1 Basic Principles and Anatomy for the Laparoscopic Surgeon

M. Jean Uy-Kroh and Tommaso Falcone

As we push open the barriers of minimally invasive surgery and incorporate new platforms, the gynecologic surgeon must utilize steadfast surgical and anatomic principles to optimize outcomes and reduce complications. In this chapter, we review laparoscopic principles and practical anatomy that allow one to safely operate in even the most challenging surgical landscapes. There is an emphasis on clearly labeled anatomy and illustration of critical anatomic relationships. We include a thorough discussion and demonstration of the anterior abdominal wall, vasculature, and innervations of the abdomen and pelvis, peritoneal landmarks, pelvic viscera, and the pelvic diaphragm.

The common objective of single-port, laparoscopic, and robotic gynecologic surgery is to treat conditions using techniques that safely maximize operative exposure and minimize patient recovery time and pain. No matter what approach is used, the surgeon requires an intimate knowledge of abdominal and pelvic anatomy to achieve optimal outcomes and reduce complications. This chapter reviews basic principles and practical surgical anatomy encountered by the laparoscopic, gynecologic surgeon.

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P.F. Escobar, T. Falcone (eds.), *Atlas of Single-Port, Laparoscopic, and Robotic Surgery*,
DOI 10.1007/978-1-4614-6840-0_1, © Springer Science+Business Media New York 2014

1.1 Surface Landmarks

Surface anatomy and osseous structures are important markers for surgeons. Once identified, they can be used to avoid underlying vasculature and plan safe surgical points of entry. A surgeon should always begin with a brief survey of the supine patient. The osseous landmarks of the anterior abdominal wall are fixed (Table 1.1) and frame the clinical decisions that are made prior to surgery, such as port placement. The osseous landmarks include the xyphoid process, the inferior margins of the tenth costal cartilages, the anterior superior iliac spines (ASIS), and the pubic symphysis (Fig. 1.1).

The nonosseous landmarks are in variable relationship to each other and the bony landmarks. Their anatomic positions are influenced by patient habitus, skin laxity, and patient positioning (i.e., supine versus Trendelenburg).

The umbilicus is an important nonosseous landmark that is a common point of surgical entry. It has a variable position and is influenced by patient habitus. Owing to its relationship to the adjacent vasculature, the angle of trocar entry must be planned. The umbilicus lies in close proximity to the aorta and its bifurcation into the right and left common iliac arteries [1, 2]. While the patient is supine, the aortic bifurcation is located cephalad to the umbilicus in almost 90 % of patients. In contrast, when the patient is in the Trendelenburg position, the aortic bifurcation is located cephalad to the umbilicus in only 70 % of patients. When the bifurcation lies caudal to the

Table 1.1 Anterior landmarks and corresponding vertebral levels

Landmark	Vertebral level
Xyphoid process	T9
Tenth costal cartilage inferior margin	L2/L3
Umbilicus	Variable
Ideal body weight	Intervertebral disc between L3/L4
Anterior superior iliac spine (ASIS)	Sacral promontory
Inguinal ligament	
Pubic symphysis	

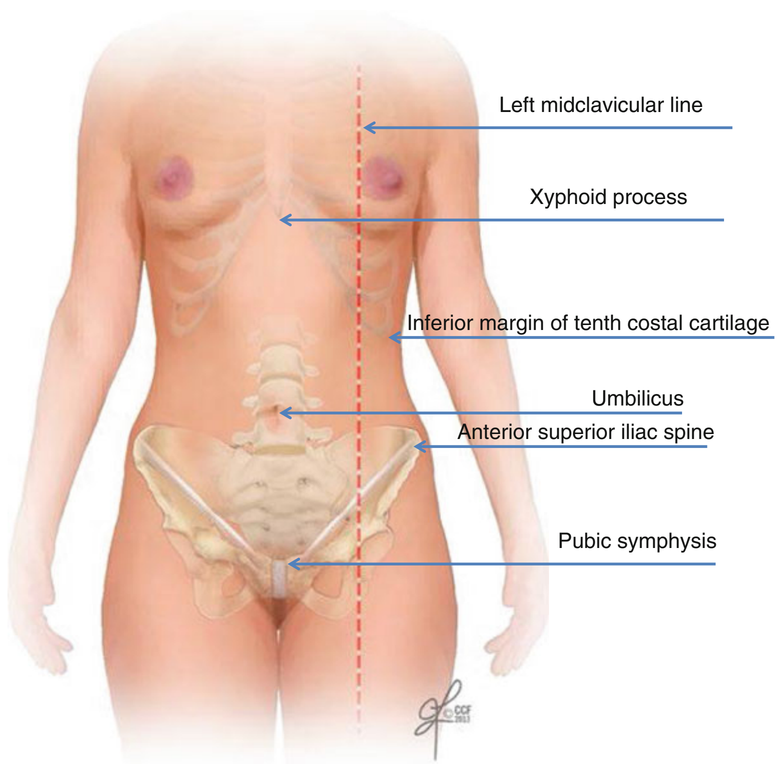

Fig. 1.1 Supine abdomen with osseus and nonosseous landmarks

umbilicus, the iliac vessels, in particular the left common iliac vein, are more susceptible to trocar injury. Patients are therefore usually placed in the supine position in order to minimize vessel injury during initial surgical entry at the umbilicus.

Furthermore, several studies have confirmed the effect of obesity on the position of the umbilicus, trocar angle, and distance to the retroperitoneal structures during initial umbilical entry. For patients of ideal body weight (body mass index [BMI] <25 kg/m^2), the umbilicus is often at the level of the intervertebral disc between the L3 and L4 vertebrae. For these patients, the trocar or Veress needle should be introduced at a 45-degree angle to protect the retroperitoneal vessels, since these vessels can be as close as 4 cm from the skin. In contrast, for obese patients a more vertical, almost 90-degree trocar entry is necessary to traverse the increased width of the abdominal wall (Fig. 1.2) [3].

The inguinal ligament, formed by the aponeurosis of the external oblique, marks the anatomic boundary between the abdomen and the thigh. The abdominal wall midline is the area between the xyphoid and the pubic symphysis. The left midclavicular line refers to a line drawn from the middle of the left clavicle to the middle of the left inguinal ligament.

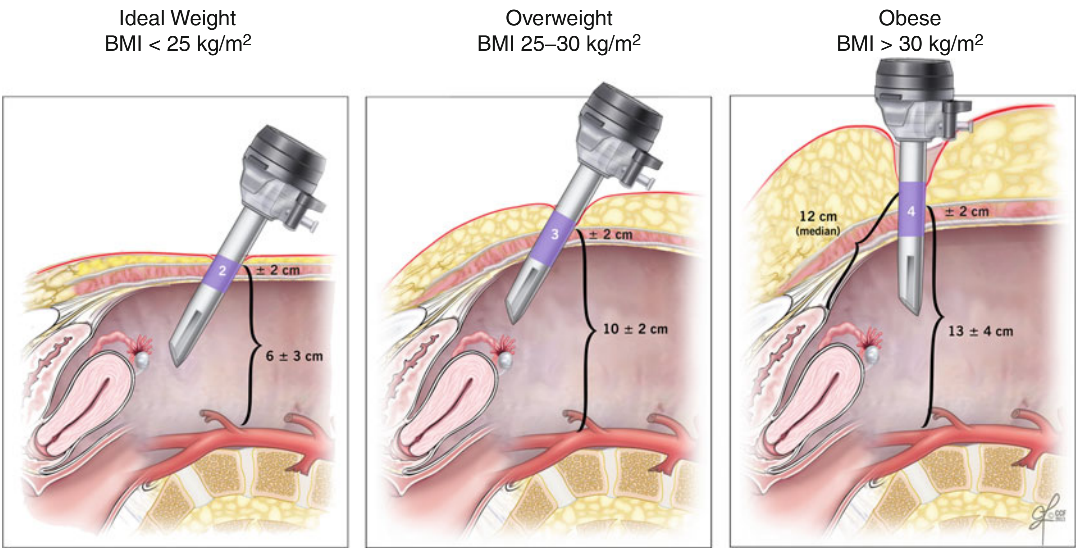

Fig. 1.2 The effect of increasing weight on anterior abdominal wall anatomy. These sagittal views illustrate that as a patient's body mass index increases, the distance from the base of the umbilicus to the peritoneum and the distance from the base of the umbilicus to retroperitoneal structures increase. To accommodate for these increased distances, the trocar angle must move from a 45-degree angle in an ideal weight patient to almost a 90-degree angle in an obese patient in order to traverse the abdominal wall. The purple trocar area denotes the distance from the base of the umbilicus to the peritoneum at a 45-degree angle in ideal and overweight patients. In the obese patient, this distance is measured at a 90-degree angle, to mimic the recommended trocar trajectory. Furthermore, if one were to utilize a standard 45-degree trocar for insertion in the obese patient, the median distance from the base of the umbilicus to the peritoneum is 12 cm (Adapted from Hurd et al. [3])

1.2 Anterior Abdominal Wall

The abdominal wall from superficial to deep includes skin, subcutaneous tissue/superficial fascia, rectus sheath and muscles, transversalis fascia, extraperitoneal fascia, and parietal peritoneum. Several important nerves and blood vessels course through these layers.

1.2.1 Subcutaneous Tissue

Camper's fascia is the superficial fatty layer and Scarpa's fascia is the deeper, thin fibrous layer; collectively they represent the "superficial fascia" or subcutaneous tissue. Superficial abdominal wall vessels course through the fascia. This tissue layer tends to be deceptively prominent in obese patients.

1.2.2 Muscles and Fascia

The abdominal wall is composed of five pairs of interconnected muscles. There are two midline muscles (the rectus abdominis and pyramidalis) and three sets of lateral muscles (the external and internal obliques and the transversus abdominis). In the midline, the rectus abdominis originates from the xiphoid process and costal cartilages of the fifth to seventh ribs and extends to the pubic symphysis. This broad strap muscle is encased within the anterior and posterior rectus sheath. The aponeuroses of the rectus muscles fuse in the midline as the linea alba and fuse laterally as the linea semilunares.

The pyramidalis muscle is a small triangular muscle that lies in the rectus sheath, anterior to the inferior aspect of the rectus abdominis. Occasionally this muscle is absent on one or both sides. When it is present, it arises from the pubis and inserts into the lower linea alba.

The three lateral muscles, found bilaterally, are also referred to as flat muscles. The most superficial of these is the external oblique. It arises from the lower eighth rib, where its fibers interdigitate with the serratus anterior muscle and extend inferiorly to the linea alba and pubic tubercle, creating a broad fibrous swath known as an aponeurosis.

Aponeuroses are tendon-like membranes that bind muscles to each other or to bones. Posterior to the external oblique lies the internal oblique muscle, whose fibers arise from the lumbar fascia, the iliac crest, and the lateral two-thirds of the inguinal ligament. The internal oblique fibers are at right angles to the external oblique fibers. The anterior and posterior layers of the internal oblique separate into the anterior and posterior rectus sheath and are responsible for creating the arcuate line landmark. The deepest lateral muscle is the transversus abdominis. Its muscle fibers run in a transverse fashion across the abdomen. The fibers arise from the costal cartilages of the sixth to eighth ribs, interlocking with the diaphragm, the lumbodorsal fascia, the lateral third of the inguinal ligament, and from the anterior three-fourths of the iliac crest and terminate anteriorly as an aponeurosis. The transversalis fascia lies deep to the transversus abdominis and is a continuous layer that lines the abdominal and pelvic cavity (Fig. 1.3).

The arcuate line is a transverse line located midway between the umbilicus and the pubic symphysis. Above the arcuate line, the rectus abdominis muscles possess both anterior and posterior sheaths formed by the aponeuroses of the midline and lateral muscles. Below the arcuate line, all layers of the sheaths course anterior to the rectus abdominis muscles.

The extraperitoneal fascia is the layer of connective tissue that separates the transversalis fascia from the parietal peritoneum. It contains a varying amount of adipose tissue and lines the abdominal and pelvic cavities. Viscera in the extraperitoneal fascia are referred to as retroperitoneal. Last, the parietal peritoneum lines the abdominal cavity. Remarkably, it is only one cell layer thick. Inward reflections of this peritoneum form a double cell layer known as mesentery.

The inguinal ligament is formed by the aponeuroses of the external oblique. It arises from the ASIS and inserts into the pubic tubercle. The inguinal canal runs parallel to the inguinal ligament. The inguinal canal is classically described by its four walls. Its anterior wall is formed by the aponeurosis of the external oblique, the inferior wall (floor) is formed by the inguinal ligament, the superior wall (roof) is formed by arching fibers of the internal oblique and transversus abdominis muscles, and the posterior wall is formed by the transversalis fascia.

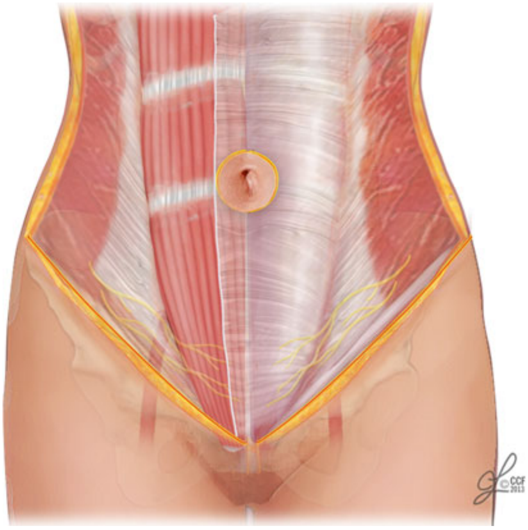

Fig. 1.3 Anterior abdominal wall muscles

The deep internal inguinal ring is the tubular evagination of the transversalis fascia, located halfway between the ASIS and the pubic symphysis. The inferior epigastric vessels lie medial to the deep internal inguinal ring. The round ligament dives through this deep internal ring, enters the inguinal canal, exits through the superficial external inguinal ring, and terminates at the labia majora. In addition, the terminal aspect of the ilioinguinal nerve and the genital branch of the genitofemoral nerve exit the inguinal canal via the superficial external inguinal ring. The superficial external inguinal ring is created by the opening of the external oblique aponeurosis and is located superior and lateral to the pubic tubercle (Fig. 1.4).

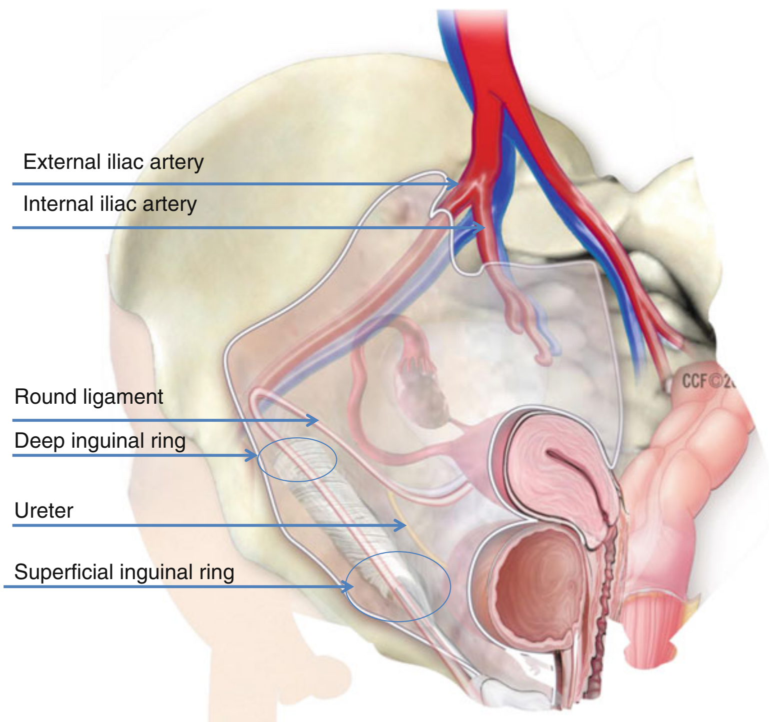

Fig. 1.4 The peritoneum drapes over the ureters, vital blood vessels, and large organs within the pelvis. The round ligament is seen entering the deep inguinal ring and exiting the superficial ring

1.2.3 Nerves

The clinically relevant upper and lower anterior abdominal wall nerves contain both motor and sensory fibers. The thoracoabdominal and subcostal nerves originate from T7 to T11 and T12, respectively. Their distributions are summarized in Table 1.2.

The iliohypogastric nerve and ilioinguinal nerve originate from L1 and accompany the thoracoabdominal and subcostal nerves as they course between the internal oblique and transversus abdominis muscles. At the ASIS, they traverse the internal oblique and run between the internal and external oblique muscles. The iliohypogastric nerves innervate the lateral abdominal wall, inferior to the umbilicus. The ilioinguinal nerve runs within the inguinal canal and emerges from the superficial, or external, inguinal ring to provide sensory innervation to the labia majora, inner thigh, and groin.

During laparoscopic and robotic surgery, the iliohypogastric and ilioinguinal nerves are particularly susceptible to injury because of their close proximity to traditional, lower quadrant trocar sites. Nerve damage may result from trocar placement or nerve entrapment secondary to lateral closure of transverse incisions or scar tissue (Table 1.3). The nerve injury usually results in chronic neuropathic pain (Fig. 1.5) [4].

Postoperative nerve damage should be suspected if the patient reports a burning or searing pain in the lower abdominal, pelvic, or medial thigh areas. The pain may be worsened by the Valsalva maneuver and is often relieved by hip and trunk flexion. A diagnostic and therapeutic injection of local anesthetic at the origin of the affected nerves, 3 cm medial to the ASIS, may provide relief.

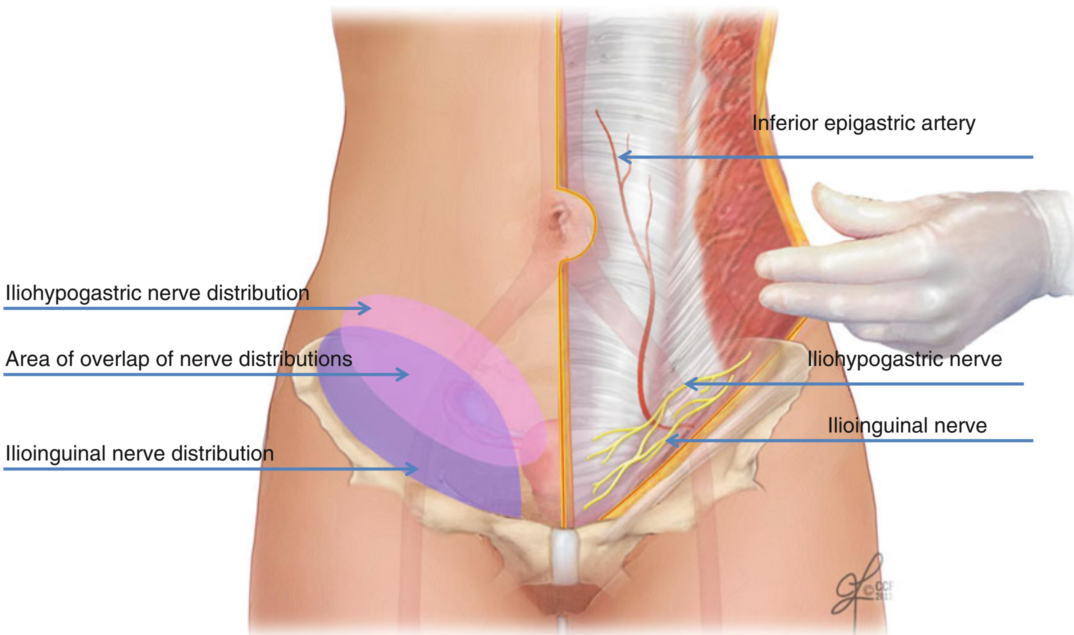

Fig. 1.5 Laparoscopic port placement two fingerbreadths superior and medial to the anterior superior iliac spine usually avoids ilioinguinal and iliohypogastric nerves and the inferior epigastric vessels

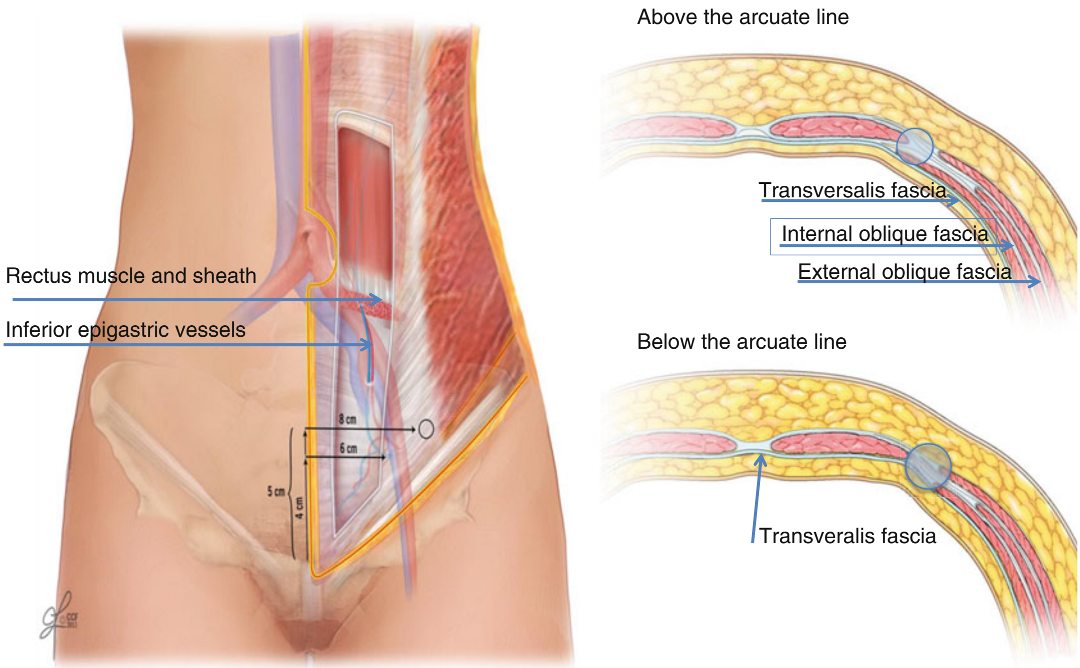

Fig. 1.6 Lower abdominal trocars should be placed lateral to the inferior epigastric vessels. These vessels travel medially from their origin off the external iliac artery and course toward the umbilicus. The vessels penetrate the transversus abdominis fascia and muscle approximately 4 cm superior and 6–7 cm lateral from the pubic symphysis. They then continue to run obliquely for an additional 7 cm and enter the posterior rectus sheath. Given these landmarks, a safe area for trocar entry is 5 cm superior and 8 cm lateral to the pubic symphysis (Modified from Park and Barber [7])

Table 1.2 Anterior abdominal wall innervations

Thoracoabdominal n.
T7–T9 superior to the umbilicus
T10 – at level of umbilicus
T11 – inferior to umbilicus
Subcostal n. (anterior and lateral branches)
T12 – inferior to the umbilicus
Iliohypogastric n.
L1 lateral and inferior to the umbilicus
Ilioinguinal n.
L1 labia majora, inner thigh, and groin

Table 1.3 Basic principle: decrease the risk of neuropathy

Basic principle: Reduce the risk of iliohypogastric and ilioinguinal nerve damage by utilizing transverse skin incisions and small trocars.
If possible, place laparoscopic trocars at or above the level of the ASIS [5].
If necessary, place lower abdominal trocars 2 cm medial and superior to the ASIS

1.2.4 Blood Vessels

The most notable anterior abdominal wall arteries are the epigastric vessels and the circumflex iliac vessels. Both pairs of vessels can be further classified into superficial and deep vessels. The deep epigastric vessels include the superior and inferior epigastric arteries and veins. The superior epigastric artery originates from the internal mammary artery and descends through the thorax into the rectus muscle, where it anastomoses with the inferior epigastric artery. The superior epigastric artery is accompanied by two superior epigastric veins. The deep inferior epigastric artery arises from the external iliac artery, just above the inguinal ligament. The inferior epigastric artery and vein travel in a medial and oblique fashion along the peritoneum to pierce the transversalis fascia and the rectus muscle. Owing to the absence of the posterior rectus sheath below the arcuate line, the inferior epigastric vessels can be seen within the lateral umbilical fold (Table 1.4) [6]. Accidental laceration of these deep vessels may result in life-threatening hemorrhage that must be swiftly occluded using electrosurgery or sutures (Fig. 1.6) [7].

In contrast, the superficial epigastric artery originates from the femoral artery and courses through the superficial fascia toward the umbilicus. Prior to placing secondary laparoscopic trocars, the superficial epigastric vessels are often identified by intra-abdominal transillumination in order to avoid vessel injuries (Table 1.5) [8].

Vascular trauma to the superficial epigastric vessels may result in a hematoma or abscess and, on rare cases, may even expand to the labia majora [9].

The circumflex iliac arteries consist of the deep and superficial circumflex iliac arteries. They arise from the femoral and external iliac arteries, respectively.

Table 1.4 Basic principle: decrease the risk of vascular injury

Always identify the deep, inferior epigastric vessels as they course along the parietal peritoneum. The deep vessels are located lateral to the medial umbilical folds but medial to the deep inguinal ring. Identify the deep inguinal ring by locating where the round ligament enters the inguinal canal and continues into the deep inguinal ring.
If the deep epigastric vessels are obscured by excess tissue and cannot be easily identified, one of two strategies may be employed: 1. Place the trocars approximately 8 cm lateral to the midline and 5 cm above the pubic symphysis [6]. These right and left anterior abdominal areas approximate "McBurney's point" and "Hurd's point," respectively. Or, 2. Place the trocar medial to the medial umbilical fold, as the inferior epigastrics are consistently lateral to these. One problem with positioning the trocar this medially, however, is poor access to the adnexa.

Table 1.5 Basic principle: identify the vasculature

To avoid vessel injury, transilluminate the superficial epigastric and circumflex vessels, and identify their course prior to placing secondary trocars.

1.2.5 Peritoneal Landmarks

Distorted anatomy and severe surgical scarring challenge even experienced laparoscopic surgeons. When difficult situations are encountered, it is imperative to identify key structures that will facilitate safe surgical dissection and avoid injury to retroperitoneal vessels and viscera (Table 1.6). In the midline, there are two peritoneal folds. In the upper abdomen, the falciform ligament extends from the umbilicus to the liver and includes the obliterated umbilical vein. It is a remnant of the ventral mesentery. In the pelvis, the median umbilical fold extends from the umbilicus to the apex of the bladder and encases the urachus. Occasionally, the urachus fails to close after birth and continues to communicate with the bladder. Therefore, one should avoid this fibrous fold during laparoscopic trocar placement. In addition, a pair of bilateral, medial, and lateral umbilical folds encase the obliterated umbilical arteries and inferior epigastric vessels (Figs. 1.7 and 1.8).

There are two naturally occurring peritoneal pouches within the pelvis. Located anteriorly, the vesicouterine pouch is found between the uterus and the bladder. In a pristine pelvis, the ventral aspect of the bladder may be seen behind the anterior abdominal wall peritoneum. However, after cesarean sections, myomectomies, and previous abdominal surgery this area may be scarred and the ventral bladder margin may be more cephalad than expected. Similarly, the dorsal bladder margin usually lies on the anterior surface of the uterus. It is an important landmark for avascular dissection, but after pelvic surgery it may be adherent and require meticulous dissection (Table 1.7).

Located posteriorly, the rectouterine pouch, or the pouch of Douglas, lies posterior to the vagina, cervix, uterus, and anterior to the rectum. This pocket can be completely obliterated in cases of advanced endometriosis. The scarring may extend inferiorly to the posterior wall of the vagina and the anterior wall of the rectum. This area is an extraperitoneal fascial plane known as the rectovaginal septum. On pelvic examination, endometriosis can be appreciated as palpable nodularity along this fascial plane that runs from the rectouterine pouch to the perineal body (Fig. 1.9).

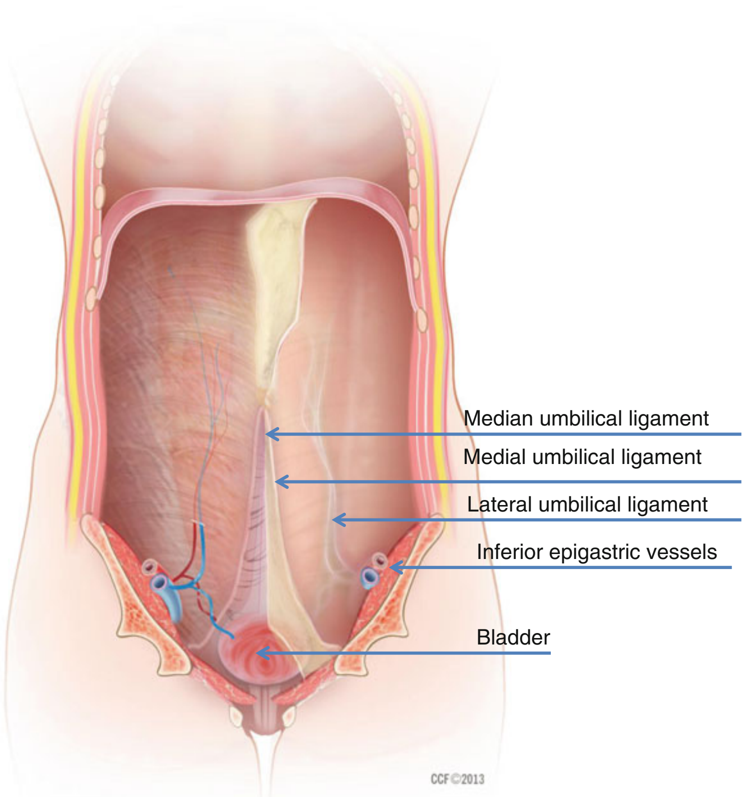

Fig. 1.7 Peritoneal folds of the anterior abdominal wall. The nonmidline folds aid in identifying critical vasculature. The medial umbilical folds lie on each side of the median fold and extend from the umbilicus to the anterior division of the internal iliac artery. The medial folds contain the obliterated umbilical arteries and form the boundaries of the bladder dome. Lateral to the medial folds are the lateral umbilical folds that extend from the arcuate line to the inguinal ring. The lateral umbilical folds are vital landmarks that contain the large, inferior epigastric vessels

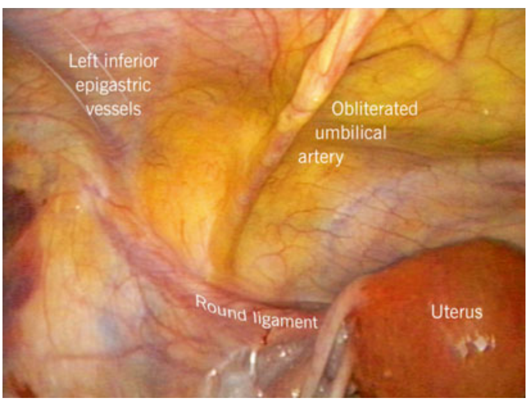

Fig. 1.8 Laparoscopic view of the left anterior abdominal and pelvic side wall. The medial umbilical fold, lateral umbilical fold, and round ligament provide peritoneal landmarks. Note that the round ligament inserts into the deep inguinal ring and is lateral to the deep inferior epigastric vessels contained within the lateral umbilical fold

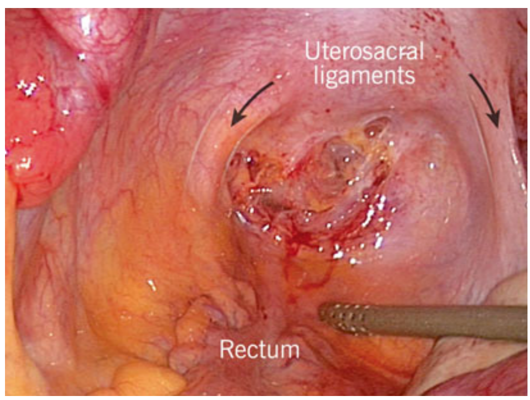

Fig. 1.9 The rectouterine pouch is shown after resection for endometriosis. Bilateral uterosacral ligaments (*black arrows*) as well as the rectum are visible

Table 1.6 Peritoneal landmarks: their location and clinical significance

Peritoneal landmark	Anatomic location	Clinical significance
Median umbilical fold	Midline	Contains the fibrous and potentially patent urachus
	From umbilicus to bladder apex	
Medial umbilical fold	Bilateral	Forms the boundaries of the bladder dome
	From umbilicus to the anterior division of the internal iliac artery	Contains the fetal/obliterated umbilical artery
Lateral umbilical fold	Bilateral	Lie lateral to the medial folds but medial to the deep inguinal ring
	From arcuate line to inguinal ring	Contains the deep inferior epigastric vessels

Table 1.7 Basic principle: avoid vesical injury

To decrease bladder injury, incise the peritoneum laterally, and work medially. Keep in mind, that the bladder apex is most cephalad at the midline and is triangular in shape. The medial umbilical ligaments mark the bladder dome boundaries and are contiguous with the parietal peritoneum.

1.3 Upper Abdomen

Historically, laparoscopists only utilized the left upper quadrant as the initial entry point in patients with previous surgeries, suspected umbilical adhesions, or a large pelvic mass. However, today the left upper quadrant and other upper abdominal sites are routinely used in laparoscopic and robotic surgery. To perform a left upper quadrant entry, a Veress needle or trocar is introduced at Palmer's point, located in the midclavicular line just below the left subcostal margin. Anatomic structures at the greatest risk of injury are the stomach, left lobe of the liver, and the splenic flexure of the colon [10, 11]. Hence, prior to attempting this entry, the patient should be placed in the supine position and the stomach decompressed. Although the upper abdomen has become a more familiar landscape in recent years, caution should be exercised when using this entry in patients with relative contraindications such as hepatosplenomegaly, portal hypertension, and gastric or pancreatic masses (Fig. 1.10).

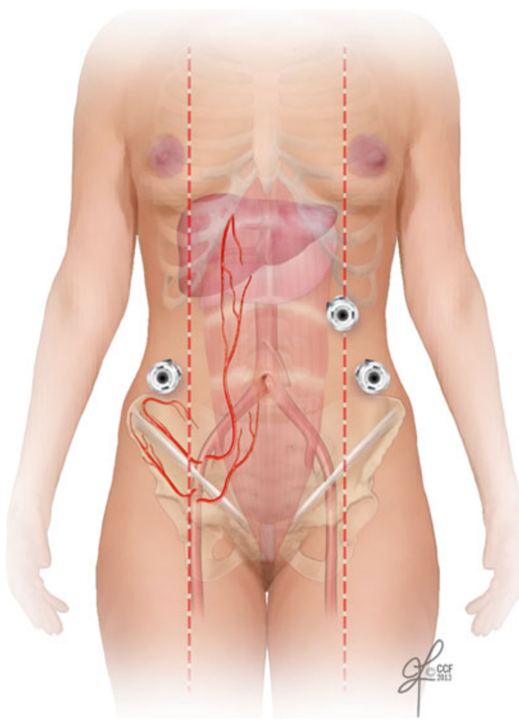

Fig. 1.10 The relationship of standard lower and upper abdominal trocar sites to important vascular landmarks and organs

1.4 Posterior Abdominal Wall and Pelvic Side Walls

Thorough knowledge of the posterior abdominal wall and the pelvic side wall structures is necessary for safe retroperitoneal dissection and effective management of surgical complications.

1.4.1 Muscles

There are six clinically relevant muscles of the posterior abdominal wall and pelvic side wall. Beginning superiorly, the diaphragm is a dome-shaped muscle that separates the thorax from the abdomen. The psoas major muscle originates from the transverse processes of the lumbar vertebrae and runs longitudinally to insert onto the lesser trochanter of the femur. The psoas major muscle constitutes a substantial portion of the posterior and medial walls. The psoas minor muscle lies anterior to the psoas major and its tendon is seen during dissection near the external iliac vessels. The quadratus lumborum muscle is located lateral and posterior to the psoas major. It spans the transverse process of lumbar vertebrae and ribs to the iliac crest. The iliacus muscle is a flat, triangular muscle that fills the iliac fossa and joins the psoas major to form the iliopsoas muscle. Ending inferiorly, the piriformis muscle lies immediately posterior to the internal iliac vessels. It originates from the anterior sacrum, passes through the greater sciatic foramen, and inserts into the greater trochanter of the femur.

1.4.2 Nerves

There are many nerves that innervate and course along the pelvic side wall. Deep nerves, such as the superior and inferior gluteal nerves, supply the pelvic muscles but are not visible during reproductive surgery. The obturator nerve, however, can easily be identified during pelvic side wall dissections. It provides sensory innervation to the medial thigh and is responsible for thigh adduction (Fig. 1.11).

The genitofemoral nerve (from spinal cord levels L1 and L2) lies on the anterior surface of the psoas major muscle and as its name implies, it divides into two branches: the femoral and the genital nerves (Fig. 1.12). The genitofemoral nerve provides sensory innervation over the anterior surface of the thigh.

The femoral nerve (spinal cord levels L2–L4) is usually not seen during pelvic surgery, but it may be injured during laparotomy. The femoral nerve is a branch of the lumbar plexus. It dives into the psoas major muscle and then emerges at its lower lateral border. The nerve courses between the psoas and iliacus muscles and then passes posterior to the inguinal ligament to supply the motor and sensory nerves of the anterior thigh. Prolonged pressure on the psoas major muscle may cause temporary or permanent damage to the femoral nerve. Therefore, it is imperative to ensure that the lateral blades of a self-retaining retractor do not exert excessive pressure on the pelvic side walls.

The sacral and coccygeal nerve plexuses are located beneath the branches of the internal iliac artery and are found anterior to the piriformis muscle. The sciatic and pudendal nerves are the most important nerves in this area. The sciatic nerve (from spinal cord levels L4–S3) lies anterior to the piriformis muscle and exits the pelvis through the greater sciatic foramen. The pudendal nerve (from spinal cord levels S2–S4) also lies anterior to the piriformis muscle and exits the pelvis through the greater sciatic foramen. It then courses around the sacrospinous ligament and ischial spine, through the lesser sciatic foramen, and continues into the perineum. At this level, endometriosis may involve the sciatic nerve and cause pain related to the course of the nerve.

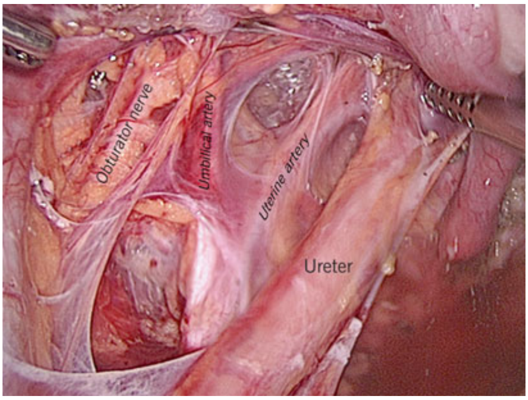

Fig. 1.11 The obturator nerve originates at spinal cord levels L2–L4 and descends through the psoas major muscle and emerges medially to course over the obturator internus muscle. The obturator nerve remains lateral to the anterior division of the internal iliac artery and ureter and then enters the thigh through the obturator canal

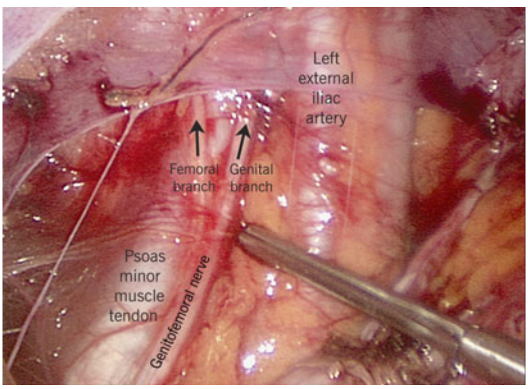

Fig. 1.12 The genitofemoral nerve lies lateral to the external iliac artery. The femoral branch enters the thigh under the inguinal ligament, and the genital branch enters the inguinal canal. The genitofemoral nerve is at risk when the peritoneal fold between the sigmoid colon and the psoas major muscle is incised

1.4.3 Blood Vessels

The aorta descends from the thorax into the abdominal cavity slightly left of the midline. It bifurcates at the level of L4 to L5, into the left and right common iliac arteries and also gives rise to the much smaller, middle sacral artery (Fig. 1.13). The inferior vena cava (IVC) lies to the right of the aorta. In the abdomen, the IVC is anterior to the aorta at the level of the renal veins. It then runs posterior to the aorta by the level of the aortic bifurcation and divides into the left and right common iliac veins (Table 1.8).

The common iliac artery courses anterior and lateral to the common iliac vein before dividing into the external and internal iliac arteries (Fig. 1.14). The external iliac artery is medial to the psoas muscle and gives rise to two vessels: the inferior epigastric artery and the deep circumflex iliac artery. Once the external iliac artery passes under the inguinal ligament, it becomes the femoral artery. Of note, its venous counterpart, the external iliac vein, is a much larger vessel, and it is situated posterior and medial to the artery, over the obturator fossa.

The internal iliac artery is the predominant artery within the pelvis. In addition to supplying the pelvic viscera, its smaller branches veer in and out of the greater and lesser sciatic foramina to perfuse the gluteal muscles and the perineum.

The internal iliac arteries split into anterior and posterior divisions that are readily seen with a retroperitoneal dissection. The anterior division of the internal iliac artery has several branches of clinical relevance. The obturator artery branches anterolaterally and dives into the obturator canal, posterior to the obturator nerve. The obliterated umbilical artery and uterine artery emerge from a common trunk and then diverge along their distinct paths. The distal portion of the obliterated umbilical artery is contained within the medial umbilical fold and serves as a peritoneal landmark. The superior vesical artery arises from the same internal iliac trunk and courses inferiorly and medially to supply the superior portion of the bladder and the distal ureter. Knowledge of these anatomic relationships is particularly useful when dealing with distorted anatomy (Table 1.9).

The uterine artery supplies the uterus and the adnexa and is of great clinical importance. In the retroperitoneum, the proximal uterine artery travels lateral and parallel to the ureter. As the uterine artery descends into the pelvis, it crosses over the ureter in a medial and anterior fashion at the level of the cervix (Fig. 1.15). The most distal aspect of the uterine artery is usually identified within the cardinal ligament, at the level of the internal os, as it propagates into smaller spiral arteries that form a network toward the uterine corpus and cervix.

The vaginal artery usually originates from the uterine artery, but it may arise directly from the internal iliac artery.

Other important branches of the anterior trunk of the internal iliac artery are the middle rectal, internal pudendal, and inferior gluteal arteries. The inferior gluteal artery is the largest branch of the anterior trunk.

The posterior division travels toward the ischial spine and gives rise to the iliolumbar, lateral sacral, and superior gluteal arteries. The superior gluteal artery is the largest branch of the internal iliac artery as it supplies the skin and muscles of the gluteal region. During uterine fibroid embolization, accidental occlusion of the superior gluteal artery can result in necrosis of the gluteal region.

The uterus and the adnexa are perfused by the uterine, vaginal, and ovarian arteries and their anastomoses with each other.

The ovarian arteries originate directly from the abdominal aorta. They descend over the pelvic brim, lateral to the ureters, and then course within the infundibular pelvic ligaments. The right ovarian vein drains directly into the IVC, while the left ovarian vein drains to the left renal vein.

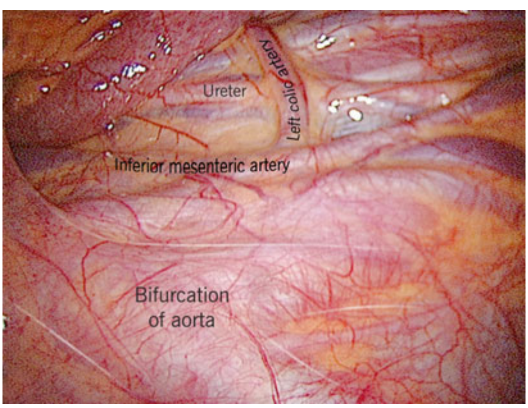

Fig. 1.13 Vessels of the abdomen and pelvis. The aorta is seen bifurcating into the iliac vessels. The left colic artery and inferior mesenteric artery are visible lateral to this bifurcation

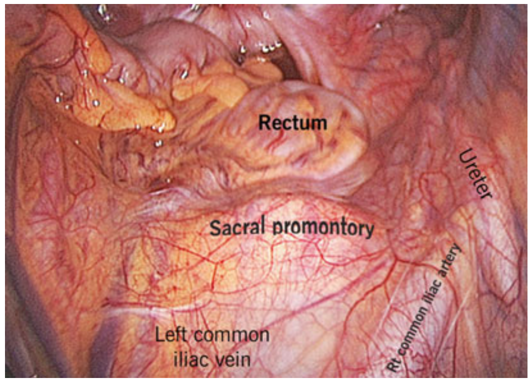

Fig. 1.14 A laparoscopic view of vessels posterior to the umbilicus. The left and right iliac vessels are seen in relationship to the sacral promontory, rectum, and ureter. Appreciation of this proximity and control of the trocar speed, angle, and depth are necessary to avoid serious complications

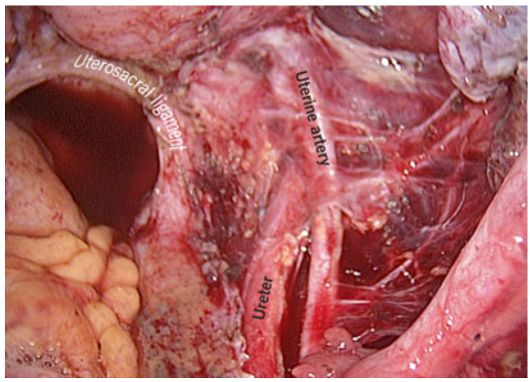

Fig. 1.15 Uterine artery crossing over the ureter

Table 1.8 Basic principle: considerations prior to inserting an umbilical trocar

When placing the initial umbilical trocar, remember that the left common iliac vein lies in the midline, just caudad to the aortic bifurcation and the umbilicus (see Fig. 1.14). Also see previous section on the impact of increasing weight on anterior abdominal wall anatomy.

Table 1.9 Basic principle: utilize peritoneal landmarks for orientation

Identification of the ureters and major vessels is critical before any ligation or cauterization is performed. When distorted anatomy poses a challenge, first identify a medial umbilical fold as a fibrous band on the anterior abdominal wall. Then apply gentle traction on this fold (and the encased obliterated umbilical artery) and follow it to its origin, the internal iliac artery. In this vicinity, the superior vesical artery and uterine artery can be identified and followed toward their terminal organs.

1.4.4 Ureters

The ureters measure approximately 25–30 cm from the renal pelvis to the bladder. They are located in the retroperitoneum and are occasionally duplicated on one or both sides. In the abdomen, the ureters descend on the medial aspect of the psoas major muscle and cross the common iliac vessels at their bifurcation into the internal and external iliac arteries at the pelvic brim (Fig. 1.16).

In the pelvis, the ureters lie in close proximity to the ovarian vessels. The ureter is located medial to the internal iliac and its anterior division (Fig. 1.17). The ureter is usually found medial to the infundibulopelvic ligament. Broad ligament dissection may be necessary to identify the ureter and to ensure the safe ligation of the ovarian vessels during a salpingo-oophorectomy (Fig. 1.18).

The ureter then dives deep into the parametrium and travels under the uterine artery. This anatomic relationship is classically referred to as "water under the bridge." It traverses the cardinal ligament, then crosses over the vaginal fornix, and finally inserts into the bladder trigone.

The average distance between the ureter and cervix is more than 2 cm. However, this distance can be less than 0.5 cm in about 10 % of women [12]. This variable distance partially explains the relatively common occurrence of ureteral injury during hysterectomy.

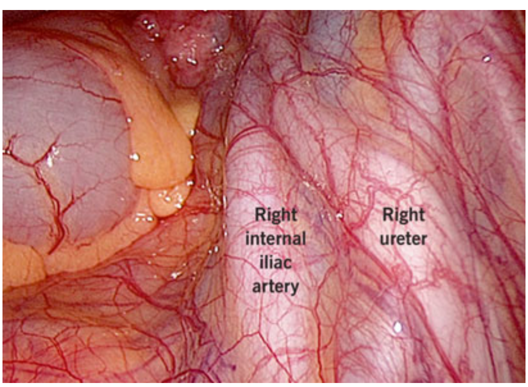

Fig. 1.16 A view of the ureter and internal iliac vessels from the pelvic brim

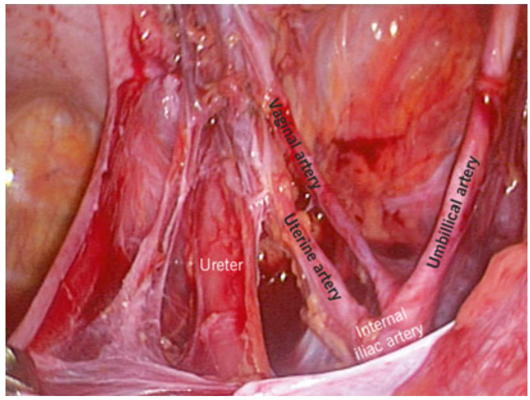

Fig. 1.17 A more caudad view of the internal iliac artery and its anterior division. Here the uterine, vaginal, and umbilical arteries are seen in relationship to the ureter. Note how the ureter moves from a lateral (in Fig. 1.16) to a medial position in relationship to the internal iliac artery as it courses from the pelvic brim to deep within the pelvis

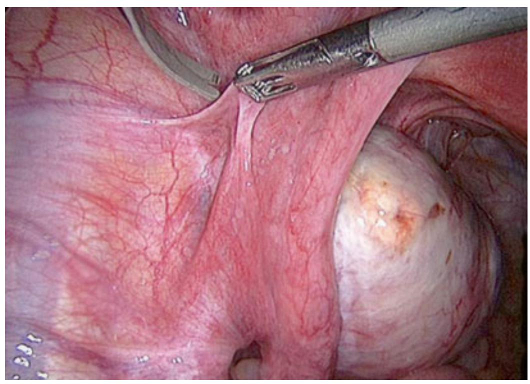

Fig. 1.18 Incising the left broad ligament to facilitate ureter identification. Retroperitoneal dissection may begin at the pelvic brim and is carried caudad to follow the course of the ureter. Alternatively, in the event of a salpingo-oophorectomy, the broad ligament may be grasped and incised between the round ligament and the infundibular pelvic ligament to access the retroperitoneum and aid in ureter identification prior to securing the vascular ovarian pedicle. The ureter is located on the medial leaf of the broad ligament

1.5 Muscles of the Pelvic Floor

The pelvic floor contains a series of muscles and endopelvic fascia that provide pelvic support to the uterus, vagina, bladder, and rectum. Disruption of these varying levels of pelvic support, described as Levels 1, 2, and 3, result in pelvic organ prolapse, paravaginal defects, and voiding and defecatory dysfunction. Pelvic floor relaxation occurs with increasing age but may be hastened by stressors such as the physiologic rigors of pregnancy, increasing parity, obesity, and birth trauma [13].

1.5.1 Pelvic Diaphragm

The pelvic diaphragm refers to the levator ani muscle complex and the coccygeus muscle. The levator ani consists of the puborectalis, pubococcygeus, and the iliococcygeus muscles (Fig. 1.19).

The thick anterior and posterior condensations of white fascia that surround the vagina are known as the arcus tendineus fascia pelvis (ATFP) and the arcus tendineous rectovaginalis (ATRV). These fasciae, together with the levator ani muscles, attach the midvagina to the pelvic side walls and support the bladder and rectum. Note the almost perpendicular axis of the puborectalis and pubococcygeus muscles to the vagina and rectum in a standing woman. Defects of Level 2 support result in cystoceles and rectoceles (Fig. 1.20) [14].

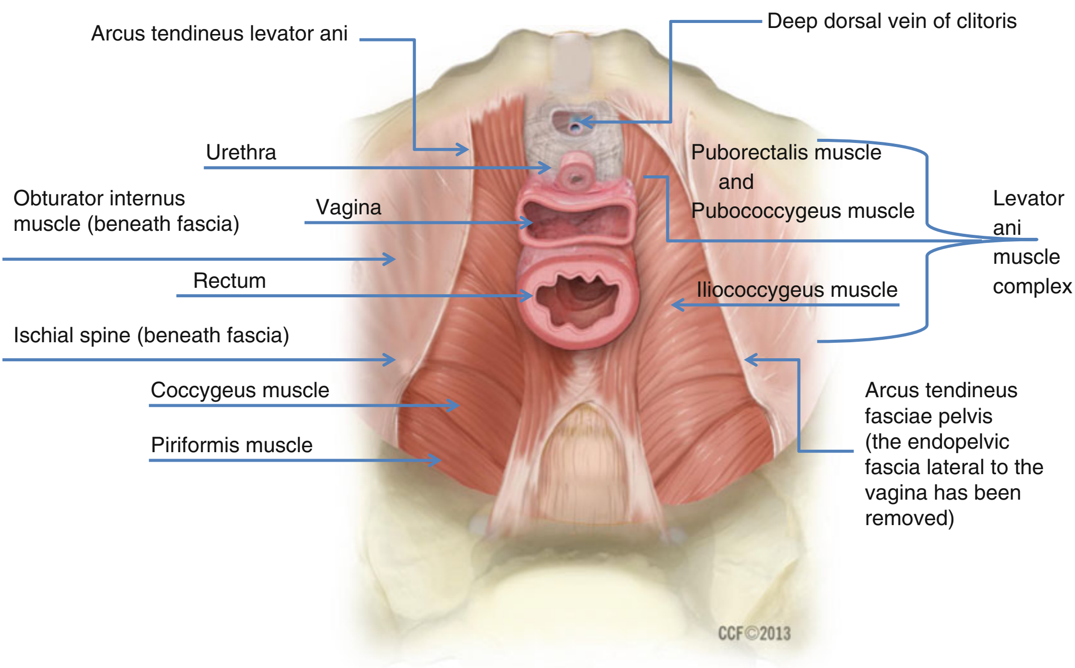

Fig. 1.19 Components of the pelvic diaphragm. The puborectalis muscle encircles the rectum and is attached to the pubic symphysis. The pubococcygeus muscle stretches in an anteroposterior fashion, from the pubis to the coccyx, and is attached to the obturator internus muscle by a dense band of connective tissue known as the arcus tendineus fascia pelvis (ATFP). The ATFP runs from the ischial spine and inserts on the pubic symphysis, and its posterior support is mirrored by the arcus tendineus rectovaginalis. The lateral iliococcygeus muscle extends from the arcus tendineus fascia pelvis and ischial spine to the coccyx. The coccygeus muscle is the most posteriolateral component and spans from the ischial spine to the coccyx and sacrum

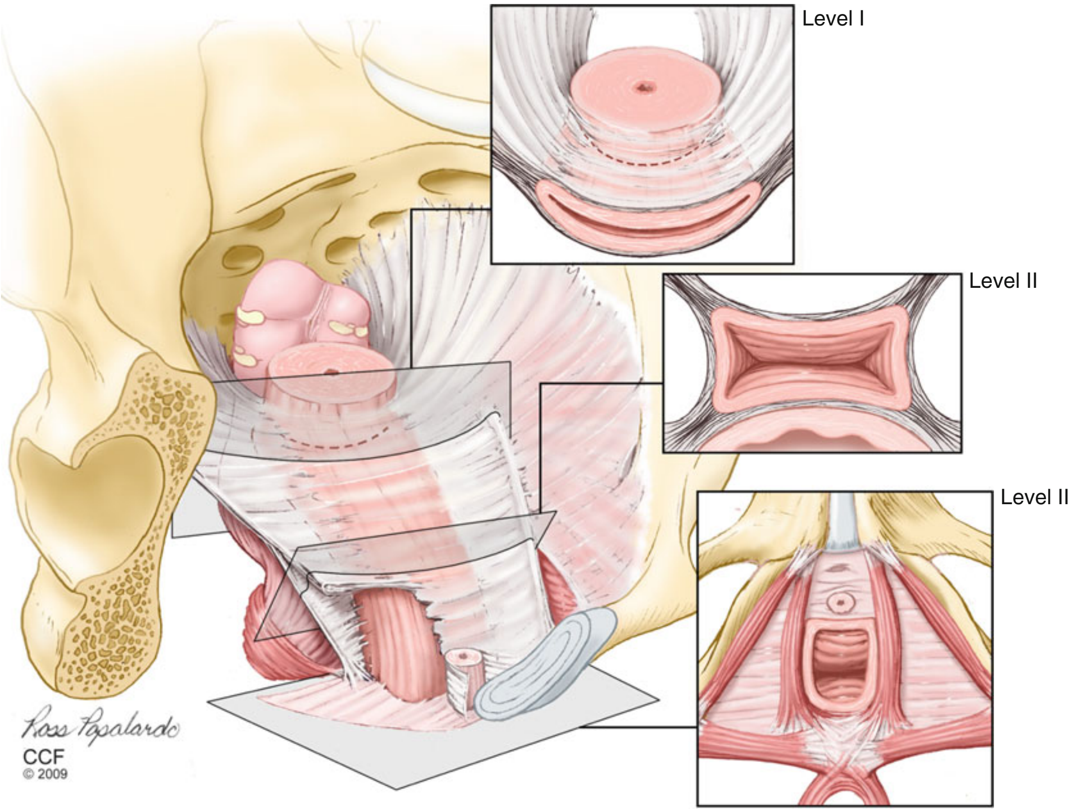

Fig. 1.20 Three integrated levels of uterine and vaginal support in a standing woman. *Level 1* support relies on the uterosacral and cardinal ligament complex to suspend the uterus, cervix, and upper vagina vertically and posteriorly toward the sacrum. *Level 2* utilizes the arcus tendineus fascia pelvis and arcus tendineus rectovaginalis to provide lateral support to the midportion of the vagina. *Level 3* support is provided by the network of connective tissue surrounding the vagina. These connective tissues bind the vagina to the urethra, perineum, and levator ani muscles

1.5.2 Deep and Superficial Perineal Pouches and the Perineal Membrane

The deep perineal pouch is somewhat of a misnomer as there is no true pouch. It refers to the area superior to the perineal membrane located between the inferior pubic rami and the perineal body. The connective tissues in this region provide the most distal level of pelvic organ support. Anteriorly, the ATFP unifies the vagina to the contiguous striated muscles of the urethra. Posteriorly, the ATRV merges the vagina to the deep transverse perineal muscles, perineal membrane, and the perineal body. And laterally, the connective fibers attach the vagina to the levator ani muscles. Defects of this Level 3 support result in perineal body descent and can cause urethral hypermobility, stress incontinence, and defecatory dysfunction [14].

The perineal membrane is a fascial layer that separates the deep and superficial perineal pouches but still allows passage of the vagina and urethra to the pelvic outlet.

The superficial perineal pouch includes the greater vestibular glands (Bartholin glands), and the ischiocavernosus, bulbospongiosus, and superficial transverse perineal muscles.

1.6 Presacral Space

Appreciation of the innervations and vascular anatomy of the presacral space is required prior to presacral dissection. Surgeries performed within this region include presacral neurectomy, sacral colpopexy, and rectal resection. In this space lies the superior hypogastric plexus that contains prelumbar sympathetic and parasympathetic nerve fibers. The superior hypogastric plexus divides into two branches at the level of the bifurcation of the aorta. These nerves carry visceral afferent fibers from the uterus in addition to parasympathetic fibers that stimulate bladder contraction and modulate activity of the distal colon. Therefore, patients undergoing presacral neurectomy must be counseled that surgery can result in both bladder and bowel dysfunction.

Vascular injury in this confined, deep space is problematic at the very minimum and at times can be life-threatening. The left common iliac vein marks the left superior margin of the presacral space. The median sacral vessels that originate from the aorta and descend in the midline into the presacral area are at risk during dissection. Laceration and bleeding from any of these vessels and the presacral venous plexus may result in hemorrhage.

1.7 Pelvic Viscera

The pelvic viscera include the rectum, urinary organs, the vagina, uterus, uterine tubes, and ovaries.

1.7.1 The Rectum

The rectum of the adult is approximately 12–15 cm in length. It begins at the rectosigmoid junction at the level of S3 and ends at the level of the coccyx. It is distinguished from the colon by its lack of taenia coli, haustra, and omental appendices.

The upper third of the rectum projects into the peritoneal cavity. At its midpoint, the rectouterine pouch is formed by the extension of the rectum's anterior peritoneum onto the vaginal fornix. The distal one-third of the rectum is located in the retroperitoneum.

The blood supply to the rectum includes the superior rectal artery, a branch from the inferior mesenteric artery, the middle rectal artery, a branch from the internal iliac artery and the inferior rectal artery, and a branch from the internal pudendal artery. Sympathetic fibers from the inferior hypogastric plexus, parasympathetic fibers from S2 to S4, and sensory fibers from the rectum all join the inferior hypogastric plexus to innervate the rectum.

1.7.2 Vagina

The vagina is a muscular membranous cylinder that extends anteroinferiorly from the uterine cervix to the vestibule and is approximately 7–9 cm in length. The vagina is separated from the bladder and rectum by the vesicouterine and rectouterine pouch. The vagina receives its blood supply from the uterine, vaginal, and middle rectal arteries. The inferior hypogastric plexus and pelvic splanchnic nerves innervate the vagina.

1.7.3 Uterus

The uterus is a dynamic, fibromuscular organ that varies in size and weight according to life stage and parity. The uterus is composed of a body (corpus) and a cervix. The fundus is the portion of the uterine body above the fallopian tubes. The uterine cavity is triangular in shape. The length of the uterine cavity changes according to life stage owing to the profound effect of hormones on uterine size. In premenarchal females the uterine length from the external os to the fundus is 1–3 cm. During the reproductive years, this increases to 6–7 cm, and in postmenopausal women the uterus decreases to 3–5 cm in length. Similarly, the inner lining of the uterus is hormonally active and varies throughout a woman's life cycle. The endometrium varies from 5 to 15 mm during a single menstrual cycle during the reproductive years but should measure less than 5 mm in thickness during the postmenopausal period.

The myometrium is thickest in the midportion of the corpus and thinnest in the cornua. The outer and innermost layers are composed mostly of longitudinal fibers in contrast to the middle layer, which consists of circular and oblique fibers that enwrap blood vessels and loose connective tissue.

The majority of the uterine blood supply is from the uterine artery, a branch of the internal iliac artery. Uterine arteries run along the lateral borders of the uterus and form anastomoses with the ovarian and vaginal arteries. The anterior and posterior arcuate arteries branch off the uterine arteries and run circumferentially around the uterine corpus and anastomose in the midline. Interestingly, no large blood vessels are found in the uterine midline. Radial arteries develop from the arcuate arteries and deeply penetrate the myometrium to reach the endometrium. The spiral arteries, which arise from the radial arteries, supply the endometrium and are the terminal blood vessels of the uterus.

1.7.4 Uterine Tubes

The uterine tubes are enshrouded within the uppermost aspect of the broad ligament and measure about 10–12 cm. Each tube is divided into four anatomic segments: intramural (or interstitial), isthmic, ampullary, and infundibulum.

The intramural portion is usually 1.5 cm long and less than 1 mm in diameter and may be tortuous. The isthmic portion is often the segment excised or ligated during tubal ligation and therefore is also the site of tubal anastomosis. The lumen is approximately 0.5 mm. Subsequent pregnancy rates are highest for procedures done in this area.

The ampulla comprises two-thirds of the length of the tube and is characterized by 4–5 longitudinal ridges. It is the site of fertilization. Not surprisingly, it is also the most common site of ectopic pregnancy. Tubal ligations are often performed at this more distal site. Pregnancy rates after anastomosis are lower in this segment despite the larger lumen.

The infundibulum is the most distal section of the tube. It is open to the peritoneal cavity and is readily identified by its fimbriae. The lumen diameter may reach 10 mm.

The tubal wall is made up of three layers: mucosa, muscularis, and serosa. The muscular layer possesses an external longitudinal layer and an inner circular layer of smooth muscle. Branches of the uterine and ovarian arteries course though the mesosalpinx and provide the blood supply for the fallopian tube.

1.7.5 Ovaries

The ovaries are hormonally dynamic ovoid structures suspended from the posterior aspect of the broad ligament by the mesovarium. This fold of peritoneum contains a complex of blood vessels. The ovarian ligament enters the ovary along its inferior pole and the suspensory ligament of the ovary, or infundibulopelvic ligament, enters the ovary along its superior pole. The infundibulopelvic ligament carries the ovarian vessels, lymphatics, and nerves from the pelvic side wall and lies in close proximity to the ureter at the pelvic brim. The ovary is attached to the broad ligament by the well-vascularized mesovarium. The highly coiled, cascading anastamoses of uterine and ovarian vessels are prominent in the gravid uterus or a uterus laden with leiomyomata.

1.8 Pelvic Fasciae and Ligaments

The pelvic viscera are attached to the pelvic side walls by (1) peritoneal folds, (2) condensations of pelvic fascia, and (3) remnants of embryonic structures. Historically, these structures were called ligaments because it was believed that they supported the uterus and prevented genital prolapse. However, it has become clear that they do not provide significant support for the pelvic viscera in the presence of pelvic floor defects.

1.8.1 Peritoneal Folds

The broad ligament is a double-layered transverse fold of peritoneum that drapes the uterus, fallopian tubes, lateral pelvic side walls, and pelvic floor. On the lateral aspects of the uterus, the mesometrium encloses the uterine vessels and the ureters. Posteriorly, the mesovarium attaches the ovary to the broad ligament, while the mesosalpinx connects the fallopian tube near the base of the mesovarium.

The suspensory ligament of the ovary, or the infundibulopelvic ligament, is a lateral continuation of the broad ligament beyond the fallopian tube that connects the ovary to the pelvic brim and contains the ovarian vessels. The ureter crosses beneath these vessels near the ligament's insertion into the pelvic side wall (Fig. 1.21).

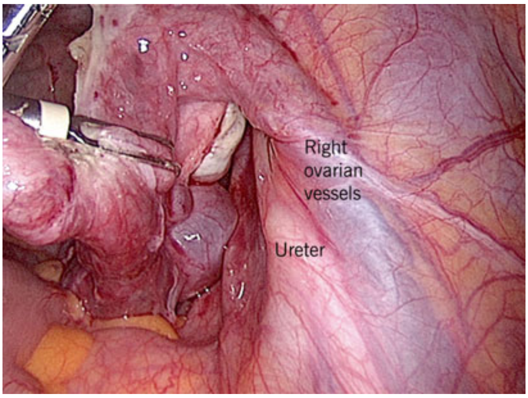

Fig. 1.21 Proximity of the ureter to the ovarian vessel. In order to minimize ureteral injury a surgeon may perform ureterolysis or create a clear window between the ovarian vessels and the ureter prior to ligation and incision of the blood vessels. Damage to the ureter most commonly occurs at the following locations: at the pelvic brim while securing the ovarian vessels, at the level of the cardinal ligament (in this area the ureter dives under the uterine artery), at the level of the uterosacral ligaments along the pelvic side wall, and at the level of the vaginal cuff while securing the angles for hemostasis

1.8.2 Fascial Ligaments

Together, the cardinal and uterosacral ligaments provide Level 1 support for the uterus, cervix, and upper vagina [14].

The cardinal ligament is the dense connective tissue located lateral to the cervix. It is abutted by the broad ligament anteriorly, posteriorly, and inferiorly by the pelvic floor. It is continuous with the paracervix, a thick fibrous sheath around the lower cervix and the upper vagina. It is attached to the pelvic walls laterally and contains major branches of the uterine vessels.

The uterosacral ligaments are bands of connective tissue and smooth muscle that stretch from the posterior paracervix to the sacrum and rectum.

1.8.3 Gubernacular Ligaments

The ovarian ligament runs within the broad ligament and attaches the medial pole of the ovary to the posterolateral uterine surface beneath the fallopian tube. The round ligament is a fibromuscular structure that runs from the anterolateral surface of the uterus and continues through the deep, external, inguinal ring and terminates in the connective tissue of the labium majora.

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