# Clinical Anatomy and Physiology of the Abdominal Wall

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## Introduction

The modern field of abdominal wall surgery relies on a thorough understanding of all components of the abdominal wall as well as their function and physiology. Advancements in technology have provided surgeons with a wide variety of mesh prosthetics along with novel tools to assist in hernia repair. As a result, improvements in recurrence rates and patient outcomes have been well documented [1, 2]. However, it is the steady progress in the understanding of the abdominal wall itself that has enabled the creation of more complex procedures including myofascial and musculocutaneous advancement flaps via component separation and muscle release [3–9]. Such advancements have allowed surgeons the technical ability to deploy prosthetics in novel manners and allow for closure of abdominal defects that were in the past considered impossible. Consequently, a comprehensive grasp of technical options should occur in tandem with a complete and systematic understanding of abdominal wall anatomy and physiology.

This chapter serves to provide a framework for understanding the clinical anatomy of the abdominal wall as well as the relevant physiology and critical relationships that arise during surgery. A fundamental grasp of surface and deep anatomy is assumed with focus given to more subtle clinical findings based on these foundations. The chapter is framed to emphasize the importance in restoration of the linea alba during these repairs.

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## Boundaries

The anterior abdominal wall is a hexagonal area bounded by the xiphoid process superiorly with delineation of the superolateral edges by the costal margins. Inferiorly it extends along the iliac crests and narrows to the superior edge of the pubic bone of the pelvis in the midline. The inferolateral margins are defined by the inguinal ligaments bilaterally. Lateral extension occurs posteriorly to the erector spinae and quadratus lumborum muscles adjacent to the lumbar spine as these muscles contribute to the thoracolumbar fascia along with transversus abdominis [10] (Fig. 1.1).

The dynamic group of muscles contained in these boundaries is unique in that they are void of any bony structures aside from their attachments. However, given their broad area, the muscular groups serve a variety of purposes in coordination with other body systems. Integral roles include assistance with defecation and urination as well as respiration and coughing via an increase or decrease in intra-abdominal and intra-thoracic


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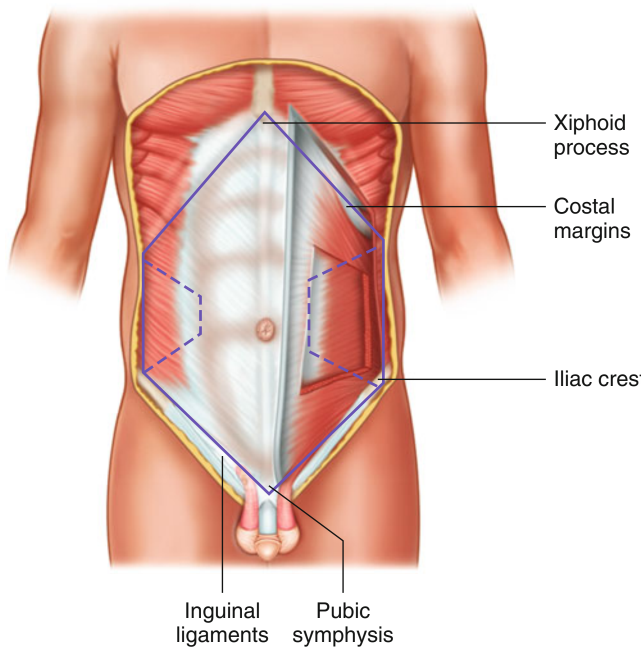


**Fig. 1.1** Boundaries of the abdominal wall shown as a hexagonal area anteriorly with lateral extension around the flanks toward the muscles of the back

pressures. Additionally, in concert with muscles of the back the abdominal wall serves to flex, extend, and rotate the torso from the hips. Tension generated in the thoracolumbar fascia along with muscles of the back provides stabilization for the lumbosacral spine and pelvis, both playing a critical role in posture [11]. Finally, the robust overlap of the muscular girdle also provides physical protection for the underlying viscera when contracted. Given the large variety of roles of the abdominal wall, a critical understanding of each component and its function is paramount, with the ultimate goal of restoration or maintenance of these functions following surgery.

## Components

The abdominal wall can be divided into midline and anterolateral groups of muscles comprising four main paired muscle groups and a variably present paired fifth muscle group. The muscular groups are covered by subcutaneous fat and skin along with superficial neurovascular structures which overlay the fascia. The rectus abdominis and the pyramidalis muscles comprise the midline group, although the presence of the pyramidalis is not consistent among the population [12, 13] (Fig. 1.2). The bilateral anterolateral groups are composed of a trilaminar structure consisting of the external oblique muscles (EOMs), internal oblique muscles (IOMs), and transversus abdominis muscles (TAMs) (Fig. 1.3). In addition to the muscular groups and their associated neurovascular supply, there are a number of key tendinous structures and delineations including the linea alba, linea semilunaris, linea semicircularis (arcuate line of Douglas) as well as the anatomic spaces of Retzius and Bogros, formed from the interaction of these muscle groups, that are equally as important to understand.

## Linea Alba

While the muscular components of abdominal wall are of crucial importance, the restoration of linea alba remains the goal of definitive abdominal wall reconstruction. This chapter begins with attention given to this oft-overlooked, but ultimately vital structure.

Literally translated as *the white line*, the linea alba is a completely fibrous structure composed of collagen and elastin traversing from the

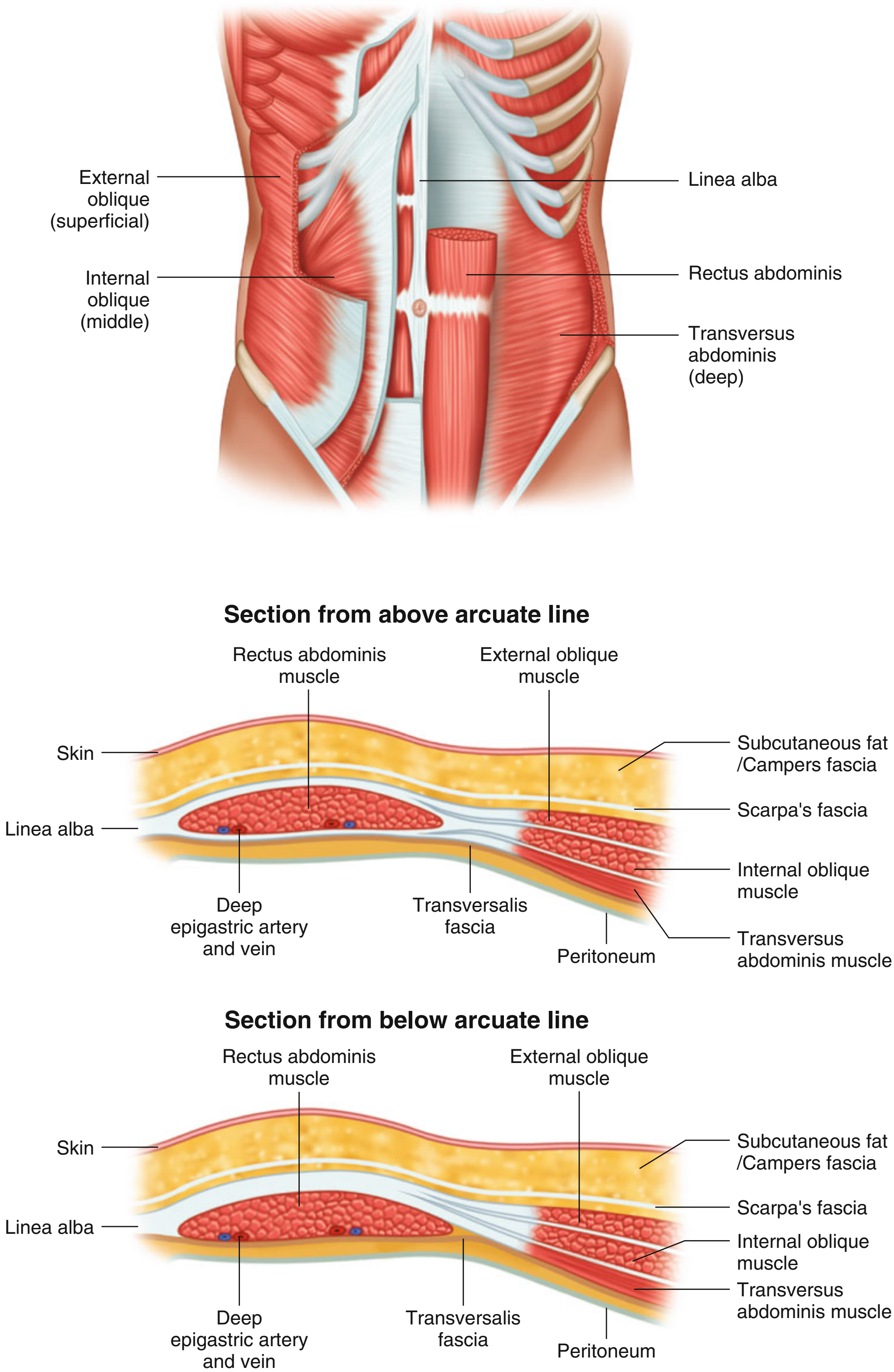


**Fig. 1.2** Muscles of the abdominal wall with the anterolateral group comprising the external and internal oblique along with the transversus abdominis extending medial to the linea semilunaris. The midline group is comprised of the rectus abdominis and pyramidalis muscles. Cross sections are illustrated above and below the arcuate line

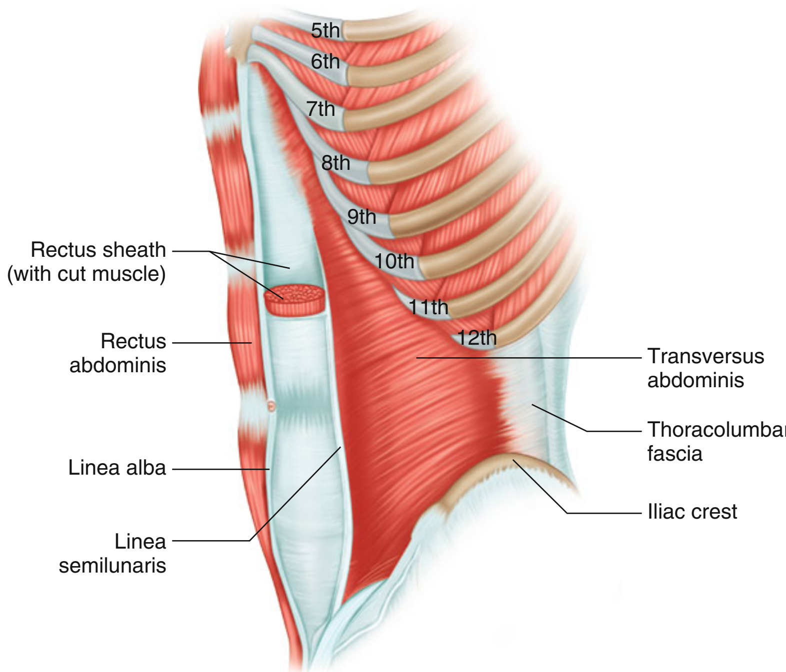


**Fig. 1.3** Transversus abdominis shown with relation to the rectus sheath, notably the fibers extend medial to the linea semilunaris superiorly with a more aponeurotic component inferiorly

xiphoid process to the pubis symphysis. The linea alba varies in width among the population but generally is accepted as being approximately 15–22 mm along its course, widest at or just above the umbilicus and narrowing at superior and inferior extremes [14, 15]. It is formed as the aponeurosis of the EOMs, IOMs, and TAMs merge terminally in the midline, thus bisecting the paired rectus abdominis muscles. Given its completely avascular nature, it is a preferred location for incision and intra-abdominal access. However, the completely fibrous nature of this structure with implied lack of muscular coverage leads to weakness and the formation of the majority of de novo ventral hernias [16]. Additionally, as most intra-abdominal access occurs via a midline laparotomy, the linea alba is the location of most iatrogenic hernias as well.

Ultimately, the goal of abdominal wall reconstruction remains to restore linea alba by bringing the paired rectus muscles back to the midline. For patients with massive hernias and loss of domain, this is accomplished with various myofascial or musculocutaneous advancement techniques. Once complete, restoration of linea alba has been shown to improve isokinetic and isometric function of the abdominal wall and ultimately quality of life [17]. In the modern era of abdominal wall reconstruction, this functional restoration is critical for not only a complete repair but one that maintains the integrity and actions of the whole abdominal wall unit.

## Rectus Abdominis

The rectus abdominus muscles (RA) are the predominant component of the midline group, flanking the linea alba on each side. Occurring as paired strap-like muscles, they are distinctly unlike the broad muscles of the anterolateral group. The recti originate from the pubic crest and ligamentous portion of the pubic symphysis, the fibers course superiorly to insert onto the xiphoid process and anterior surface of the 5th–7th costal cartilages bilaterally. The linea alba bisects the two recti, where the aponeuroses of the anterolateral group decussate and fuse to form the tendinous line. There also exist approximately 3–4 separate tendinous bands that occur at variable points along the rectus in a transverse manner. These bands are irregular in nature and do not necessarily occur along regular intervals, but function as transverse anchor points along the muscle body allowing for flexion of the trunk. A strong attachment of the rectus is found to the anterior rectus sheath with posterior sheath attachment occurring more variably [18].

Vascular supply to the rectus muscles is distinctly different from the anterolateral group, with blood supply originating from paired superior epigastric arteries (SEAs) and deep inferior epigastric arteries (DIEAs), which run along the deep surface of the rectus after perforating the posterior sheath. Anastomotic connection between these two systems is generally found just above the umbilical area. The SEA vessels originate as terminal branches of the internal mammary artery around the level of the sixth costal cartilage. The SEAs enter the rectus sheath at the midpoint of the xiphoid process. The DIEAs arise as branches from the external iliac arteries just proximal to their course through the femoral ring where the external iliac arteries become the femoral arteries. The DIEAs serve as the pedicles for perforator techniques such as the TRAM (transverse rectus abdominis myocutaneous) and DIEP (deep inferior epigastric perforator) flaps seen in plastic surgery. Innervation, unlike vascular supply, is similar to that of the anterolateral group with the ventral rami of T6/7–L1 traveling in the transversus abdominis plane (TAP) to perforate the rectus sheath laterally. Sacrifice of these neurovascular perforating bundles during surgery can lead to atrophy of the rectus complex and should be avoided whenever possible. Ultimately, preservation of the neurovascular supply leads to maintenance of native rectus function and thus a more robust and functional repair.

The rectus abdominis is responsible primarily for flexion of the abdominal wall as well as assistance with increasing intra-abdominal pressure. Flexion of the abdominal wall can be the movement of the ribcage toward the pelvis, the pelvis toward the rib cage or both if neither point of flexion is fixed. The increase in abdominal pressure has contributions to various bodily functions including exhalation, defecation, and micturition. While the rectus is not necessarily engaged in any significant capacity during normal effort, it comes into play when these functions are forceful.

Clinically, it is important to return the rectus muscles back to the midline to recreate linea alba in order to allow for restoration of function. Without the central anchor point in the linea alba, the forces exerted by both the rectus muscles and the lateral abdominal wall are unlikely to translate to physiologic action that constitutes a truly functional repair.

## Pyramidalis

The pyramidalis muscles are the second and most variable component of the midline group, with reported absence in 10–70% of the population on one or both sides [13]. The paired triangular muscles lie between the anterior surface of the rectus abdominis and associated anterior sheath caudal to the arcuate line. The fibers course superomedially, originating from the pubic crest and ligamentous portion of the pubic symphysis, inserting onto the linea alba. The function of the pyramidalis is not well understood, however it is thought to play a supplementary role in tensing the linea alba and increasing intra-abdominal pressure thus providing local compression of the bladder during micturition [12]. Given the variability in its occurrence in the population, the clinical significance of this muscle is essentially negligible.

## Transversus Abdominis Muscle

The innermost muscle in the anterolateral group is the TAM. It lies directly under (dorsal to) the IOM and above (ventral to) the transversalis fascia. The muscle fibers originate from the inner surfaces of the 7th–12th costal cartilages, anterior leaflet of the thoracolumbar fascia, iliac crest, and lateral third of the inguinal ligament. These fibers course medially from their posterolateral origins in a largely horizontal manner until they insert onto the linea alba, pubic crest, and pectineal line. Superiorly, the fibers interdigitate with those of the diaphragm and travel in a more superior-medial manner. Moving inferiorly, there is a significant aponeurotic component to the muscle, which occurs closer to the midline at the inferior extreme, though clinically there is significant variation to the extension of the fibers toward the recti.

Generally, around the level of the umbilicus the aponeurotic component begins lateral to the rectus abdominis muscle. Clinically, however it is not uncommon to encounter muscle fibers themselves medial to the linea semilunaris when performing transversus abdominis release after reincision of the ventral portion of the posterior rectus sheath. Travelling inferiorly (caudad) the aponeurotic component occurs further medially, past linea semilunaris until the arctuate line.

Crucially, a major distinction occurs in the aponeurotic component of the TAM above and below the arcuate line. Above the arcuate line of Douglas, the transversus abdominis aponeurosis merges with the posterior lamella of the internal oblique aponeurosis forming the posterior rectus sheath, which then continues its path medially as it contributes to the linea alba. Below the arcuate line, the aponeurosis of the transversus is responsible for merging with the internal oblique, as it passes anterior to the rectus complex with eventual formation of the conjoint tendon as it reaches the pubic tubercle.

Blood supply and innervation is shared amongst the anterolateral group with a significant overlap in contributions to the trilaminar structure. Posteriorly the vascular supply arises as mirrored contributions from the aorto-subclavian and aorto-iliac system superiorly and inferiorly, respectively. Intercostal and lumbar arteries arising laterally anastomose to form a network running deep to the transversus muscle surface. This network pierces the transversus laterally to then run in the so-called TAP plane, between the TAM and the IOM. Extensions of this posterior network travel medially along the TAP as parallel neurovascular bundles medially until they perforate the posterior lamina of the internal oblique aponeurosis to innervate the rectus (Fig. 1.4). The vascular network arising posteriorly forms anastomotic connections with the anterior vascular supply, which is derived from descending branches of the intercostal and subcostal arteries. Medially, the SEAs and inferior epigastric arteries, which supply the rectus, also provide anastomotic connections to the posterolateral system creating a dense network with extensive collateralization.

Innervation to the TAM is also shared amongst the trilaminar group with nerves that arise from the ventral rami of T6/7–L1; traveling in parallel to the vascular supply in the TAP. During retrorectus ventral hernia repair, it is important to identify and spare these neurovascular branches as they perforate the posterior lamella of the internal oblique fascia and enter the rectus muscle. When the neurovascular bundles are encountered, dissection

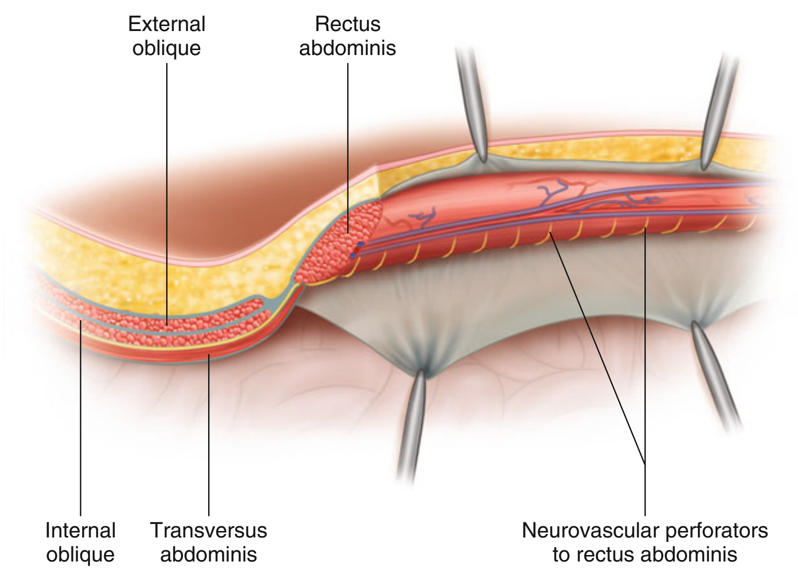


**Fig. 1.4** Cross section of the anterior abdominal wall with posterior rectus sheath dissected away from the rectus abdominis revealing the perforating neurovascular bundles which pierce the posterior lamina of the internal oblique

should occur medial to the location of perforation to allow continued supply to the rectus abdominis, thus preventing atrophy. Although retrorectus dissection is traditionally thought of as limited by the linea semilunaris, in reality, it is just medial to this perimeter, as defined by the perforating vessels. These vessels may be dissected off the posterior sheath to be kept with the overlying muscle. If the neurovascular bundles are transected inadvertently and dissection is carried laterally past this threshold, one may find themselves transitioning from the posterior rectus sheath to the anterior one given enough tension.

TAM has significant functional role in the abdominal wall. Its main function occurs in concert with the internal oblique, acting as a “corset” around the visceral sac. The circumferential “hoop tension” created by this action is mainly through the synergistic action of the transversus and the posterior fibers of the IOMs [6]. The contraction not only provides rigidity to the anterior abdominal wall, it also serves to produce tension throughout the thoracolumbar fascia. The transversus exerts force primarily on the anterior (most ventrally positioned) leaflet of the thoracolumbar fascia. This occurs in concert with the quadratus lumborum on the middle leaflet and the sacrospinalis muscles on the posterior leaflet. This fascial tension serves to provide posterior support to the visceral sac and retroperitoneal organs as well as stabilization of the lumbosacral spine and pelvis with effects on posture.

## Internal Oblique Muscle

IOM lies interleaved between the other components of the anterolateral group, above (ventral to) the TAM and just underneath (dorsal to) the EOM. It originates from the anterior leaflet of the thoracolumbar fascia, anterior two-thirds of the iliac crest, and lateral half of the inguinal ligament. Its fibers course in a superomedial manner to insert along the inferior border of ribs 10–12 as well as the linea alba. Just superior to the inguinal ligament, the lower most fibers of the internal oblique arch around the spermatic cord to give rise to the cremasteric fibers of the scrotum. In females, these fibers are attenuated and arch around the round ligament. Additionally, the aponeurotic component inferiorly merges with that of the transversus to insert onto the pectineal line as the conjoint tendon. The aponeurotic component of internal oblique also carries a crucial distinction occurring above and below the arcuate line similar to that of the transversus abdominis. Above the arcuate line, the aponeurosis splits to form two lamellae that encompass the rectus abdominis muscle, contributing to both the anterior and posterior sheaths. Inferior to the arcuate line however, the aponeurosis is only found above the rectus muscle where it fuses with that of the external oblique and TAM to contribute to the anterior sheath. Inferiorly, the posterior aspect of the rectus is only covered by the transversalis fascia (Fig. 1.5).

Neurovascular supply of the internal oblique is largely identical to that described for the transversus with posterior contributions traveling in the TAP and medial contributions from intercostal, subcostal, and epigastric arteries. As mentioned previously, the vessels of the posterolateral network perforate the posterior lamella of the internal oblique rather than the merged transversus and internal oblique sheaths. This anatomic distinction is crucial with attention given to ensure dissection occurs medial to the perforators during retrorectus plane development. Distinct to the internal oblique, the ilioinguinal and a branch of iliohypogastric nerve both pierce the muscle as they travel to their destinations. The ilioinguinal nerve perforates medially to travel with the spermatic cord as it traverses the inguinal canal. Laterally, the anterior cutaneous branch of the iliohypogastric, which travels in the TAP, transitions to a location between the internal and external oblique at the level of the anterior superior iliac spine (ASIS) on its way to the rectus muscle.

Functionally, the internal oblique serves a number of roles. As stated previously, it has a synergistic relationship with TAM, assisting with creation of circumferential hoop tension for the abdomen. It also works in tandem with the external oblique on the contralateral side to create ipsilateral rotation and torsion of the trunk.

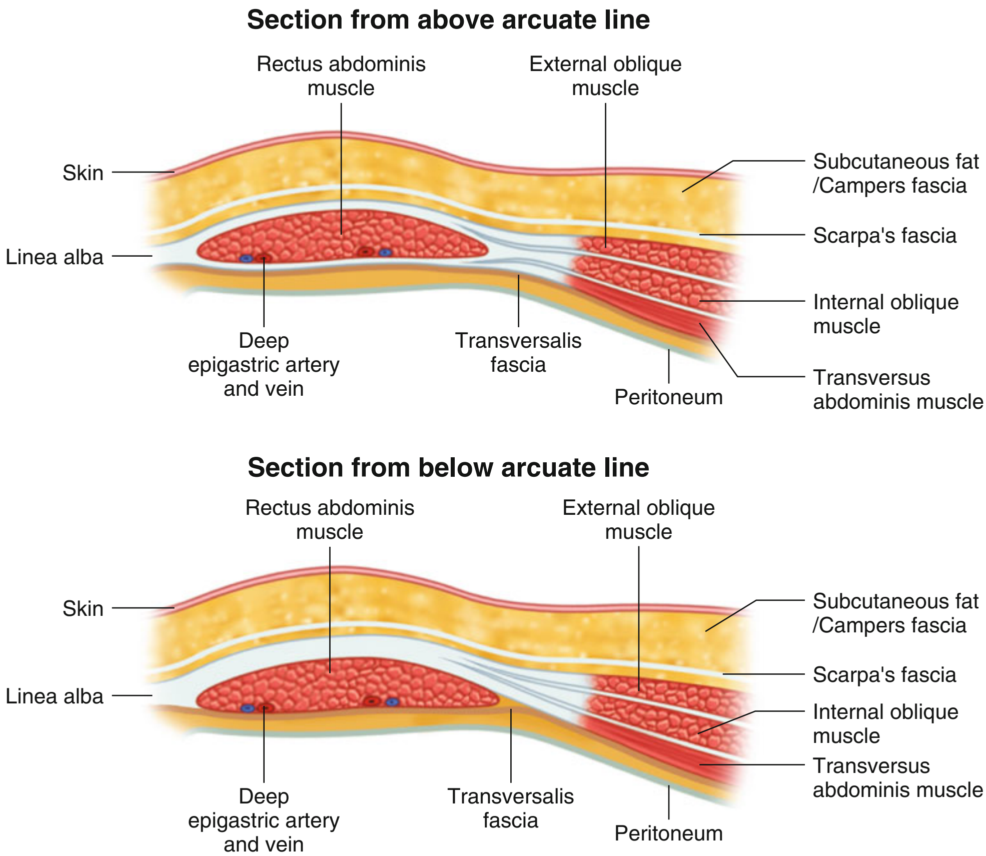


**Fig. 1.5** Sections of the abdominal wall from above and below the arcuate line, importantly the posterior layer below the arcuate line consists only of the transversalis fascia

Lumbosacral stabilization occurs as a result of tension in the thoracolumbar fascia, once again a concerted effort from the IOM and TAM, although proportionally it is more so from the latter. Finally, the contraction of the IOM opposes that of the diaphragm assisting with exhalation by increasing intra-abdominal pressure.

Clinically, the fibers of internal oblique are seldom manipulated given their location between the external oblique and transversus abdominis. However, as mentioned previously, above the arcuate line the aponeurosis splits to form two lamellae encompassing the rectus muscles. The posterior lamella which merges with the transversus aponeurosis to form the posterior sheath is the location of the second incision made, albeit on the ventral aspect as one transitions from retrorectus dissection to posterior component separation. While the two aponeuroses do eventually merge without distinction medially as they contribute to the linea alba, the area covering the lateral portion of the rectus abdominis muscle medial to linea semilunaris still occurs as two distinct fascial planes. This is again dependent on the degree to which the transversus fibers course medially past the lateral edge of the rectus. This variability is important to recognize during posterior component separation because if dissection is not carefully done to separate the two layers, whether fascia from fascia or fascia from muscle fiber, fenestrations are created in the posterior sheath which subsequently need to be repaired to exclude the viscera from mesh placed as a sublay.

## External Oblique

The EOM is the most superficial of the anterolateral group of muscles, located directly on top of the IOM. Originating from the external surface of the 5th–12th ribs, the muscle fibers course inferomedially to insert along the linea alba, the pubic tubercle, and anteriorly along the iliac crest. The linea semilunaris is ultimately formed by the aponeurotic component of the muscle as it passes vertically downward from the ninth costal cartilage to the pubic tubercle along with the merger of the internal oblique and transversus abdominis aponeuroses lateral to the rectus abdominis muscles. The aponeurotic component of the EOM itself contributes heavily to the anterior rectus sheath along with the anterior lamella of the IOM above the arcuate line. Below this line, the transversus aponeurosis merges as well, leaving only the transversalis fascia and peritoneum between the rectus and the viscera. Inferior to the level of the ASIS, the muscle is completely aponeurotic in nature. This portion has clinical significance as it gives rise to the inguinal ligament between the ASIS and the pubic tubercle. A small triangular aperture approximately 1–1.5 cm superior and lateral to the pubic tubercle occurs as the superficial inguinal ring, allowing passage of the spermatic cord in males and round ligament in females. The external oblique aponeurosis also forms the regionally termed lacunar ligament as it inserts on the pectineal line as well as the reflected portion of the inguinal ligament termed the shelving edge.

Vascular supply of the EOM originates from the lower 6 or 7 intercostal arteries cranially and deep muscular branches of the deep circumflex iliac arteries caudally. Again, vascular arcades form with the deep epigastric system supplying the rectus abdominis. Innervation arises from the ventral rami of T7–T12 and L1 as with the remainder of the anterolateral group.

The EOM functions in conjunction with the remaining anterolateral group to provide compression for the visceral sac as well assisting with flexion and rotation of the trunk. By contracting the chest wall toward the abdomen, it is primarily responsible for lateral flexion as well as contralateral rotation. The EOM is distinct in that it does not function in tandem with the TAM to nearly the degree of the IOM in creating circumferential tension.

Traditional anterior component separation, as originally described by Ramirez [3, 19], involves the release of the EOM. Although there is morbidity associated with raising cutaneous flaps, this remains a widely used technique for myofascial advancement [5, 20]. Ultimately, while release of the EOM does reduce some circumferential tension, the TAM remains the primary contributor to generation of this force.

## Arcuate Line

The arcuate line of Douglas or linea semicircularis is a critical landmark in abdominal wall anatomy which carries with it a number of clinical pearls. Located halfway between the umbilicus and pubic symphysis, the arcuate line represents the lower limit of the posterior rectus sheath. Inferior to this landmark, the posterior lamina of the internal oblique aponeurosis and that of the transversus pass anterior to the rectus muscle. While the arcuate line is generally regarded as a sharp cutoff to the posterior rectus sheath, in actuality it may occur as a much more gradual shift of the posterior sheath fibers toward the anterior sheath in a majority of the population [21]. Below the arcuate line only the transversalis fascia remains between the rectus abdominis and peritoneum, representing a layer with minimal strength (Fig. 1.5). Here, both Spigelian and exceedingly rare arcuate line hernias may occur [22]. Finally, the arcuate line also serves as a landmark where the inferior epigastric vessels perforate the rectus abdominis; care must be taken to identify these vessels while performing the retrorectus dissection. The arcuate line must be incised at its lateral-most point in order to enter the space of Retzius and Bogros from within the rectus sheath to carry out the caudal portion of the dissection during retrorectus repair and transversus abdominis release.

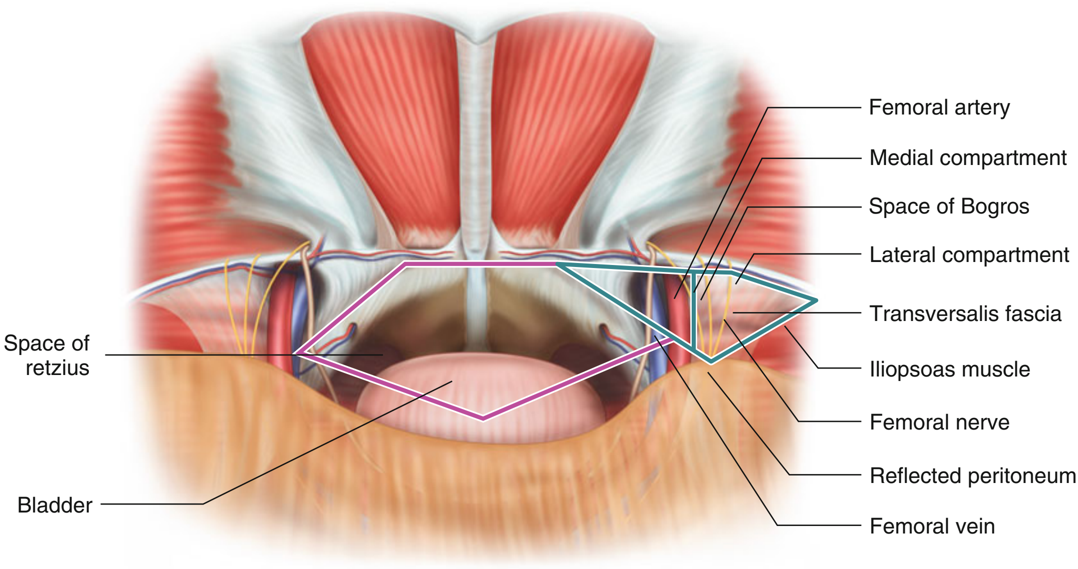


**Fig. 1.6** Space of Retzius (*purple*) and Space of Bogros (*teal*) which is split into medial and lateral compartments with passing anatomic structures

## Extraperitoneal Spaces

The space of Retzius is defined as the extraperitoneal space between the pubic symphysis and the bladder. This area is separated from the abdominal wall by the transversalis fascia and contains loose connective tissue and fat. Additionally, it may contain normal or aberrant variants of obturator vessels along with accessory pudendal vessels in 10% of patients. Appropriate dissection of this space is critical for the visualization of the pectineal ligament used for inferior mesh fixation in ventral and inguinal hernia repair (Fig. 1.6).

The space of Bogros is a similarly extraperitoneal space lying laterally to the space of Retzius and deep to the inguinal ligament. It is bound anteriorly by the transversalis fascia and posteriorly by the peritoneum. The space can be split into medial and lateral compartments with the medial compartment housing the femoral artery and vein while the lateral component allowing passage of the iliopsoas muscle and femoral nerve (Fig. 1.6).

## Vascular Supply

The blood supply to the abdominal wall was previously described in a regional manner by Huger, consisting of three anatomically distinct zones [23] (Fig. 1.7). Zone I refers to the upper anterior midline of the abdominal wall with the SEAs and DIEAs as they supply the rectus abdominis and overlying subcutaneous tissue and skin. Zone II comprises the entirety of the caudal portion of the anterior abdominal wall. The blood supply in this region arises from four main arterial conduits with contributions from the femoral and iliac arteries. The superficial inferior epigastric and superficial external pudendal arteries originate from the femoral artery to supply the superficial fascia and skin in this area. The DIEAs and deep circumflex iliac arteries supply the musculature in this lower area. Zone III is located laterally past linea semilunaris with lumbar and intercostal arteries which arise from the aortic system. These arcades supply the lateral abdominal wall and eventually anastomose with the midline vascular structures.

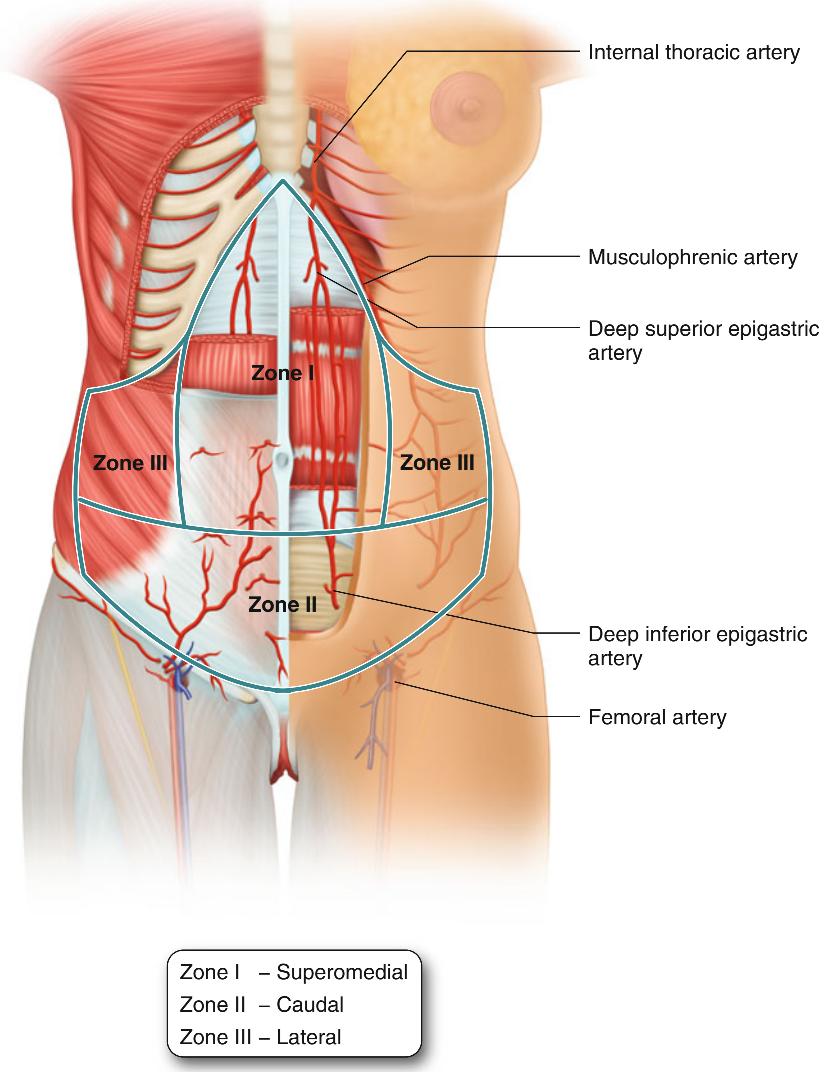


**Fig. 1.7** Vascular supply to the abdominal wall with delineated Huger Zones I–III

## Nerve Supply

As described before, the innervation to the abdominal wall is primarily derived from the ventral rami of T6/7–T12 and L1. Sensory innervation occurs from anterior branches of intercostal and subcostal nerves from the aforementioned spinal levels. Levels T6–9 are responsible for innervation of the area above the umbilicus while T10 innervates the umbilicus itself. The remainder including T11–L1 is responsible for the area below the umbilicus. Innervation to the overlying skin of the lateral abdominal wall arises as direct branches from the intercostal nerves. Motor innervation to the trilaminar and midline groups is provided by the intercostal branches as above along with named contributions from L1 as the

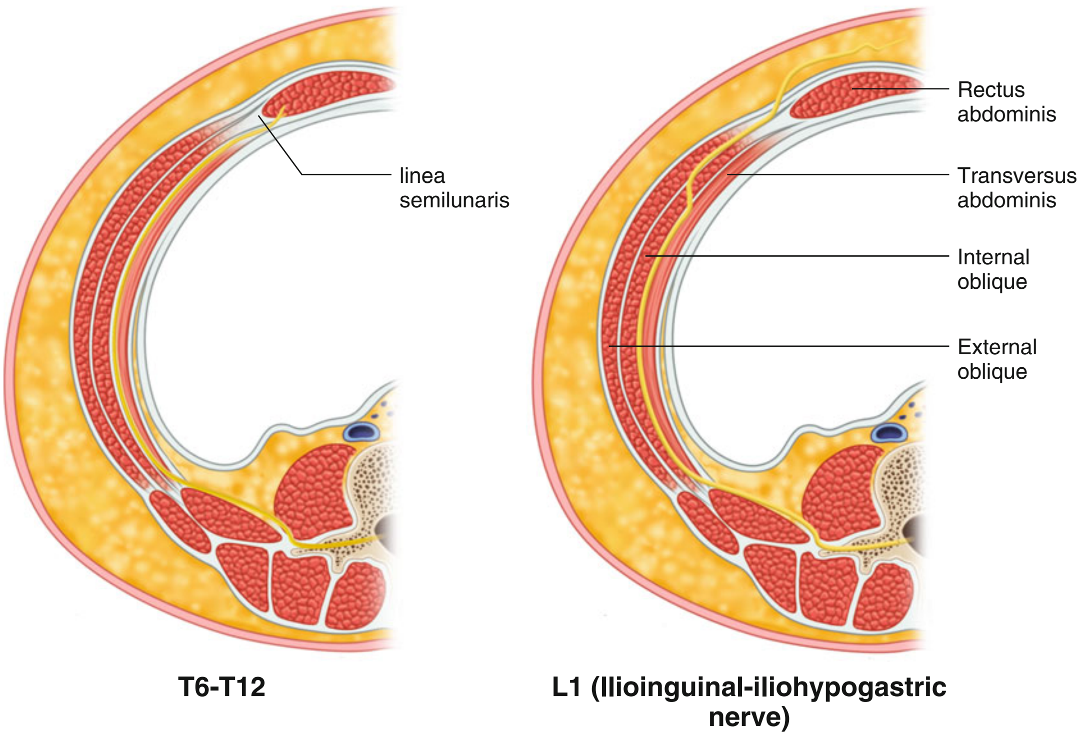


**Fig. 1.8** Nerves supplying the anterior abdominal wall traveling in the transversus abdominis plane (TAP). T6–T12 perforate the posterior lamina of the internal oblique fascia to supply the rectus abdominis. L1 perforates laterally to supply the skin and subcutaneous tissue of the lower abdomen

ilioinguinal and iliohypogastric nerves. The latter pair of nerves has isolated contributions to the IOMs and transversus muscles.

The lateral neurovascular structures travel in the TAP between the TAM and IOM (Fig 1.8). The so-called TAP block has gained favor in the surgical world as an adjunct for post-operative analgesia. Delivery of local anesthetic into this plane provides blockade to the sensory nerves that innervate the anterolateral group with reported improvements in post-operative pain scores, opioid use, and hospital stay [24–27].

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