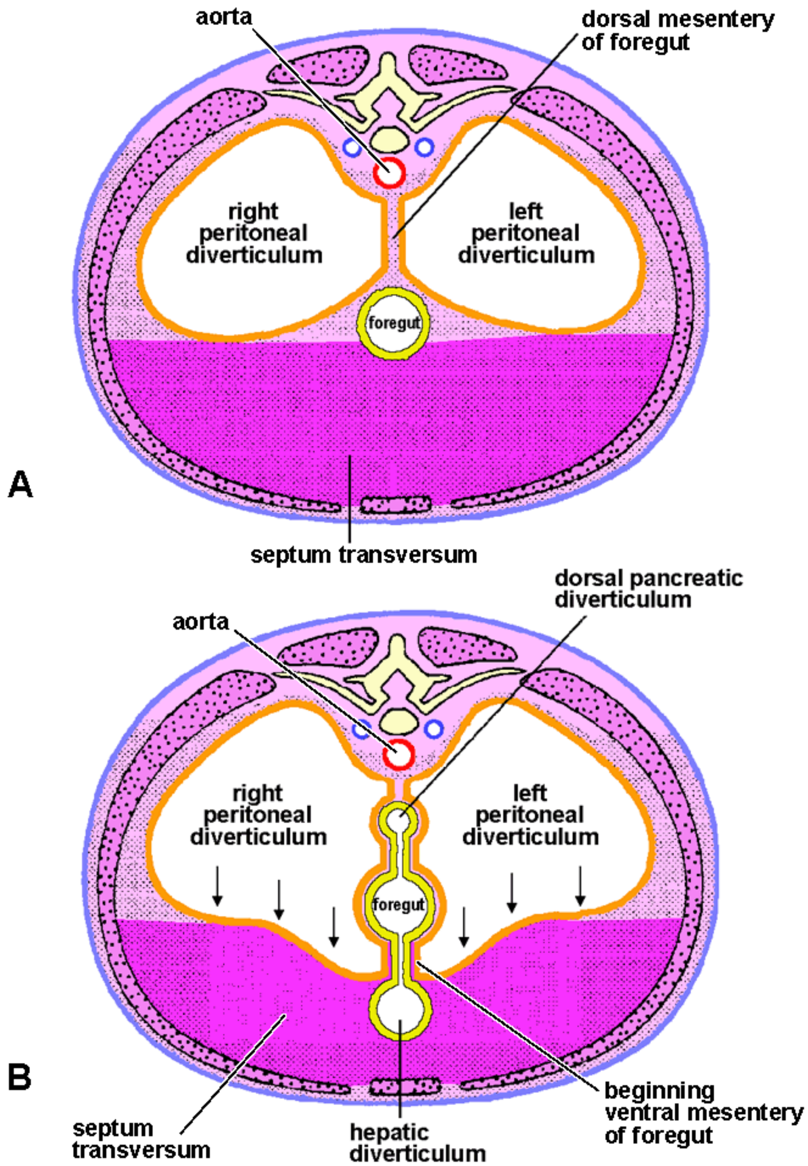


Figure 5-8. Schematic transverse sections (at sequential stages of development) through the embryonic abdomen at the level of the foregut and septum transversum. *A*, An early stage that is prior to the development of any glandular diverticula. *B*, A later stage, in which the dorsal pancreatic diverticulum 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.

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.

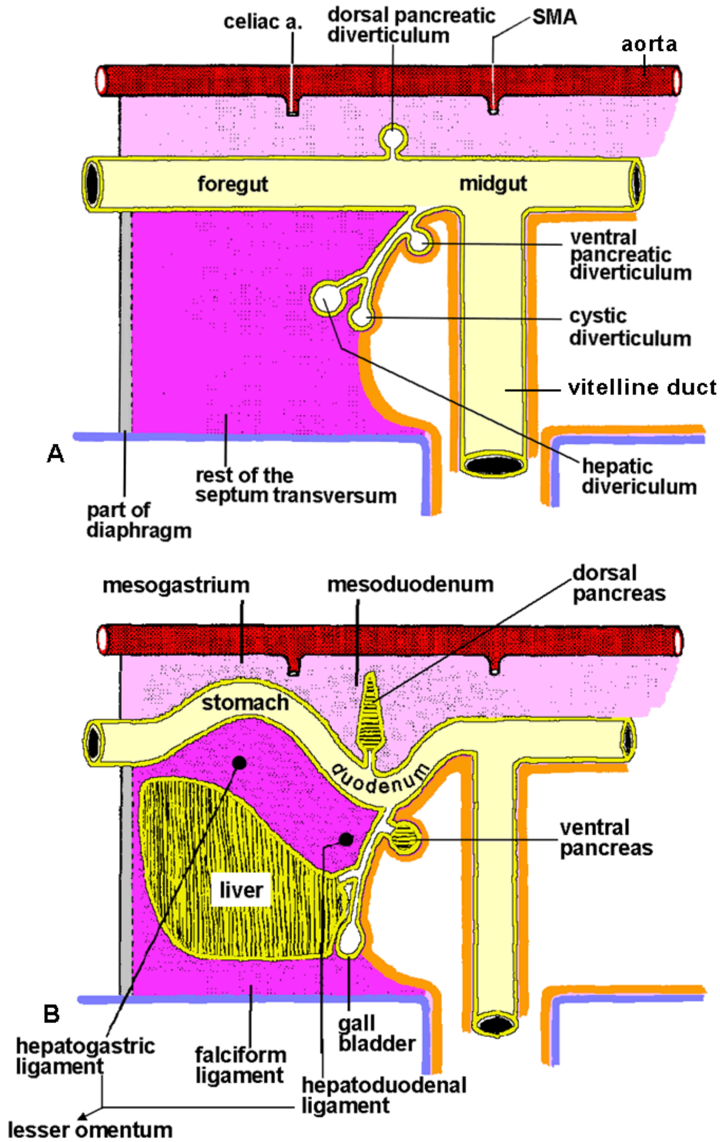
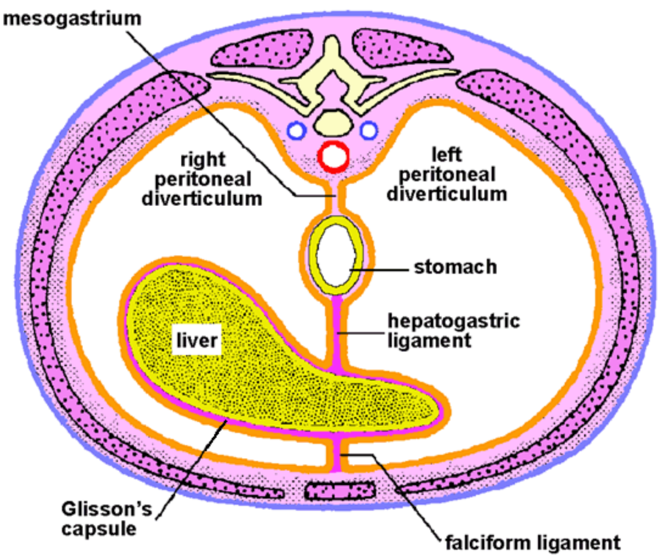


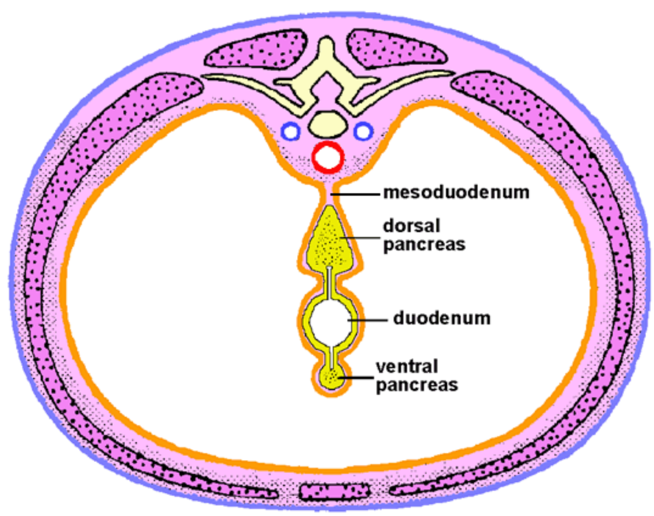
Figure 5-9. Schematic median sagittal "sections" (at sequential stages in development) through the embryonic foregut and related structures. *A*, A stage corresponding to Figure 5-8*B*, depicting initial outgrowth of dorsal pancreatic and hepatopancreatic diverticula. *B*, A later stage, in which the glandular diverticula are more differentiated and the foregut has developed curvatures that allow us to distinguish the stomach from the duodenum.

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 falciform ligament is continued onto the upper surface of the liver as a "cranial" mesentery. However, the back 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.

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



A



B

Figure 5-10. 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.

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. 5-9*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 curvatu**re. In the region of the dorsal pancreatic and 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. 5-11*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. 5-11*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. 5-11*A*).

Growth of the stomach allows its different regions to be identified (Fig. 5-12). 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. 5-12). 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. 5-12). 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. 5-11*B*, 5-12). 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.

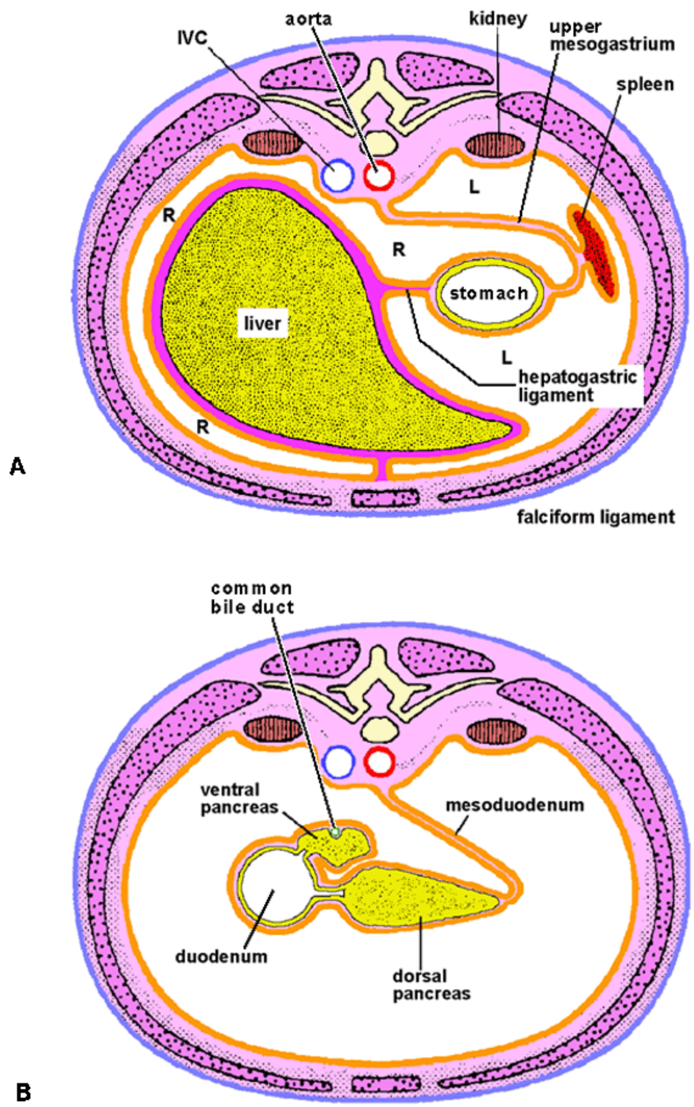


Figure 5-11. Schematic transverse sections of an embryonic abdomen at a stage in development subsequent to that depicted in Figure 5-10. *A*, A section through the stomach and liver after the former has rotated to the left and growth of the right lobe of the liver has carried it toward the posterior 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 dorsal pancreas, which comes off the lesser curvature of the second part of the duodenum, now runs toward the left in the mesoduodenum (Fig. 5-13; see Fig. 5-11*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. 5-11*B*, 5-13). During this leftward migration of the ventral pancreas, the opening of the hepatopancreatic diverticulum is "dragged" onto the posterior surface of the

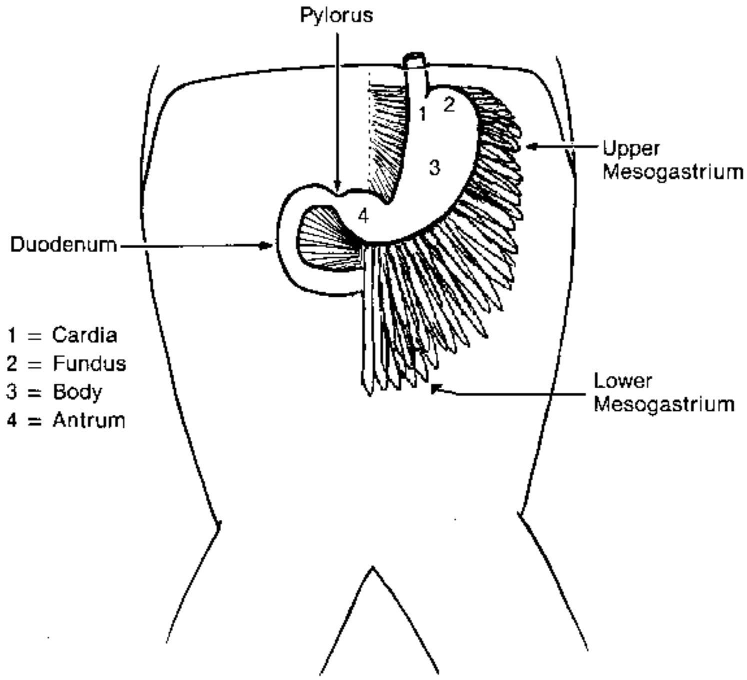


Figure 5–12. Schematic anterior view of embryonic abdominal cavity showing only the stomach, duodenum, and their mesenteries at a stage subsequent to rotation of the foregut (see Fig. 5–11).

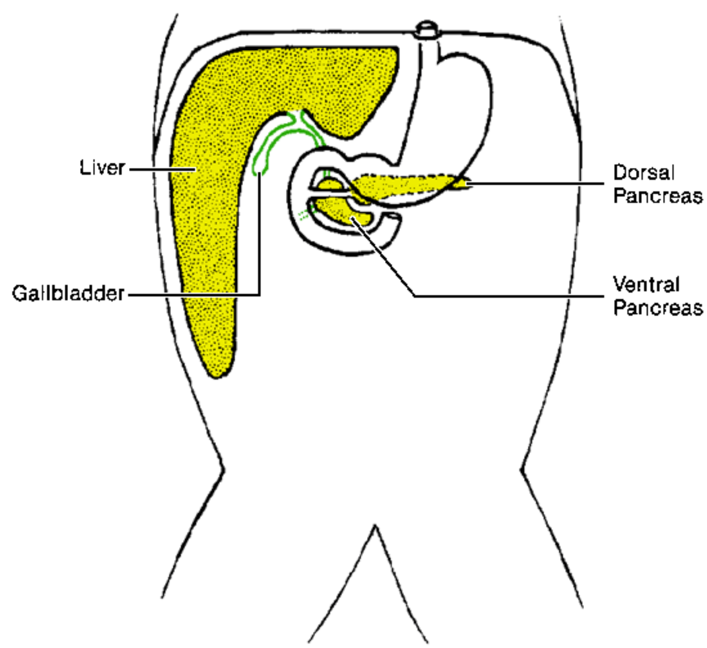


Figure 5–13. Schematic anterior view of embryonic abdominal cavity at same stage in development as depicted in Figure 5–12, but showing only stomach, duodenum, and their glandular diverticula.

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. 5-11*B*, 5-13). The free edge of the lesser omentum, in which the common bile duct runs, now faces to the right instead of caudally.

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. 5-11*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. 5-14*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 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. 5-14*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. 5-14*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. 5-14*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. 5-14*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. 5-15). 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

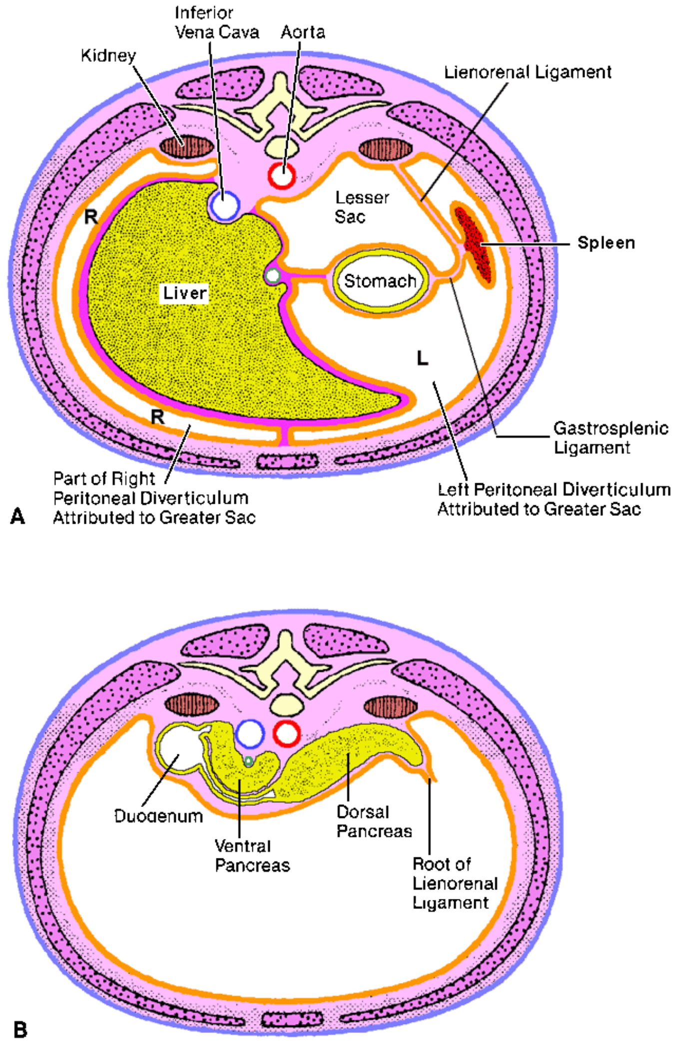


Figure 5-14. Schematic transverse section of embryonic abdomen at a stage in development subsequent to that depicted in Figure 5-11. *A*, A section through stomach and liver showing that the root of the upper mesogastrium has shifted to the left, and that the visceral peritoneum of the liver has fused 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 pancreas 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.

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. 5-15).

Spleen

Lymphoid cells accumulate between the layers of the upper mesogastrium to become the spleen (see Fig. 5-11*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. 5-14*A*); and (3) a region from the spleen to the

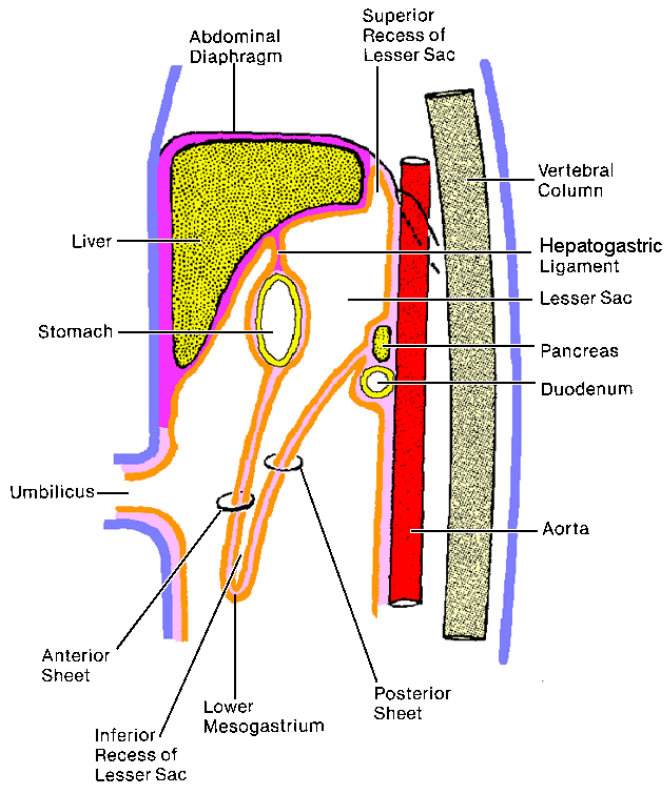


Figure 5–15. Schematic median sagittal section of embryonic abdomen showing the mesenteries of the stomach and the lesser sac.

stomach (see Fig. 5-14*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. 5-11*A*). The two peritoneal layers fuse and dissolve, bringing the liver capsule into direct contact with the inferior vena cava (see Fig. 5-14*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. 5-11*A*). Now this route is blocked (see Fig. 5-14*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. 5-13). 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. 5-14*A*), passes downward (as the **inferior recess of the lesser sac**) between the folds of the lower mesogastrium (see Fig. 5-15), 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. 5-14*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**.

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 most of that segment of the duodenum derived from the foregut. From the fourth part of the duodenum smooth muscle fibers migrate upward behind the pancreas to reach the perivascular connective tissue at the origins of the celiac and superior mesenteric arteries. The resulting fibromuscular band is called the **suspensory muscle of the duodenum.** A fold of peritoneum covers the part that extends between the lower border of the pancreas and the duodenojejunal junction. This peritoneal fold marks the boundary between the duodenum and jejunum, and is called by surgeons **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. 5-16). 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. 5-16). 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. 5-16).

In the caudal limb of the midgut loop, not far from the vitelline duct, an outpocketing develops that marks the **cecum** (see Fig. 5-17). The cranial loop and the prececal part of the caudal loop continue an unabated growth which throws them into many subsidiary loops (see Fig. 5-17). 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. 5-18). 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.

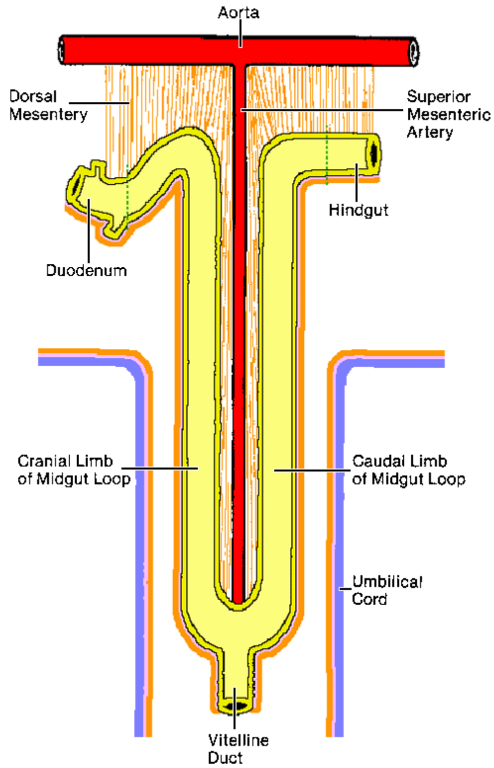


Figure 5–16. Left lateral view of embryonic midgut loop having herniated into the umbilical cord.

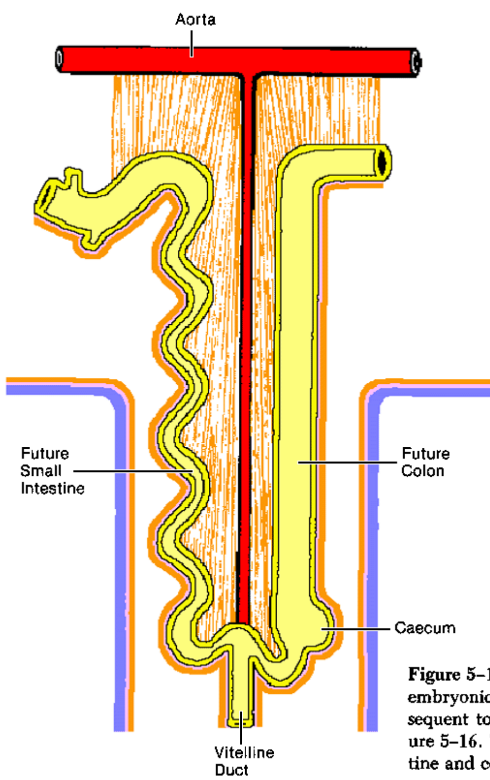


Figure 5–17. Left lateral view of embryonic midgut at a stage subsequent to that depicted on Figure 5–16. The future small intestine and colon can be identified.

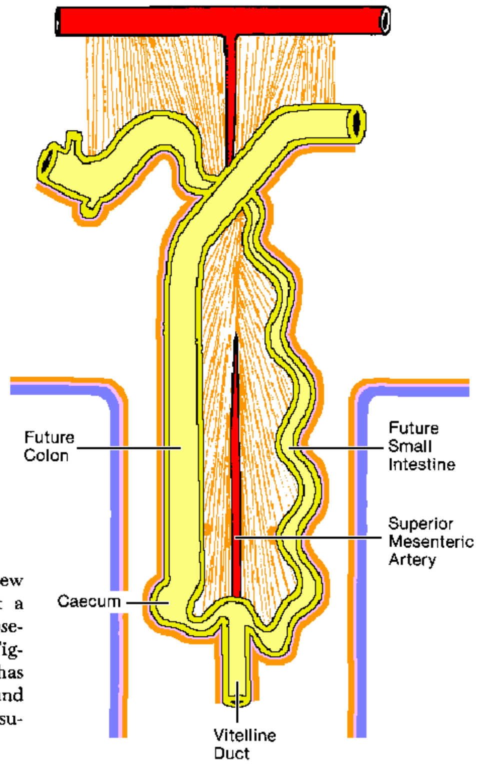


Figure 5-18. Left lateral view of embryonic midgut at a stage in development subsequent to that depicted in Figure 5-17. The midgut loop has undergone a rotation around an axis coinciding with the superior mesenteric artery.

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. 5-19). 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. 5-19). 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. 5-20). 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. 5-21), 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. 5-22), 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 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. 5-22).

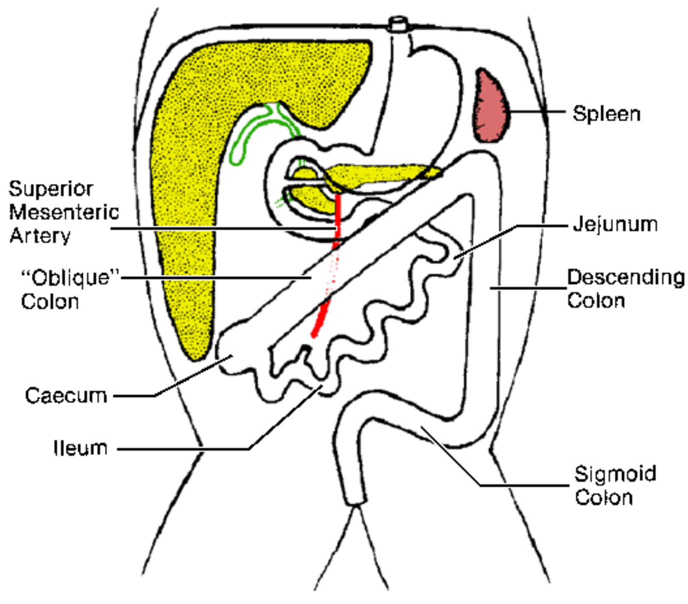


Figure 5–19. Schematic anterior view of embryonic abdominal cavity immediately following return of the midgut into this cavity (mesenteries not drawn).

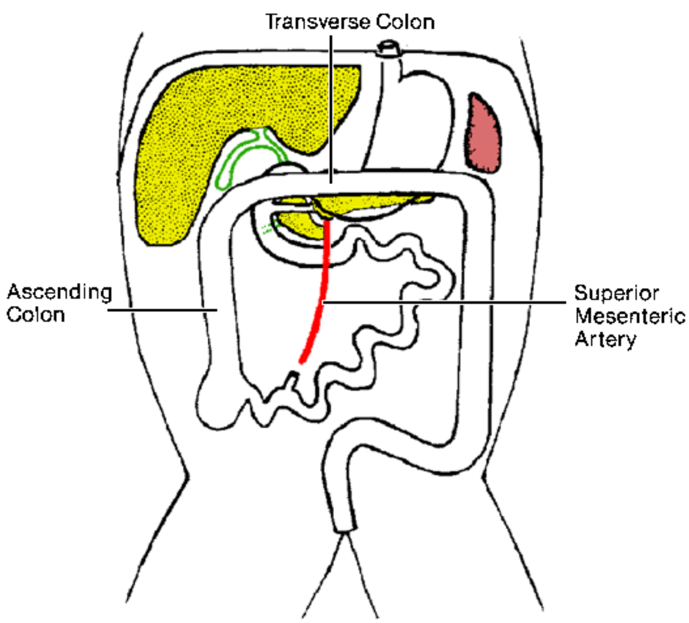


Figure 5–20. Schematic anterior view of embryonic abdominal cavity at a stage subsequent to the development of the definitive ascending and transverse colons (mesenteries not drawn).

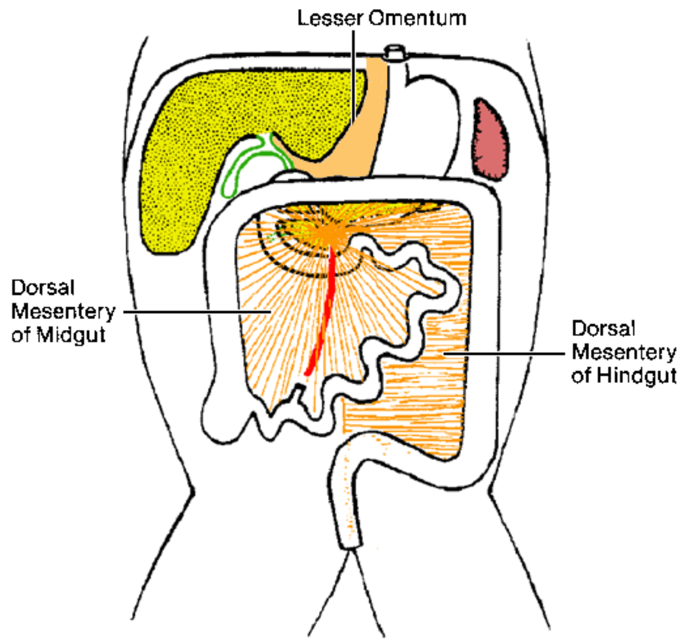


Figure 5–21. Schematic anterior view of embryonic abdominal cavity at same stage as depicted in Figure 5–20, but with lesser omentum, mesentery of midgut, and mesentery of hindgut drawn (mesogastrium not drawn). At this stage, neither the ascending nor descending colons have become secondarily retroperitoneal.

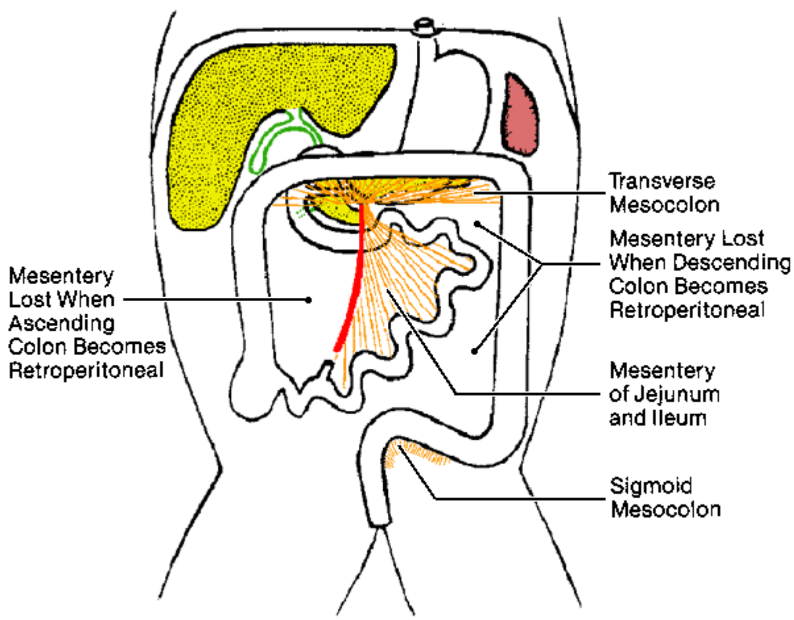


Figure 5–22. Schematic anterior view of embryonic abdominal cavity at a stage in development subsequent to that depicted in Figure 5–21 (mesogastrium not drawn). The ascending and descending colons have become secondarily retroperitoneal. Consequently, the mesentery of the jejunum and ileum, the transverse mesocolon, and the sigmoid mesocolon all gain new roots.

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 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. 5-22). 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. 5-23). 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 colon (Fig. 5-24). 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. 5-24). 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,

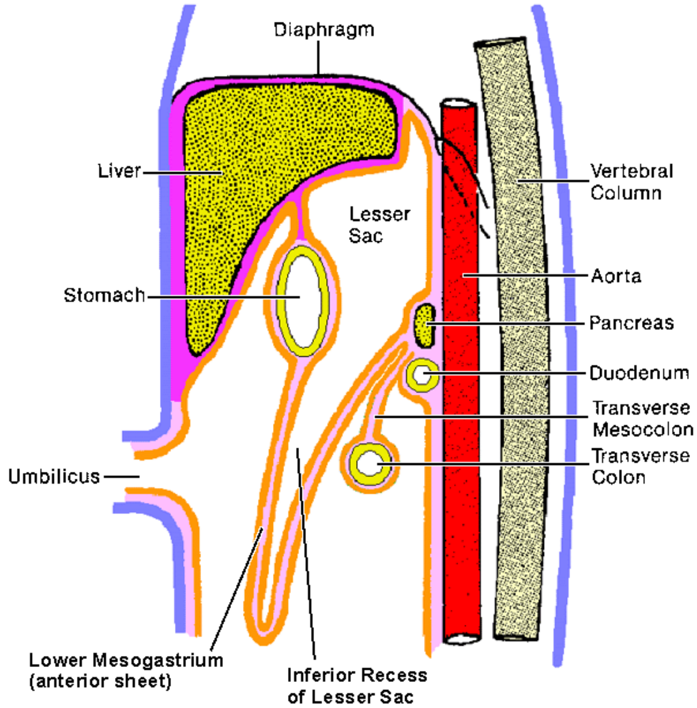


Figure 5–23. Schematic median sagittal section of embryonic abdomen showing relationships of transverse colon and transverse mesocolon to the lower mesogastrium.

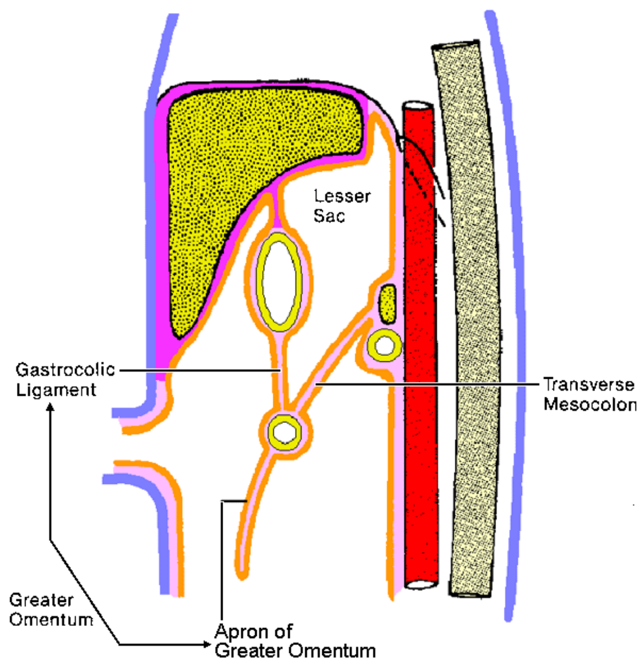


Figure 5-24. Schematic median sagittal section of embryonic abdomen at a stage in development subsequent to that depicted in Figure 5–23. The transverse mesocolon has fused to the superior portion of the lower mesogastrium, and most of the inferior recess of the lesser sac has become obliterated by fusion of the anterior and posterior sheets of the lower mesogastrium.

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. 5-25). 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**.

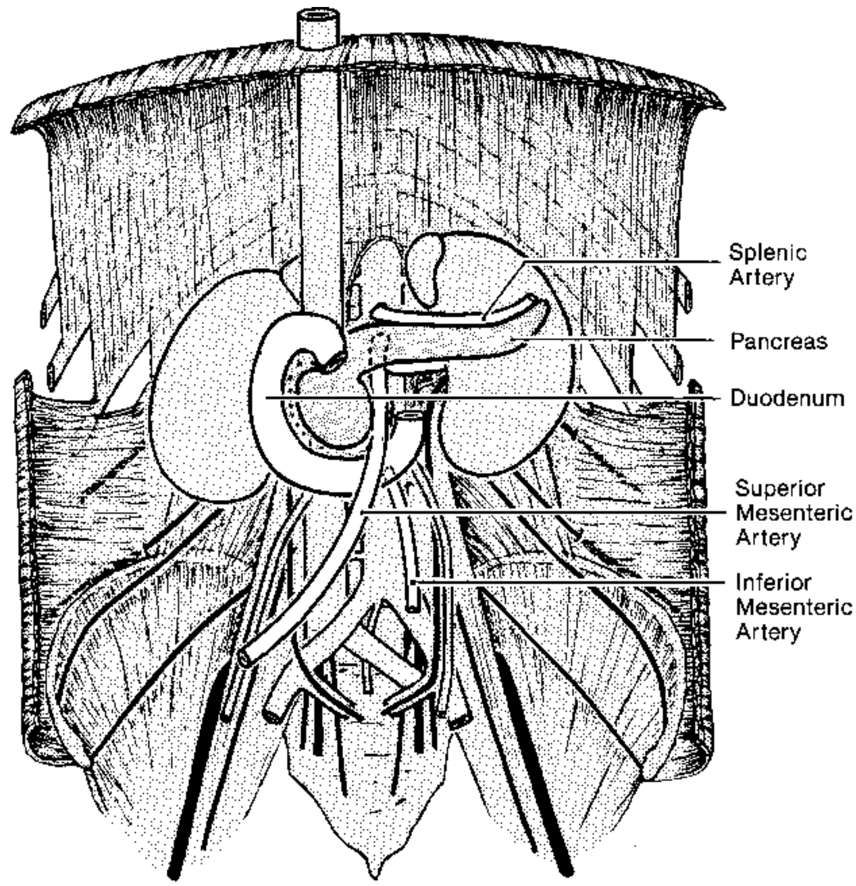


Figure 5-25. The positions of the pancreas, duodenum, splenic artery (from the celiac trunk), superior mesenteric artery, and inferior mesenteric artery in relation to other retroperitoneal structures of the abdomen.

Splenic Artery

The splenic artery runs toward the left (retroperitoneally) along the superior edge of the body of the pancreas (see Fig. 5-25), 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).

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. 5-25).

The SMA runs a course downward and to the right (see Fig. 5-25). 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. 5-25).

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. 5-25), where it runs (crossing anterior to the right ureter and gonadal vessels[18]) 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

[18] 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.

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. 5-25). 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. 5-25).

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 Between Arteries to the Gut

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:

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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. 5-26). 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. 5-26). 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,

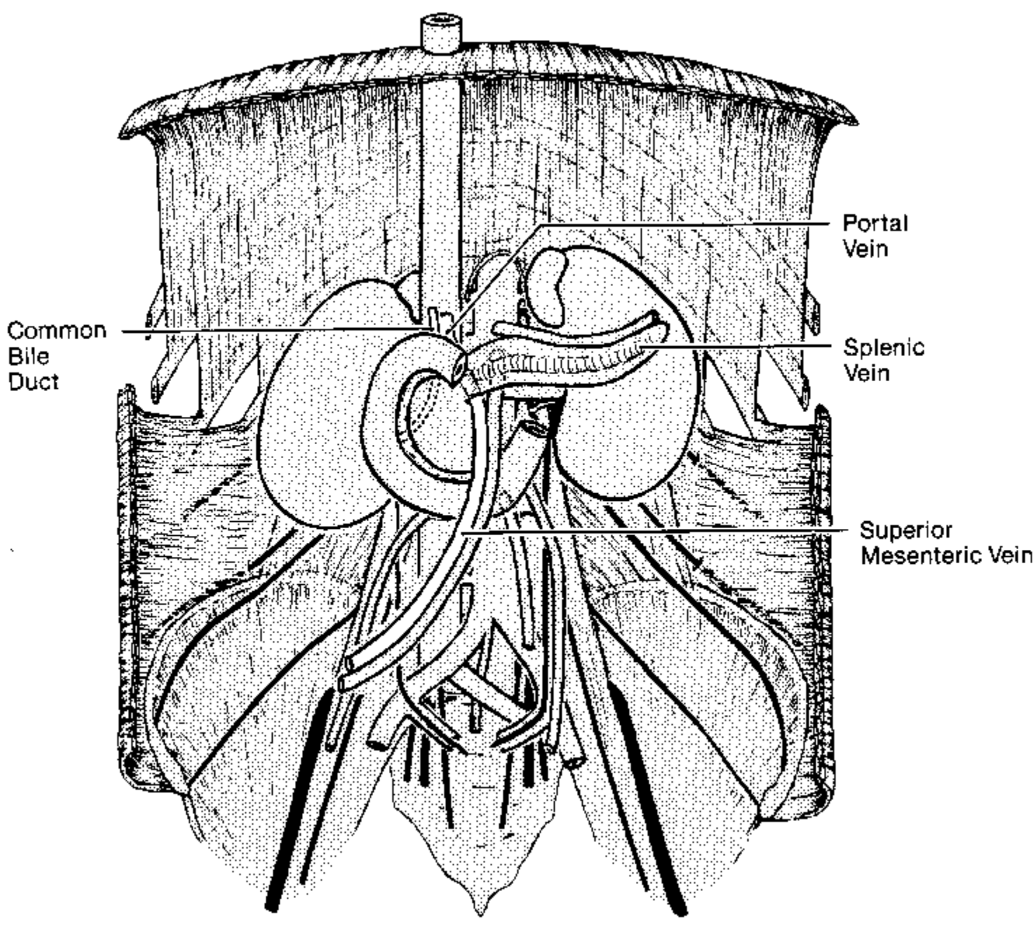

Figure 5-26. The positions of the superior mesenteric vein, splenic vein, portal vein, and common bile duct in relation to other abdominal structures.

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.

LIVER (Fig. 5-27)

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 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**.

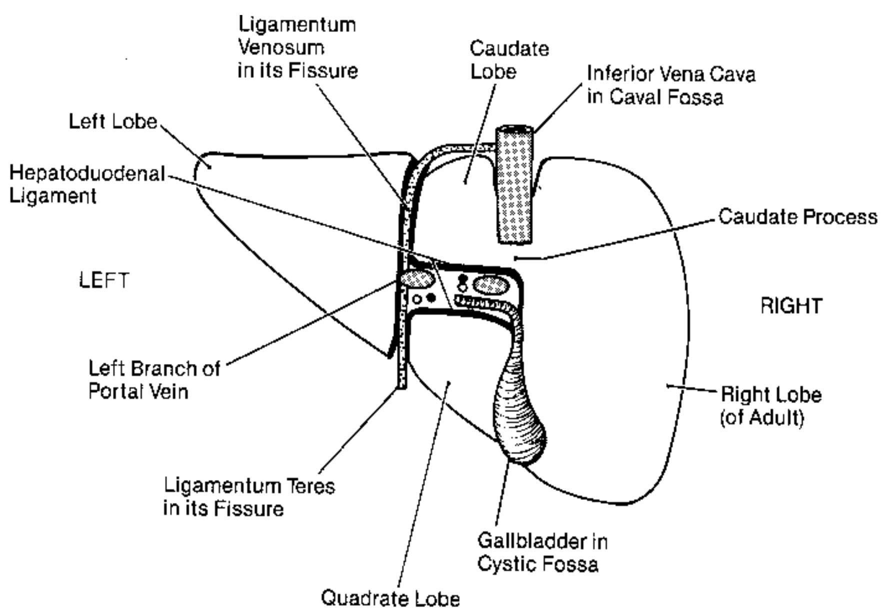

Figure 5-27. Posterior and inferior (visceral) surfaces of the liver.

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. 5-27).

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. 5-13). Together they became retroperitoneal, yet they retained separate ducts that emptied into the second part of the duodenum at different sites (Fig. 5-28*A*). This soon changes. The ventral and dorsal pancreata fuse (Fig. 5-28*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**.

As the ventral and dorsal pancreata fuse, a new segment of duct forms to bridge between the ventral and dorsal ducts (see Fig. 5-28*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 it 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. 5-28*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

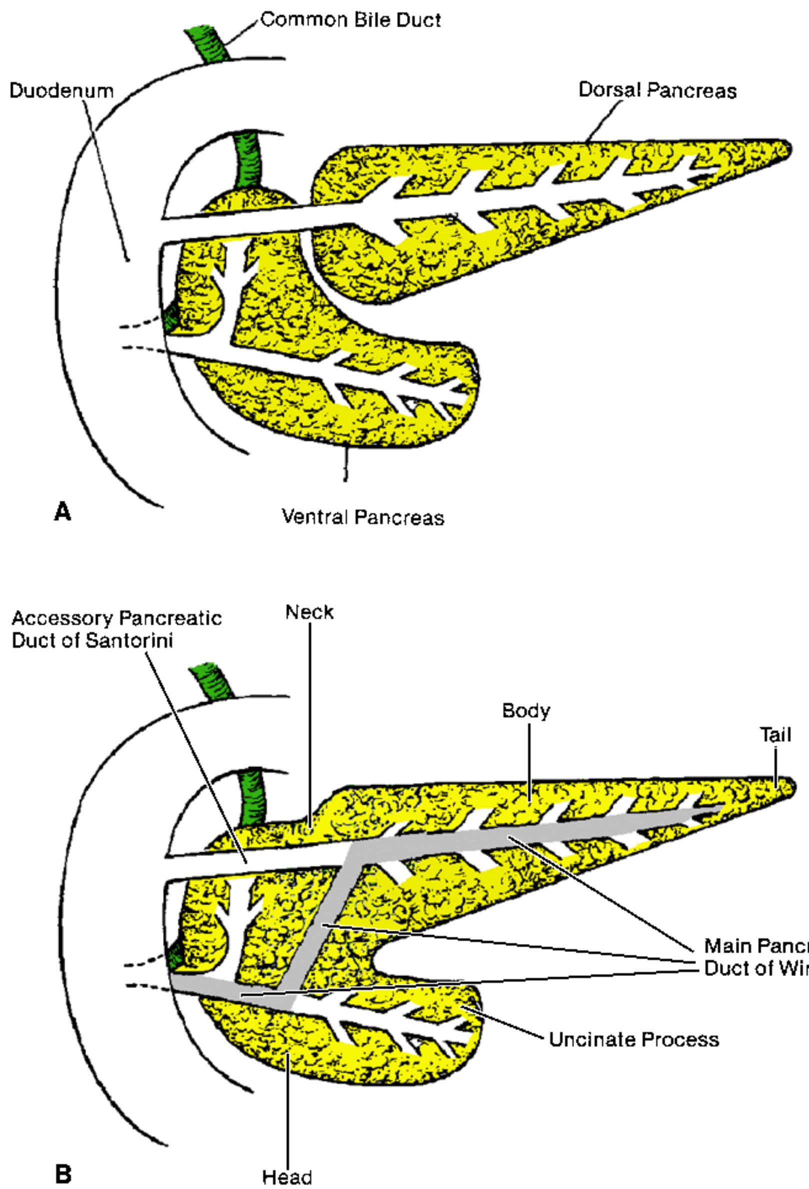

Figure 5–28. *A*, Anterior view of embryonic dorsal and ventral pancreata at a stage prior to their fusion. *B*, The final state of pancreatic form resulting from fusion of this organ's embryonic components.

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.

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. 5-29)

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. 5-5*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.

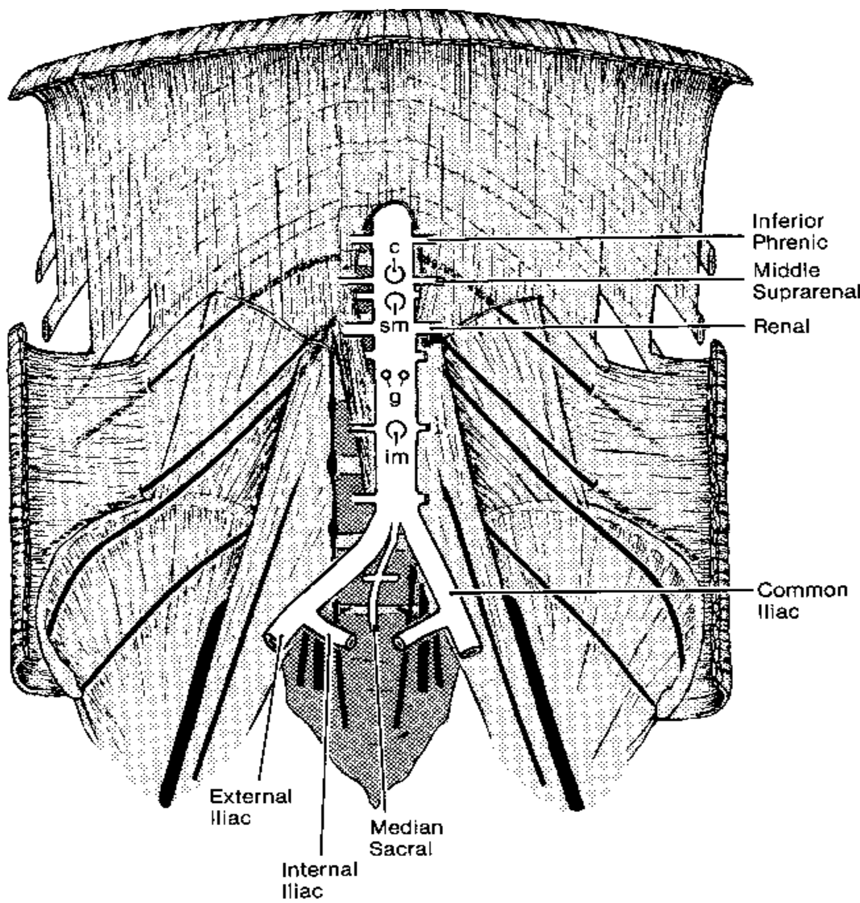

Figure 5-29. The position of the abdominal aorta (in white) and the sites of origin of its branches. c = celiac artery, sm = superior mesenteric artery, g = gonadal arteries, im = inferior mesenteric artery. Unlabelled branches are the lumbar arteries.

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[19] 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 (pp. 178-179), when the innervation of abdomino-pelvic organs 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. 5-29). 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.

Inferior Vena Cava and Iliac Veins (Fig. 5-30)

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.

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. 5-5*D*).

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

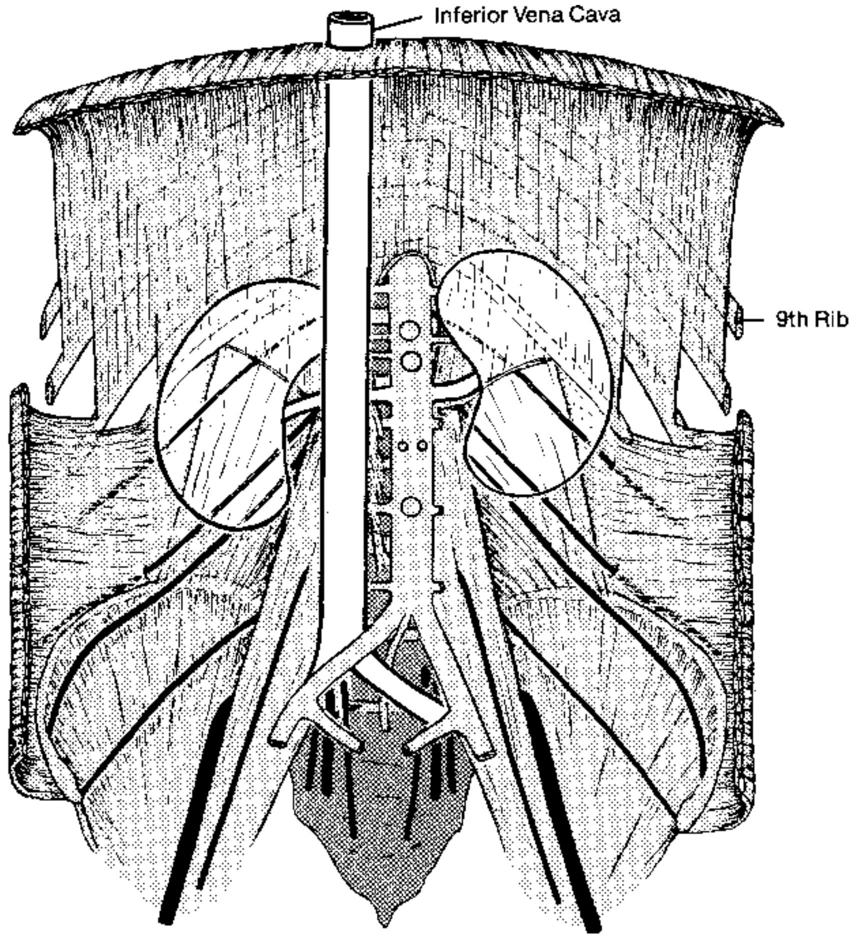

Figure 5-30. The positions of the inferior vena cava, kidneys, and renal arteries.

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**.

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.

Kidneys and Renal Vessels (see Fig. 5-30; Fig. 5-31)

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.

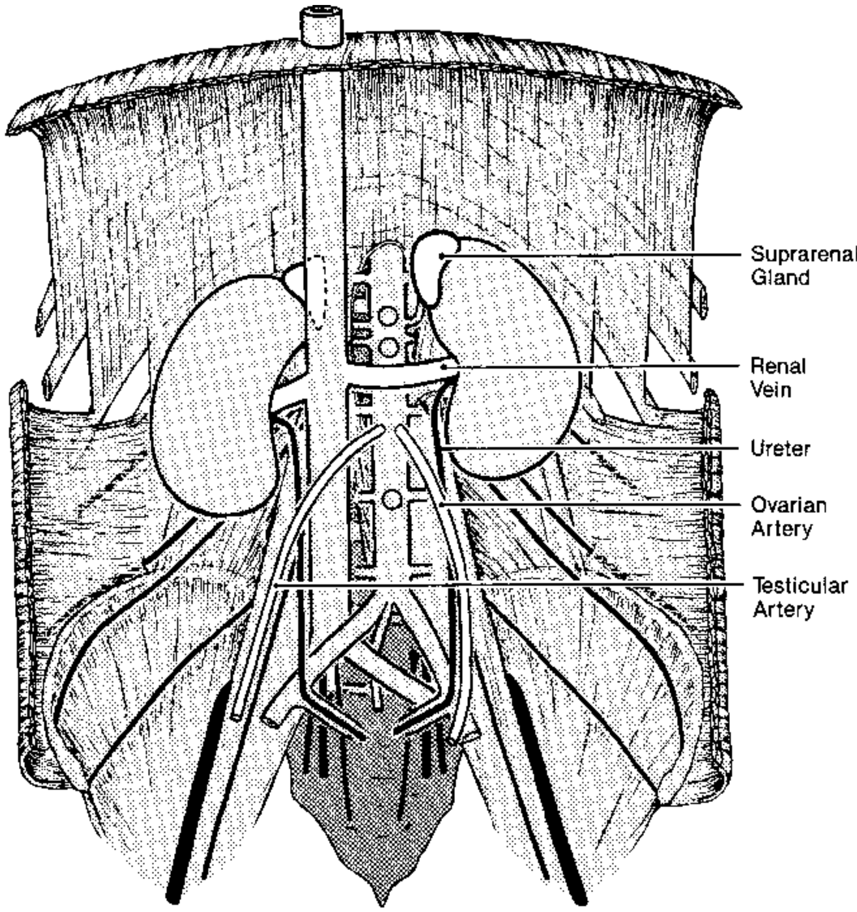

Figure 5-31. The positions of the suprarenal glands, renal veins, ureters, and gonadal arteries (testicular illustrated on one side, ovarian on the other).

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. 5-30). (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. 5-30). 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. 5-31)

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. 5-31). The **testicular artery** (see Fig. 5-31, 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. 5-31, 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.

MUSCLES OF THE POSTERIOR ABDOMINAL WALL

The muscles of the posterior abdominal wall are psoas major and iliacus (actual muscles of the lower limb), quadratus lumborum, the posterior part of transversus abdominis, and the posterior part of the abdominal diaphragm. 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).

Psoas Major and Iliacus (Fig. 5-32; see Fig. 12-16)

Being muscles of the lower limb, psoas major and iliacus will be discussed in Chapter 12 (p. 528). 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.

Quadratus Lumborum (see Fig. 5-32)

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

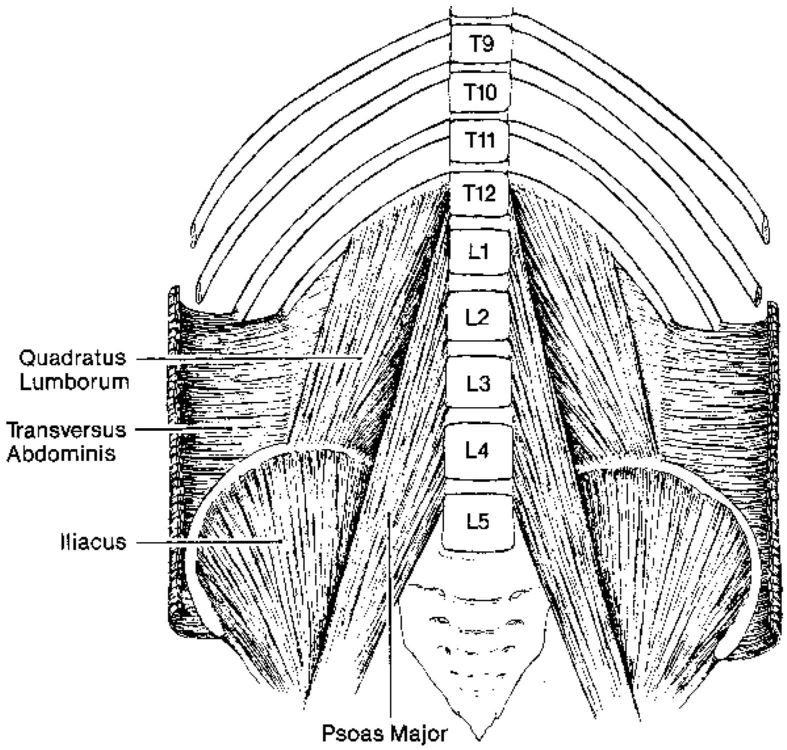

Figure 5-32. Anterior view of the posterior abdominal wall, exclusive of the contribution made by the abdominal diaphragm.

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 lumbar hypaxial dermomyotome and those small parts off the 2nd - 4th lumbar that do not migrate into the lower limb, the quadratus lumborum 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. 5-33)

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.

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.

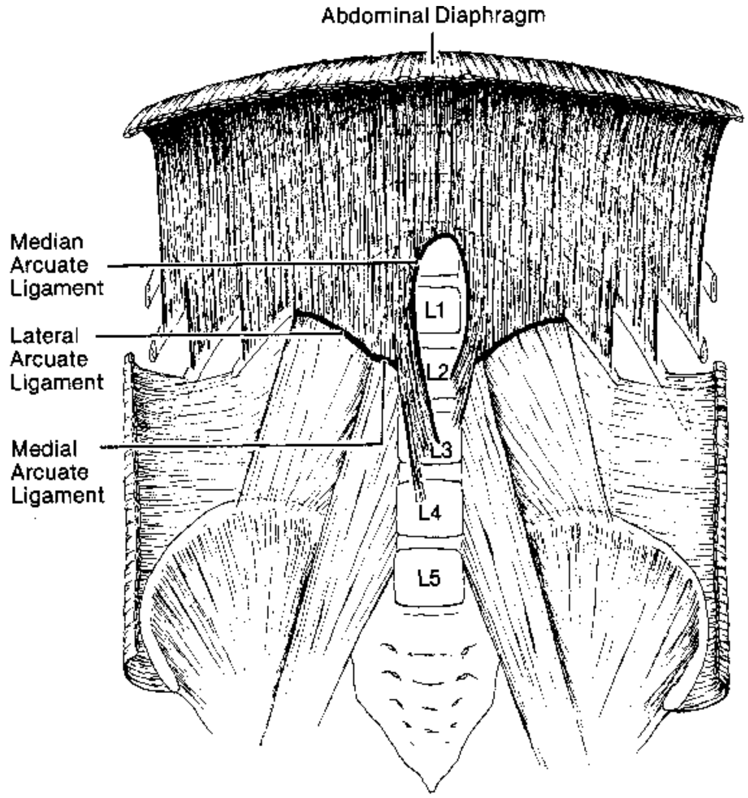

Figure 5-33. Contribution of the abdominal diaphragm to the posterior abdominal wall.

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.

NERVES SEEN IN THE POSTERIOR ABDOMINAL WALL

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. 12-6, p. 513). What emerges from the psoas (see Fig. 5-34) 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.

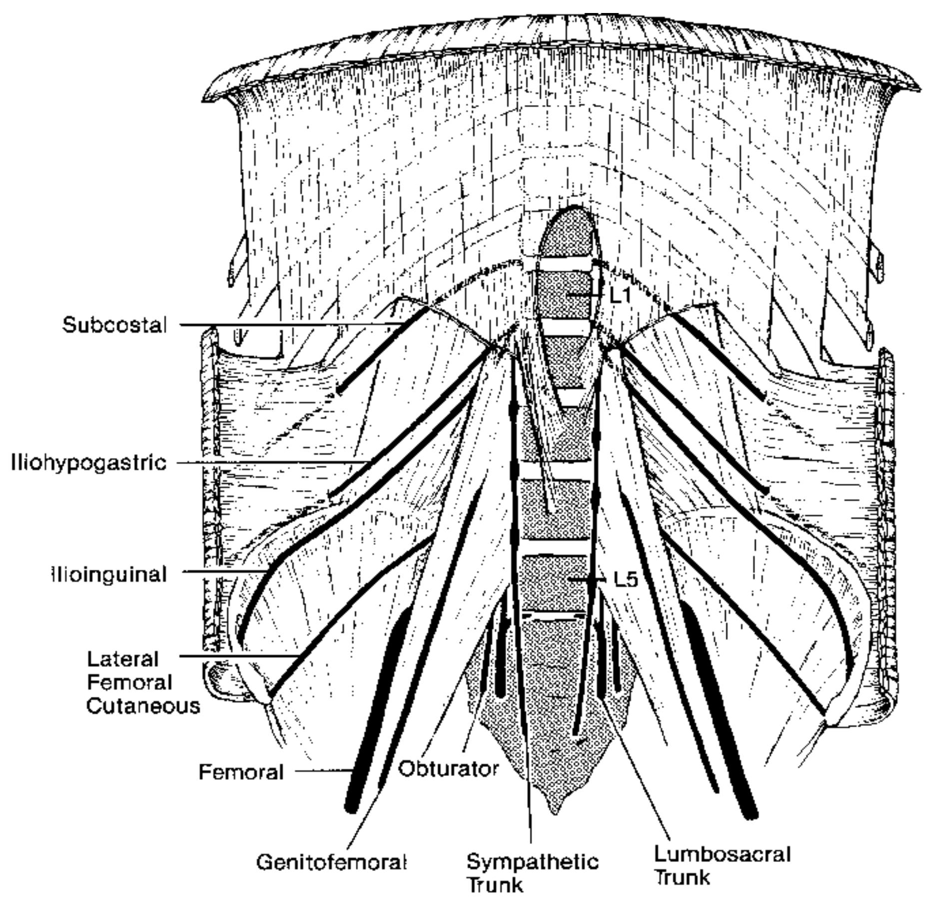

Figure 5-34. Nerves on the posterior abdominal wall.

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 12 (pp. 540-542).

Subcostal Nerve

The subcostal nerve (ventral ramus of T12) 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 (Fig. 5-34). 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. The distal portion of the subcostal nerve is seen during the dissection of the anterior abdominal wall and was described on page 118.

Iliohypogastric and Ilioinguinal Nerves

The ventral ramus of L1 is like an intercostal nerve in that it has a main trunk and a collateral branch. Usually (though not always) the collateral branch arises while the nerve is 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. 5-34). It crosses the quadratus lumborum inferolaterally, reaching its lateral border *just above the iliac crest*, 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.

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. 5-34). 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.

The distal portions of the iliohypogastric and ilioinguinal nerves are seen during the dissection of the anterior abdominal wall and were described on page 118.

Genitofemoral Nerve

This nerve passes through the psoas major to emerge onto its anterior surface (see Fig. 5-34), 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. 5-5), 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.

Lateral Femoral Cutaneous Nerve (Lateral Cutaneous Nerve of the Thigh)

The lateral femoral cutaneous nerve (derived from the ventral rami of L2 and L3) is destined for the lower limb; it has no actual role in the innervation of abdominal structures. It emerges from the lateral surface of the psoas major just *below the iliac crest* (thus, between the ilioinguinal and femoral nerves) (see Fig. 5-34) and then 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.

Femoral Nerve

The femoral nerve (derived from the ventral rami of L2 - L4) is also destined for the lower limb, but since the psoas major and iliacus are muscles of the lower limb, the femoral nerve does give branches while in the abdomen. Psoas major is innervated by small branches given off from the contributions of the 2nd-4th lumbar ventral rami to the femoral nerve. Then the nerve exits from the lateral surface of the psoas major an inch or two below the iliac crest (see Fig. 5-34). It runs in the groove between the psoas major and iliacus, supplying the latter. With these two muscles, the nerve passes behind the inguinal ligament into the thigh (see Fig. 5-5*D*).

Obturator Nerve

The obturator nerve (derived from the ventral rami of L2 - L4) is destined for the lower limb and has no actual role in the innervation of abdominal structures. It emerges from the medial surface of the psoas major opposite the 5th lumbar vertebra and descends to leave the abdominal cavity by crossing the pelvic brim to enter the true pelvis. The nerve 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.

Accessory Obturator Nerve

This 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, a muscle of the lower limb.

Lumbosacral Trunk

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 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.

ARTERIES OF THE POSTERIOR ABDOMINAL WALL

Inferior Phrenic -- Supplying the Diaphragm

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.

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

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.

INNERVATION OF THE INTERNAL ORGANS OF THE ABDOMEN

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 upper portion of the rectum are minute **inferior hypogastric ganglia**. Below these, on either side of the rectum, where it lies posterior to the seminal vesicles (in men) or uterus (in women), 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.[20] 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 Abdominal 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

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

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. 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 [21].

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.

Visceral Pain From Internal Organs of the Abdominal Cavity

Visceral pain from all organs within the abdominal 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.

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 gallbladder 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

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[21] However, in has been reported for some mammals that postganglionic sympathetic axons are found in pelvic splanchnic nerves. Presumably they are derived from cells in sacral paravertebral ganglia, and traveled via gray rami communicantes to the S3 an S4 ventral rami, then accompanied the far more numerous parasympathetic preganglionic axons as they leave to form pelvic splanchnic nerves.

that gallbladder disease can somehow irritate the right hemidiaphragm, or that the phrenic sends a branch to the gallbladder.

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.

LYMPHATICS OF THE ABDOMEN

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 and common iliac vessels are nodes that are called **external 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. 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.

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 ABDOMINAL 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. 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.

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 Fig. 12-8, p. 515). 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.

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. 5-29)

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. 5-29)

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. 5-29). 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. 5-30)

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. 5-30)

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. 5-31) 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. 5-31)

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. 5-25). The inferior mesenteric vessels are medial to the left ureter (see Fig. 5-25), but the left colic artery crosses anterior to it.

Suprarenal Glands (see Fig. 5-31)

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. 5-25)

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. 5-25)

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. 5-25)

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. 5-26)

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 (see Fig. 5-26)

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. 5-35)

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 (Fig. 5-35)

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

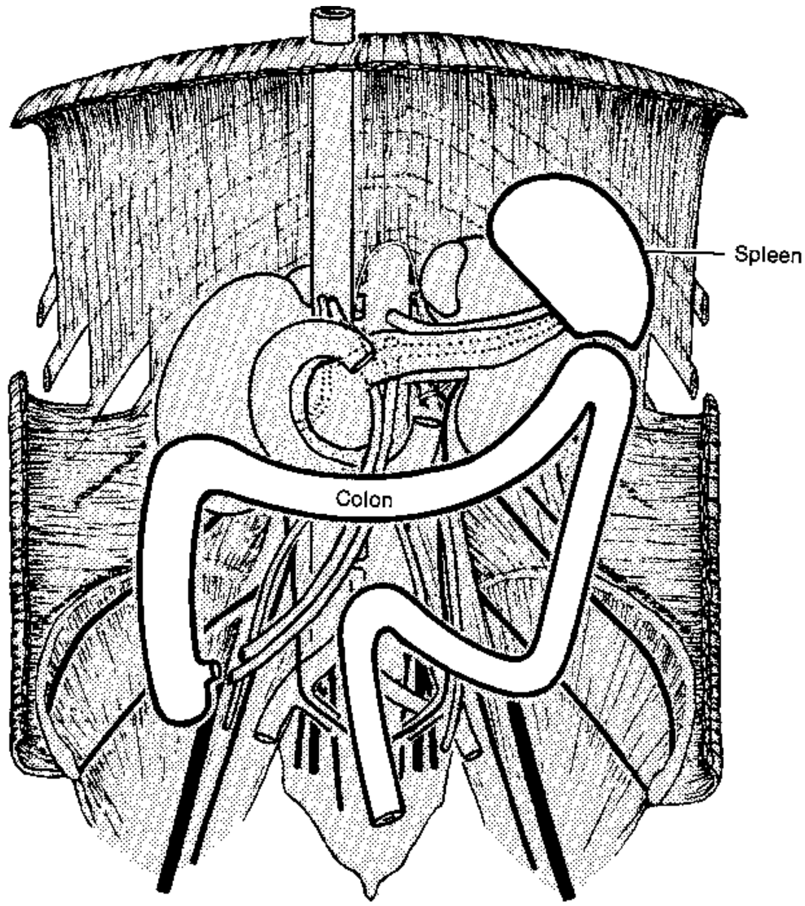

Figure 5-35. The positions of the spleen and colon (in white) in relation to other abdominal structures.

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 (Fig. 5-35)

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.

Spleen (see Fig. 5-35)

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. 5-36). 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. 5-36)

The esophagus pierces the muscle of the diaphragm posterior to the central tendon and just to the left of the midline (see Fig. 6-4*A*, p. 197) opposite T10 (the xiphoid process). It takes a short course and enters 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

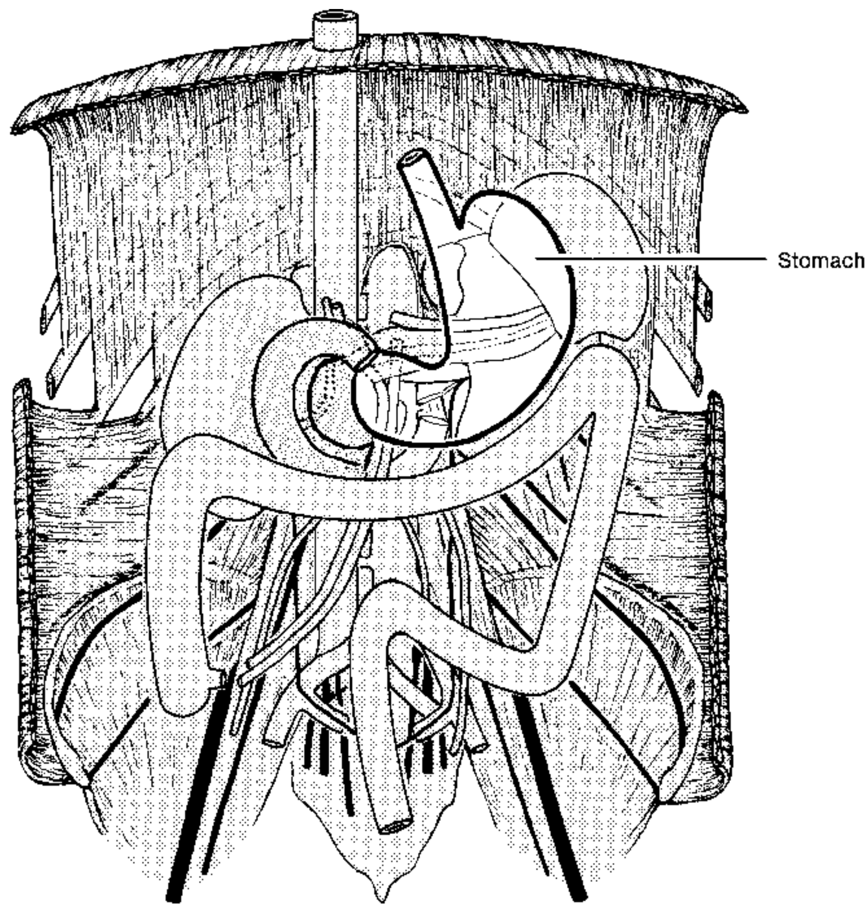

Figure 5-36. The position of the stomach (in white) in relation to other abdominal organs.

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. 5-37)

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.

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

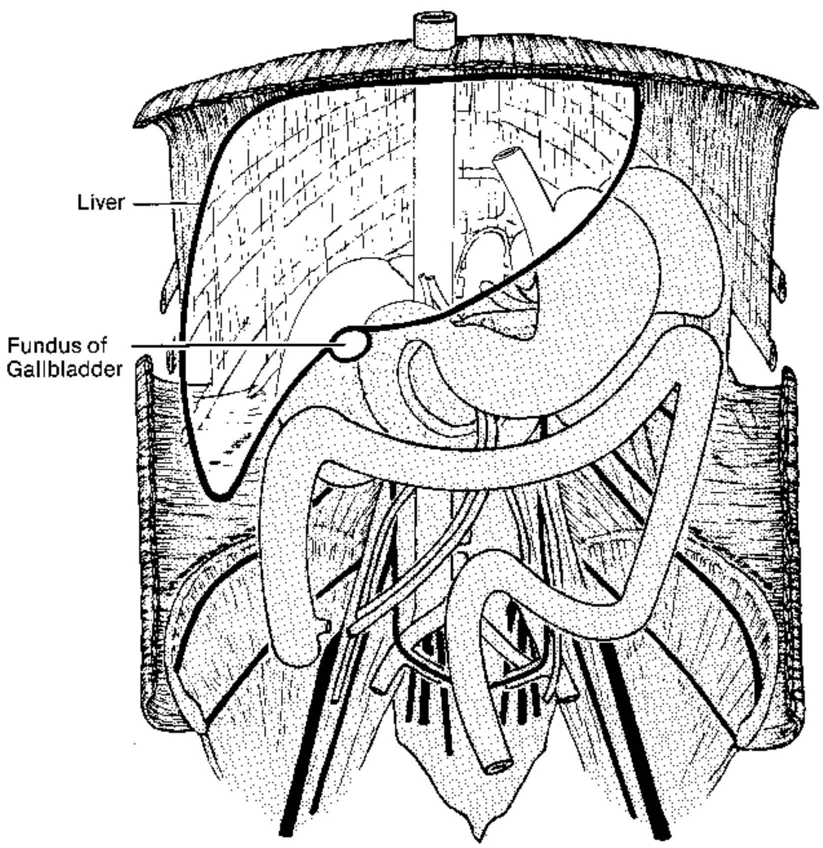

Figure 5-37. The positions of the liver and the fundus of the gallbladder in relation to other abdominal organs.

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. 5-36). 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. 5-37).

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, gallbladder.

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.