5 Normal Radiographic Anatomy of Anterior Abdominal Wall

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Introduction:

Anatomy of Anterior Abdominal Wall

Muscle Layers

While it may appear simple at first glance, the abdominal wall is anatomically complex and layered with intertwined layers of innervation and blood supply. The abdominal wall is of mesodermal origin and develops as two sheets migrate toward each other. These sheets both originate in the paravertebral region and envelop what will become the future abdomen. The leading edges of both of these sheaths eventually develop into the rectus abdominis muscles after they meet at the anterior midline. The rectus abdominis is encased by an aponeurotic sheath which allows the two sheets to fuse in the anterior midline, also referred to as the *linea Alba* (Fig. 5.1). The rectus muscles have several insertion points including the pubic bones inferiorly and the 5th, 6th ribs, 7th costal cartilages, and the xiphoid process superior. The lateral border of the rectus abdominis is known as the *linea semilunaris* (Fig. 5.2).

The pyramidalis muscle, a highly variable group of muscles comprising the lower midline muscle group, is reported to be present in only 10–70% of the population [1]. The fibers of this inconsistent muscle typically course superomedially with the inferior origin at the pubic symphysis and the superior attachment onto the linea Alba.

The muscle layers that run lateral to the rectus abdominus muscle include the external oblique, internal oblique, and transversus abdominis (Fig. 5.3). These muscle layers are derived from the mesoderm and start to form during the 6th and 7th weeks of fetal development. The external oblique muscle (EOM) runs superficial to the serratus anterior in the superior margins and superficial to the internal oblique and the latissimus dorsi muscles more inferiorly. Its origins include the 5th to 12th ribs and insert unto the linea Alba, pubic tubercle**,** and anteriorly to the iliac crest while coursing in an inferomedial orientation. The inguinal ligament is the inferior edge of the external oblique aponeurosis.

The internal oblique muscle (IOM) runs deep to the external oblique and superficial to the transversus abdominis muscle (TAM). The IOM originates from the thoracolumbar fascia, iliac crest, and inguinal ligament and inserts along the inferior border to ribs 10–12 and the linea Alba. Its fibers course in a superior-medial orientation. The lower medial and inferior portion of the internal oblique fuses with the transversus abdominis aponeurosis to form the conjoint ten-

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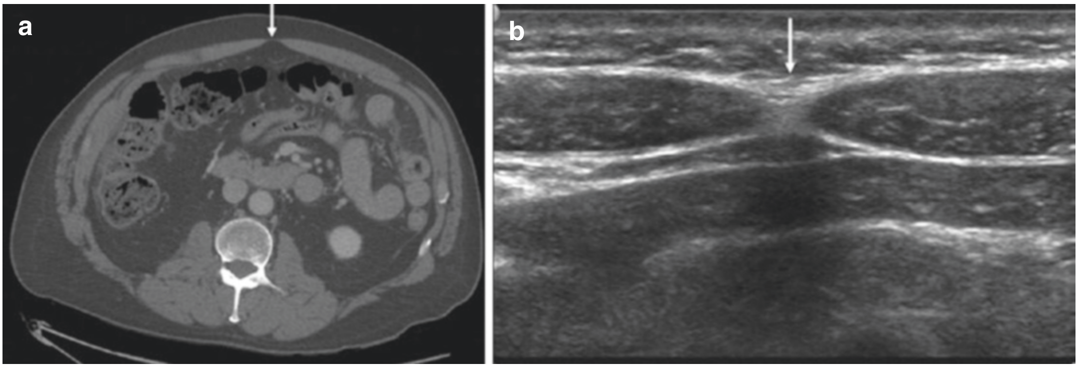

Fig. 5.1 (**a**) Computer tomography cross-sectional (axial) image with white arrow pointing to linea alba. (**b**) Coronal ultrasound of abdomen with white arrow pointing to linea alba

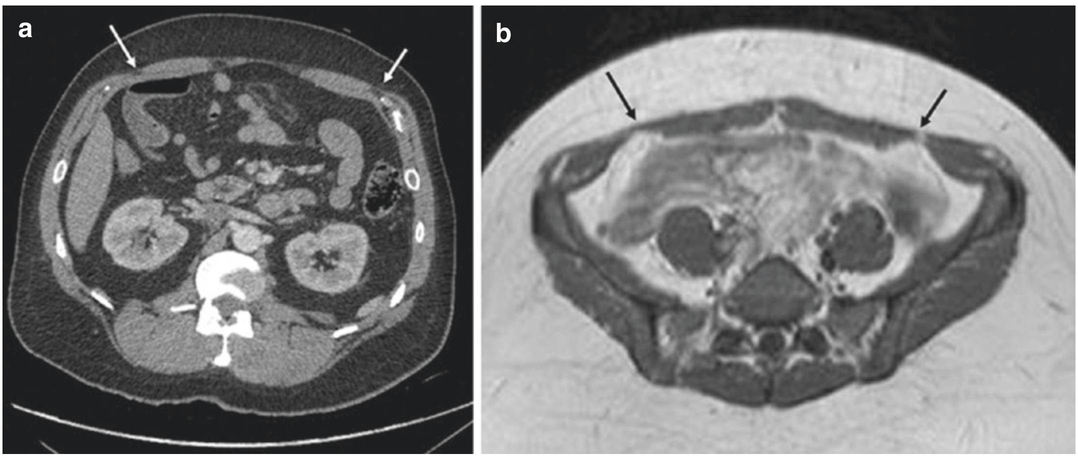

Fig. 5.2 (**a**) Computer tomography cross-sectional (axial) image with white arrow pointing to linea semilunaris on both sides. (**b**) Cross-section MRI image of abdomen with black arrows pointing to the linea semilunaris on both sides

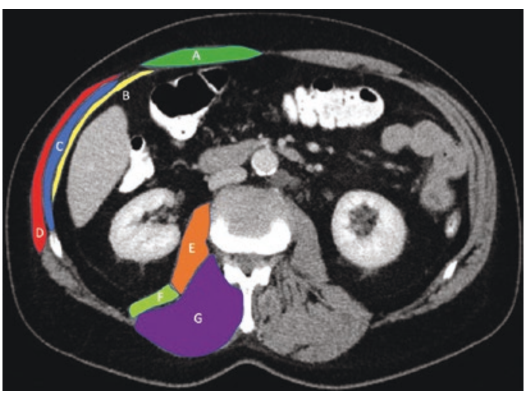

Fig. 5.3 Anatomy of the musculature of the abdominal wall. (A) Rectum abdominis, (B) Transversus abdominis, (C) Internal oblique muscle, (D) External oblique muscle, (E) Psoas major, (F) Quadratus lumborum, (G) Sacrospinalis

don. Furthermore, the internal oblique muscle layers are continuous with the cremasteric muscle fibers of the inguinal canal.

The transversus abdominis muscle is the deepest of the three muscle layers and runs in a horizontal fashion ventral to the transversalis fascia and dorsal to the IOM. The origin of the muscle is from the 7th to 12th costal cartilages, thoracolumbar fascia, iliac crest, and lateral aspect of the inguinal ligament and inserts onto the linea alba, pubic crest, and the pectineal line. The superior aspect of the muscle meets with the diaphragm.

The arcuate line is a key anatomic landmark, typically found at the level of the anterior superior iliac spine (ASIS). Above the arcuate line, the anterior rectus sheath is formed by the aponeurosis of

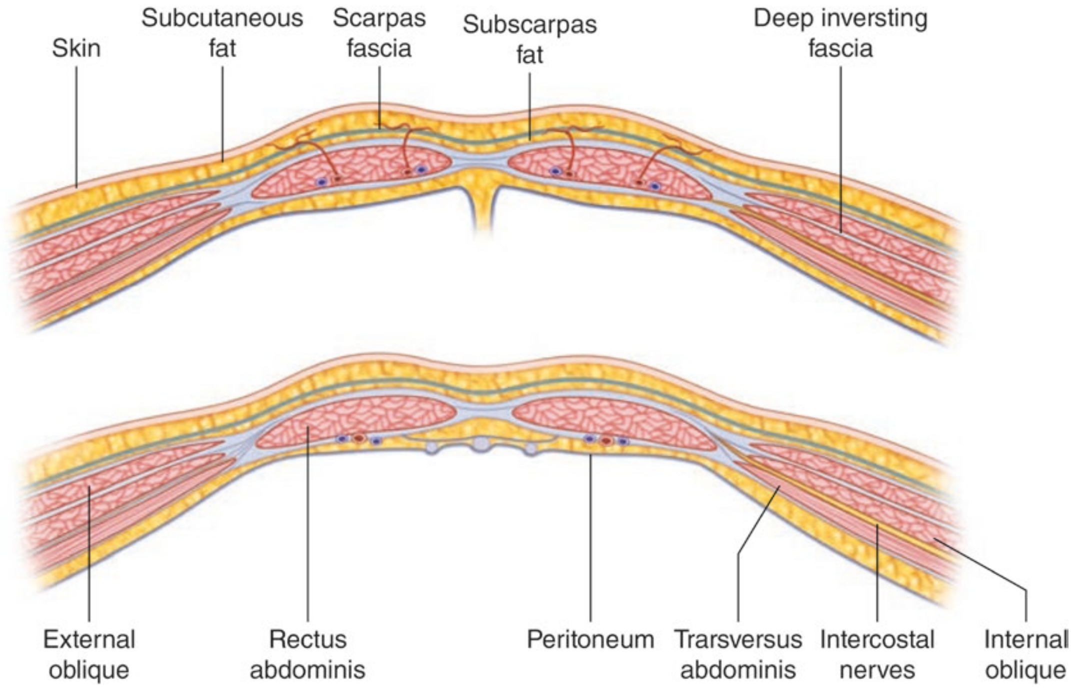

Fig. 5.4 Anatomy of abdominal wall above (top) and below (bottom) arcuate line

Modified from "Hernia Surgery: Current Principles, Yuri Novitsky, Fig. 28.1 page 300"

the external oblique and the internal oblique muscles while the posterior rectus sheath is formed by the aponeurosis of the internal oblique and the transversus abdominis aponeurosis. Below the arcuate line however only the anterior rectus sheath is present, and it is comprised of the aponeurosis of the external oblique, internal oblique, and transversus abdominis muscles. Only the transversalis fascia is present posterior to the rectus abdominus muslce below the arcuate line (Fig. 5.4).

Blood Supply

The two main arteries supplying the anterior abdominal wall include the superior and inferior epigastric arteries. The superior epigastric artery originates from the internal mammary (thoracic) artery while the inferior epigastric artery originates from the external iliac artery. In addition to those two major arteries, the abdominal wall is also supplied by an extensive network of collateral branches of the subcostal and lumbar arteries. The blood supply of the abdominal wall can be divided into three main zones, as was previously described by Huger et al. *Zone 1* is defined as the vascular region of the upper anterior midline region of the abdominal wall which is mainly perfused by the superior epigastric artery and the deep inferior epigastric artery. *Zone 2* is defined as the blood supply to the caudal portion of the anterior abdominal wall which is accomplished by four main arteries including the superficial inferior epigastric, superficial external pudendal, deep inferior epigastric artery, and the deep circumflex iliac artery. Lastly, *Zone 3* is the vascular region of the lateral abdominal wall which is mainly supplied by the lumbar and intercostal arteries which arise directly from the aorta (Fig. 5.5).

Nerves

The innervation of the abdominal wall is segmental and divided into motor and sensory innervation. The motor fibers supplying the rectus abdominis, external oblique, internal oblique, and transversus abdominis originate from the anterior rami of spinal nerves from the T6 to T12 levels. The cutaneous sensory innervation is provided by the afferent fibers from the T4 to L9

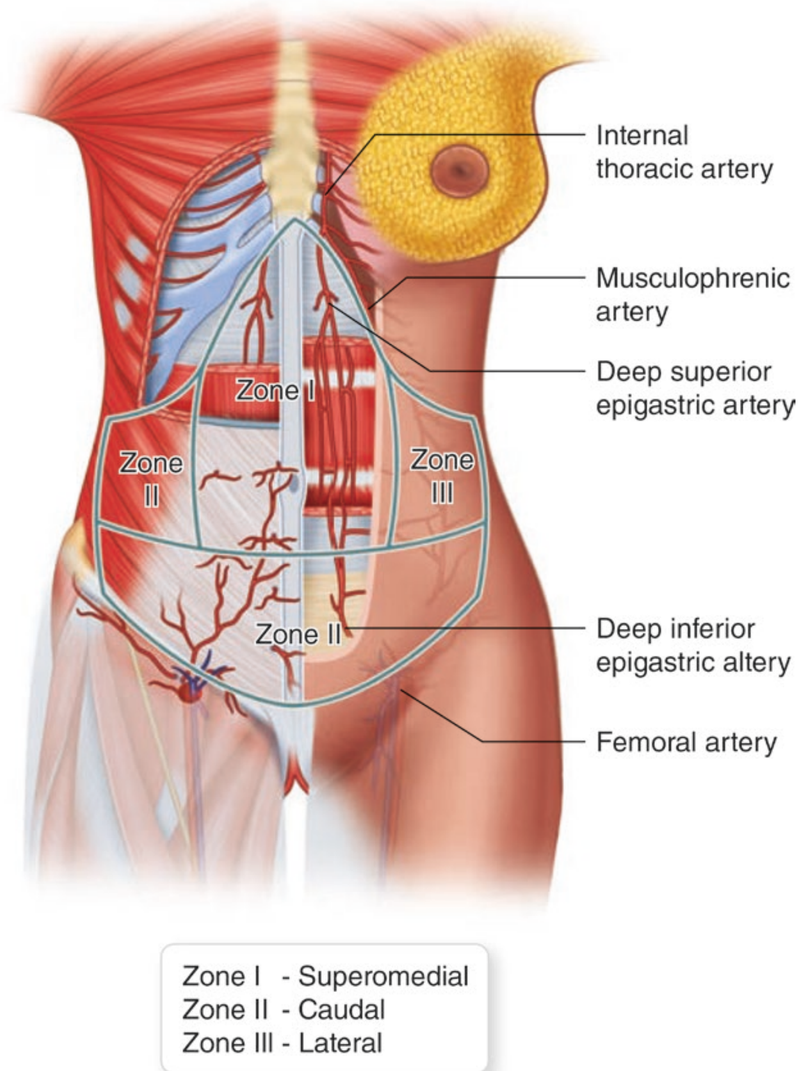

Fig. 5.5 Zones of the vascular supply of the abdominal wall **Modified from "Hernia Surgery: Current Principles, Yuri Novitsky, Fig. 1.7 page 11"**

nerve roots to the levels above the umbilicus. T10 provides sensory periumbilical innervation. The area below the umbilicus is innervated by the T11 to L1 nerve roots. The skin is directly innervated by branches of the intercostal nerves. The lateral neurovascular structures travel between the transversus abdominis muscle and the internal oblique muscle. This is important to consider when performing a transversus abdominis plane (TAP) block (Fig. 5.6).

Lymphatics

The anterior abdominal wall has two major lymphatic drainage systems: the superficial and deep. The superficial system drains the skin and the subcutaneous tissues, and the deep system drains the musculature and bones.

The superficial lymphatic system can essentially be divided by a horizontal line through the umbilicus. Above the umbilicus, the skins and subcutaneous tissue space drain into the pectoral

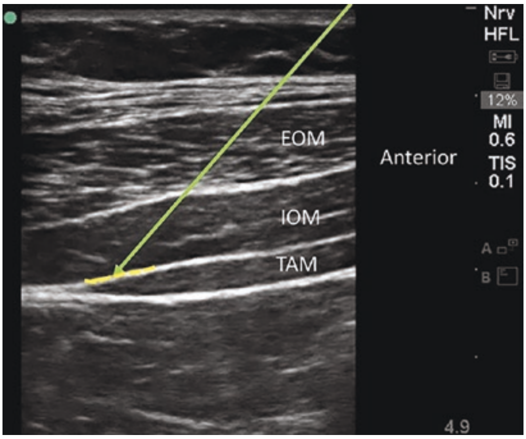

Fig. 5.6 Transversus abdominis plane (TAP) block is performed by injecting analgesic between the transverses abdominis muscle (TAM) and the internal oblique muscle (IOM) muscle layers. EOM—external oblique muscle. Vishal Uppal, Sushil Sancheti & Hari Kalagara. Current Anesthesiology Reports. Current Anesthesiology Reports. Springer Nature. 2019

axillary lymph nodes while some drain into the parasternal lymph nodes. Below the umbilicus, the superficial structures primarily drain into the superficial inguinal lymph nodes.

The deep system, on the other hand, drains into three main lymph node basins. The pathway following the superior epigastric artery drains into the parasternal nodes. The inferior epigastric artery pathway drains into the external iliac lymph nodes. Lastly, the inferior intercostal and subcostal pathways drain into the mediastinal lymph nodes (Fig. 5.7).

Physiology

The muscles of the anterior abdominal wall work as a cohesive unit to provide functionality to the abdominal wall. Anterior and lateral flexion is accomplished by the rectus muscle and the internal and external oblique muscles. Similarly, the

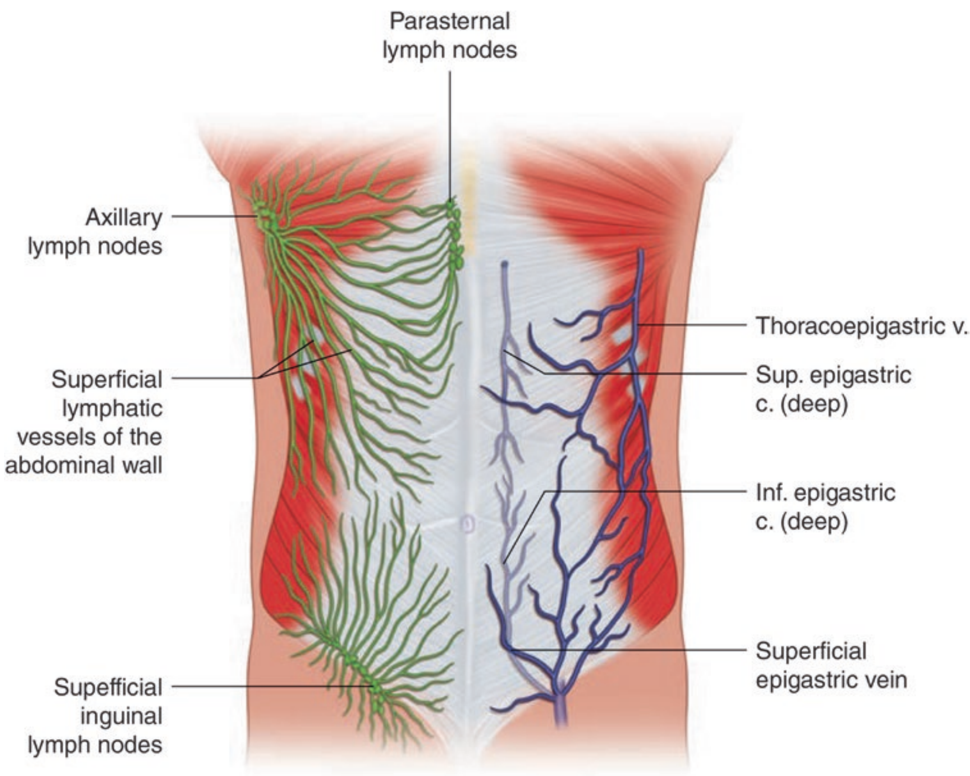

Fig. 5.7 Lymphatic drainage of the anterior abdominal wall. Green color shows the drainage of the superficial lymphatic system and blue color corresponds to the deep lymphatic drainage system

Modified from "Springer Cosmetic Surgery—https://link.springer.com/chapter/10.1007/978-3-642-21837-8_4" truncal muscles function as a unit to increase intra-abdominal pressure, such as during a Valsalva maneuver or during forced expiration.

The rectus abdominis muscle's primary function is to allow for flexion of the torso. Secondarily, it assists in increasing intra-abdominal pressure. The pyramidalis muscle also has a small role in helping to tense the linea alba; however, its contribution is likely minimal [2]. The lateral muscles function as a unit. The EOM muscle assists in flexion and rotation of the trunk and functions to contract the abdominal wall to support the visceral contents and confine them in the abdominal cavity. Both the IOM and the TAM function in a synergistic fashion to provide circumferential tension on the abdomen and along with the EOM, function to allow rotation and torsion of the abdominal trunk.

Important Anatomical Regions

Space of Bogros and Space of Retzius

The space of Retzius is in the extraperitoneal space between the bladder and the pubic symphysis. The space is enclosed by the transversalis fascia and contains connective tissue and fat. The region may also contain aberrant pudendal and obturator vessels. Furthermore, adequate dissection of this space may be necessary for appropriate placement of mesh in inguinal and ventral hernia repairs. The space of Bogros is another important region that lies lateral to the space of Retzius and is the extraperitoneal space containing structures deep to the inguinal ligament. The space contains several important structures including the femoral vessels and the femoral nerve as well as iliopsoas muscle.

Important Anatomical Triangles and Landmarks

Certain anatomical regions are important to consider during operative interventions as they may lead to complications and comorbidities that can be easily avoided if the anatomy is appreciated. "Hesselbach's Triangle" is located in the lower portion of the posterior abdominal wall. Its boundaries include the lateral border of the rectus abdominis medially, the epigastric vessels superiorly, and the

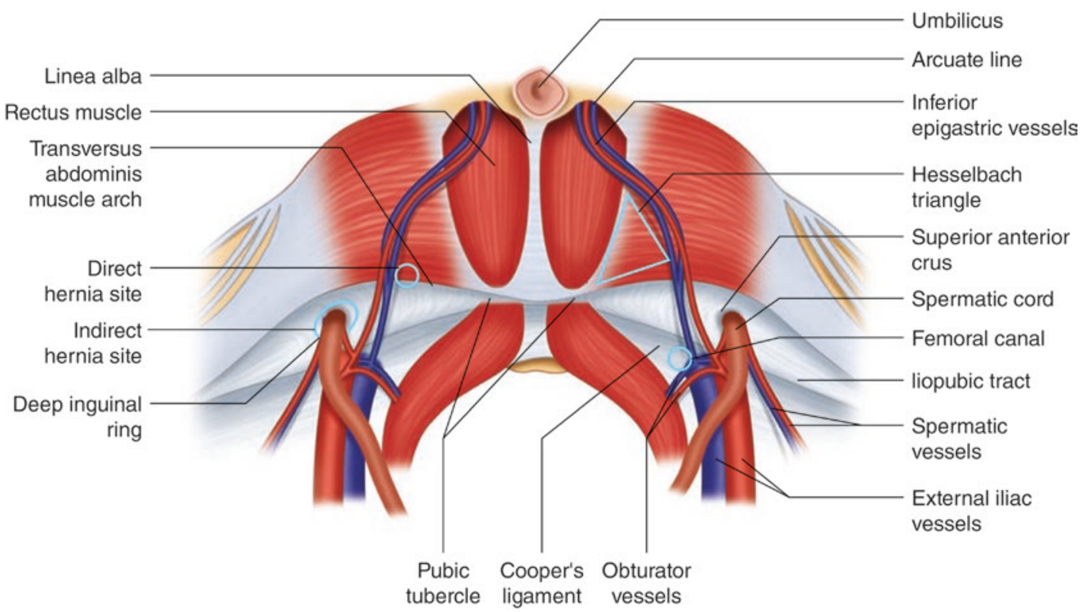

Fig. 5.8 Critical view of the myopectineal orifice Modified from Springer—Betancourt A., Pena A., Lo Menzo E. (2020) Laparoscopic Total Extraperitoneal (TEP) Inguinal Hernia Repair. In: Rosenthal R., Rosales A., Lo Menzo E., Dip F. (eds) Mental Conditioning to Perform Common Operations in General Surgery Training. Springer, Cham. https://doi.org/10.1007/978-3-319-91164-9_38)

inguinal ligament inferiorly. This region is important as it is the region of occurrence of direct inguinal hernias through the external inguinal ring. An indirect hernia, on the other hand, occurs lateral to "Hesselbach's Triangle" (Fig. 5.8).

The "*Triangle of Doom"* is one such region that has crucial vasculature and if tacks or staples are placed in that region, then there is a higher risk for excessive bleeding. The apex of the triangle is the deep inguinal ring. Lateral boundaries are the gonadal vessels and the medial boundary is the vas deferens in a male patient or the round ligament in a female. The two main vascular structures coursing in this triangle include the external iliac artery and vein (Fig. 5.9).

The " *Triangle of Pain"* is another important region to consider during laparoscopic hernia operation given the potential to cause nerve damage. As in the case of the "Triangle of Doom," the deep inguinal ring is the apex of the triangle. Anteriorly, the space is bound by the iliopubic tract and posterior-medially by the testicular vessels. The three crucial nerves that course in this region include the lateral femoral cutaneous nerve (L2-L3), femoral nerve (L2-L4), and the femoral branch of the genitofemoral nerve (L1-L2) (Fig. 5.9).

Critical View of Myopectineal Orifice

The critical view of the myopectineal orifice is defined as the area that must be visualized for the safe placement of a laparoscopic/robotic mesh. The concept has been developed by Daes et al. to standardize the steps of the exposure to minimize complications with laparoscopic inguinal hernia repair consisting of nine critical steps [3]. The first step involves the identification and dissec-

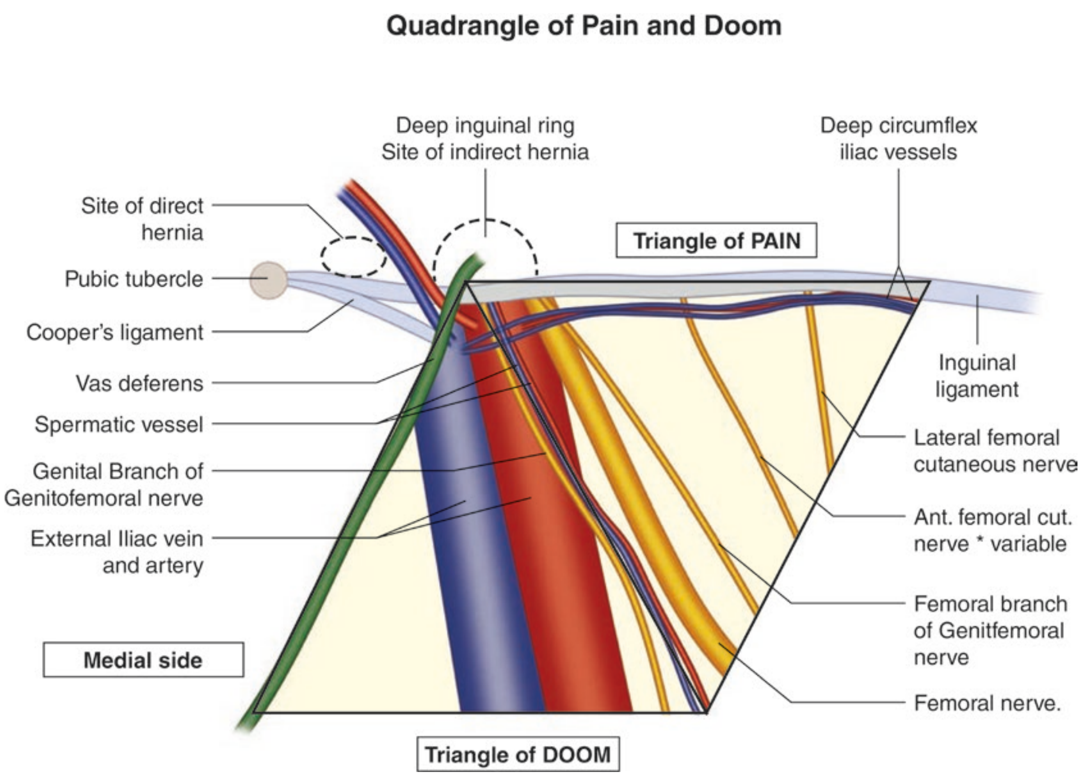

Fig. 5.9 Pre-peritoneal view of the right inguinal space demonstrating "Triangle of Doom" and "Triangle of Pain" Modified from Springer—Maker V.K., Guzman-Arrieta E.D. (2015) Abdominal Wall and Hernias. In: Cognitive Pearls in General Surgery. Springer, New York, NY. https://doi.org/10.1007/978-1-4939-1850-8_8

tion of the pubic tubercle and Cooper ligament. The second step involves dissecting Hesselbach's triangle and removing unusual fat in the area to rule out a direct hernia. The third step involves dissecting at least 2 cm between the Cooper ligament and the bladder to ensure enough medial and inferior space for the mesh to be placed. Next is to dissect the femoral space between the Cooper ligament and the iliac vessels to rule out a femoral hernia. The fifth step is to dissect the indirect sac and peritoneum such that the cord structure lies flat. Step 6 discusses cord lipomas and ensures that they are reduced appropriately and remain outside of the mesh. The seventh step discusses the lateral dissection and ensuring lateral dissection of the peritoneum beyond the cord structures and anterior superior iliac spine (ASIS). The eighth step ensures that the mesh is placed appropriately covering all the defects and that it is fixed above the inter-ASIS line. Lastly, step nine is the final placement of fixation of the mesh after the previous steps have been completed with adequate hemostasis ensuring that the mesh is flat and not rolling up (Fig. 5.8).

Imaging

Overview

Imaging of the abdominal wall is crucial for visualization of both the pathology and the patients' native anatomy, key aspects which need to be considered during surgical planning. Imaging can be as important as a physical exam and patient history and offer vital information regarding previous surgical procedures or mesh placement. The three main modalities that we will focus on include ultrasound, computed tomography, and magnetic resonance imaging in delineating the abdominal wall.

Ultrasound

Background

The quality of ultrasonography has drastically improved with the introduction of high frequency and high-resolution probes allowing it to become an essential tool in the evaluation of abdominal wall hernias. Ultrasonography has several important advantages over CT and MRI in that it is readily available, cheap, and has negligible radiation exposure. On the other hand, the quality of the sonographic imaging is highly dependable on the sonographer which permits significant variability in image quality. Furthermore, an obese body habitus also creates problems in visualizing the relationship between native anatomy and hernia pathology of the abdominal wall [4].

Technique

The best approach to evaluating the layers of the abdominal wall using sonography is using the high-frequency (6–12 MHz) linear probes [5]. The advantage is that no special preparation is necessary, and sterility can be maintained if the probe is covered with a sterile plastic sheath. When visualizing the abdominal wall layers, it is important to ensure that the rectus abdominis muscles are clearly demarcated as an initial reference point. The skin is typically echogenic, the subcutaneous layer is hypoechoic while the muscle layers have variable echogenicity with a lamellar pattern noted on ultrasound (Fig. 5.10). Another approach described by Beck et al. is termed Dynamic Abdominal Sonography for Hernia (DASH), which uses a 12 MHz linear ultrasound probe to look at 5 locations along the abdominal wall to identify small defects [6]. This approach is typically more helpful for the visual-

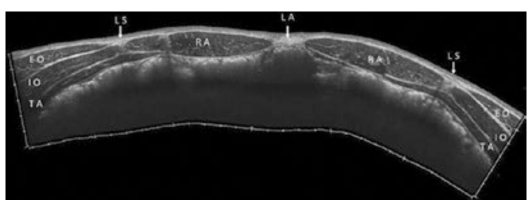

Fig. 5.10 Transverse panoramic scans of the anterior abdominal wall show detailed anatomy. *RA* Rectus abdominis, *EO* External oblique, *IO* Internal oblique, *TA* Transverse abdominis, *LA* Linea Alba, *LS* Linea Semilunaris
With permission from Springer—Draghi, F., Cocco, G., Richelmi, F.M. et al. Abdominal wall sonography: a pictorial review. J Ultrasound 23, 265–278 (2020). https://doi.org/10.1007/s40477-020-00435-0

ization of small abdominal wall defects and less so for larger defects given the size of the probe.

Visualization of Different Types of Hernias

When attempting to visualize various types of hernias, it is crucial to consider certain maneuvers to attempt to elucidate the normal and pathologic anatomy as best as possible. For example, coughing or performing a Valsalva maneuver may help visualize the hernia [7]. Furthermore, a direct vs indirect hernia may be differentiated based on the hernia location relative to the inferior epigastric arteries (Fig. 5.11). Furthermore, bowel wall thickening, that may occur due toincreased vascularity and obstruction, may be visualized with the help of an ultrasound (Fig. 5.12). Ventral hernias can also be recognized with the help of ultrasound by visualizing a defect in the abdominal wall with a "mushroom-like" appearance, which may contain pre-peritoneal fat, omentum, or a loop of bowel (Fig. 5.13). A Spigelian hernia may also be identified if there is a high suspicion of a hernia at the region of the linea semilunaris (Fig. 5.14). Incisional hernias may also be identified if there is a concern for a focal defect at a prior incision (e.g., laparoscopic incision) and will commonly appear as a protru-

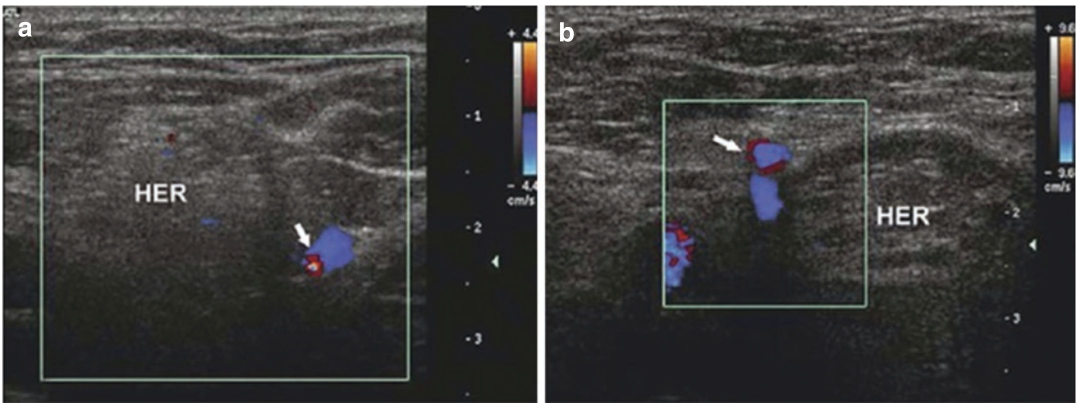

Fig. 5.11 The position of the inferior epigastric artery (arrow), shown in these color Doppler images differentiates an indirect inguinal hernia (**a**) and direct inguinal hernia (**b**) With permission from Springer—Sutaria R.B. (2017) Inguinal Hernia. In: Kahn S., Xu R. (eds) Musculoskeletal Sports and Spine Disorders. Springer, Cham. https://doi.org/10.1007/978-3-319-50512-139

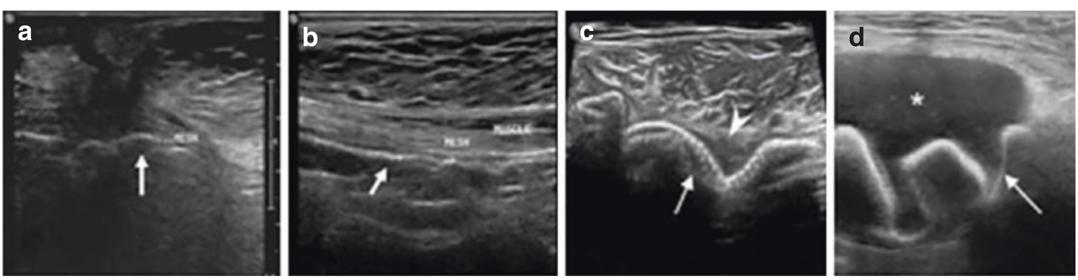

Fig. 5.12 Mesh appearances on ultrasound using high-resolution linear probe. Wavy echogenic appearance of mesh (arrow) in a post umbilical hernia repair (**a**). Inlay placement of mesh appearing echogenic on ultrasound (arrow) (**b**). Early postoperative ultrasound shows wavy echogenic mesh (arrow) made prominent by surrounding thin seroma (arrowhead) (**c**). Mesh migration (arrow) into a collection (*) in a post-inguinal hernia repair (**d**) With permission from Springer—Patil, A.R., Nandikoor, S., Mohanty, H.S. et al. Mind the gap: imaging spectrum of abdominal ventral hernia repair complications. Insights Imaging 10, 40 (2019). https://doi.org/10.1186/s13244-019-0730-x)

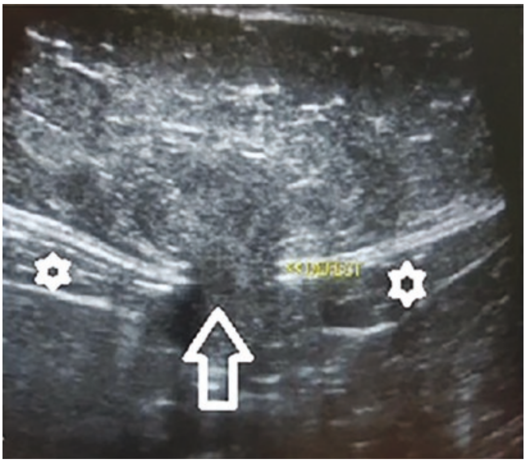

Fig. 5.13 A ventral hernia with a midline defect in the linea alba (white open arrow) between the two recti abdominus muscles (white asterisks) with the abdominal fat being seen protruding through the defect in a mushroom-like configuration
With permission from Ahmed Abdelrahman Mohamed Baz, Hatem Mohamed Said El-Azizi, Mohamed Sayed Qayati Mohamed & Ahmed Yehia Ibrahim Abdeldayem. Egyptian Journal of Radiology and Nuclear Medicine. Egyptian Journal of Radiology and Nuclear Medicine. Springer Nature. 2019

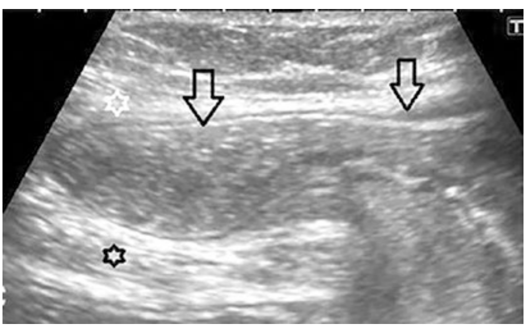

Fig. 5.14 Spigelian hernia with a bowel loop (open black arrows) being seen protruding through an abdominal wall defect to be insinuated between the transverses abdominus (black asterisk) and the internal oblique (white asterisk) muscles
With permission from. Ahmed Abdelrahman Mohamed Baz, Hatem Mohamed Said El-Azizi, Mohamed Sayed Qayati Mohamed & Ahmed Yehia Ibrahim Abdeldayem. Egyptian Journal of Radiology and Nuclear Medicine. Role of high-resolution ultrasound in the assessment of abdominal wall masses and mass-like lesions. Springer Nature. 2019

sion of fat content or bowel through a defect in the abdominal wall.

Computer Tomography (CT)

Background

Computed tomography is an excellent modality for evaluating the abdominal wall and visualizing different types of hernias [8]. The anatomy of the abdominal wall can be clearly appreciated with an axial CT (Fig. 5.15) [9]. The key applicability of CT scans is for preoperative planning to determine access points as well as the ability to close a potential defect. Along the same lines, it is also valuable in recurrent or complex cases where extensive dissection may be necessary to achieve adequate length. One of the main downsides is that it requires the patient to be supine which can cause the hernia to spontaneously reduce. Furthermore, while the radiation doses have been improving, CT is still associated with significantly more radiation exposure than its ultrasound or MRI counterpart. Interestingly, the sensitivity and specificity of CT in detecting occult inguinal hernias have been reported to be 80% and 65%, respectively [10]. While ultrasound has been reported to be the first line for evaluation for an inguinal hernia, if the clinical exam and findings are inconclusive or equivocal, it is reasonable to proceed to a CT scan.

Techniques for Visualization of Different Types of Abdominal Hernias

Multi-detector CT scan enable detailed assessment of various normal and pathological states of the abdominal wall [11]. For example, visualization of inguinal hernias allows differentiation between a direct and indirect inguinal hernia based on the location of the epigastric vessels (Fig. 5.16). An umbilical hernia can also be appreciated and based on the imaging, we can determine if it contains a bowel and whether the bowel is edematous and possibly ischemic

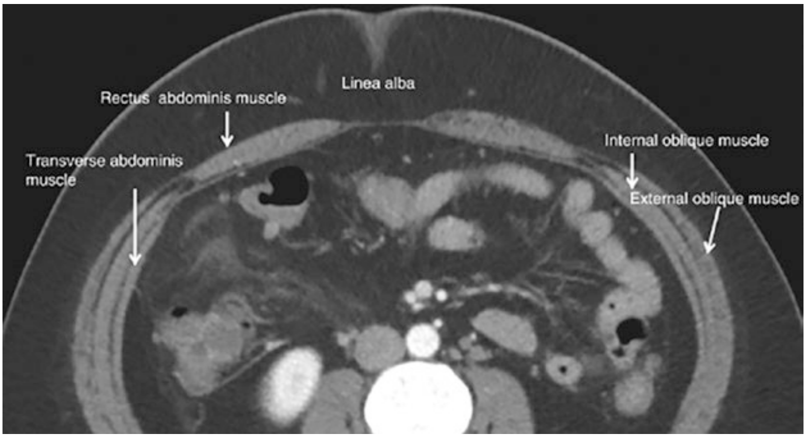

Fig. 5.15 Axial CT demonstrating the anatomy of abdominal wall
With permission from Springer—Mathur R.K., Goyal N. (2020) Imaging of Abdominal Wall Hernias. In: Chowbey P., Lomanto D. (eds) Techniques of Abdominal Wall Hernia Repair. Springer, New Delhi. https://doi.org/10.1007/978-81-322-3944-4_4)

Fig. 5.16 Bilateral direct inguinal hernias located medial to the inferior epigastric vessels (arrow)
With permission from Springer—Sodhi KS, Virmani V, Sandhu MS, Khandelwal N. Multi detector CT Imaging of Abdominal and Diaphragmatic Hernias: Pictorial Essay. The Indian Journal of Surgery. 2015 Apr;77(2):104-110. DOI: 10.1007/s12262-012-0736-9. PMID: 26139963; PMCID: PMC4484534.)

Fig. 5.17 Ventral hernia containing multiple loops of small bowel
With permission from Springer—Hernia, William W. Hope, William S. Cobb, Gina L. Adrales Springer pg278 figure 38.5)

(Fig. 5.17). Given the ability to clearly appreciate the linea semilunaris, a CT scan also enables the diagnosis of Spigelian hernias (Fig. 5.18). In fact, CT is considered first-line imaging modality in patients with concern for femoral or obturator hernias [12]. Several protocols are currently available for evaluation of various hernia defects. One such approach has been described by Xu et al. who developed an anatomical labeling protocol to characterize ventral hernias and predict mesh dimension and the need for mesh bridge closure [13].

Emby et al. describe another approach to visualizing the anterior abdominal wall using fast helical sequence CT imaging. During the scan, the patient is asked to take a full breath (full inspiration) in supine position while CT images are obtained from diaphragm to pubic symphysis. If a bulge is appreciated, it is marked with small metallic skin markers. The patient is then turned onto their side with

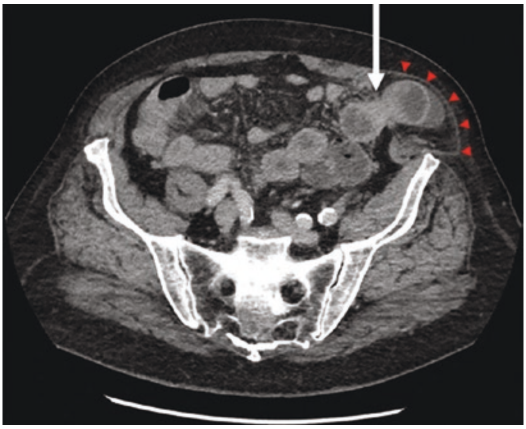

Fig. 5.18 Left-sided Spigelian hernia containing loops of bowel (arrow) through the linea semilunaris with an intact external oblique aponeurosis (red arrowheads)
With permission from Springer—Hanzalova, I., Schäfer, M., Demartines, N. et al. Spigelian hernia: current approaches to surgical treatment—a review. Hernia (2021). https://doi.org/10.1007/s10029-021-02511-8)

the symptomatic side facing downwards toward the table [14]. Another CT is obtained from diaphragm to pubic symphysis with the patient performing a full Valsalva maneuver. Oral and intravenous contrast are optional and are not routinely performed. This technique can help with the visualization of occult defects, especially in the obese population, that could otherwise be missed with a standard supine CT with reconstruction. Furthermore, it can help exclude suspicious areas of abdominal wall thinning that are not true defects.

Magnetic Resonance Imaging (MRI)

Background

Magnetic resonance imaging has several notable advantages including minimal radiation and detailed visualization of various tissues and their subtle planes [15]. Furthermore, the option of having a functional MRI is advantageous as it allows patients to perform certain maneuvers during imaging, including Valsalva. One of the major drawbacks of the modality includes its higher cost and the prolonged duration of the scan making it difficult to perform images in the still supine position. Furthermore, patients who are claustrophobic have a difficult time remaining still for the prolonged period required to obtain adequate MRI images. Though “open air” MRIs are an option, their limited availability makes access difficult. Given the MRI modality level of detail, it may also help eliminate other causes of pain that are unrelated to a hernia. Another key advantage that MRI has over a CT scan is its ability to visualize a prosthetic mesh which can be difficult to visualize on CT [16].

Technique for Abdominal Wall Visualization

While not the first- or even second-line imaging modality for the anterior abdominal wall, MRI imaging of the abdominal wall can provide unique information not appreciated with an ultrasound or a CT scan. MRI may assist in differentiating an inguinal from a femoral hernia with a high positive predictive value [17]. A potentially useful sequence when imaging abdominal wall hernia is to use coronal 3D T1-weighted Volume Interpolated Breath Hold (VIBE) without fat saturation during Valsalva maneuver and at rest [18]. Kielar et al. also recommend adding an axial TSE T2 and Axial short Tau Inversion recovery (STIR) and to include both groin regions for adequate comparison (Fig. 5.19).

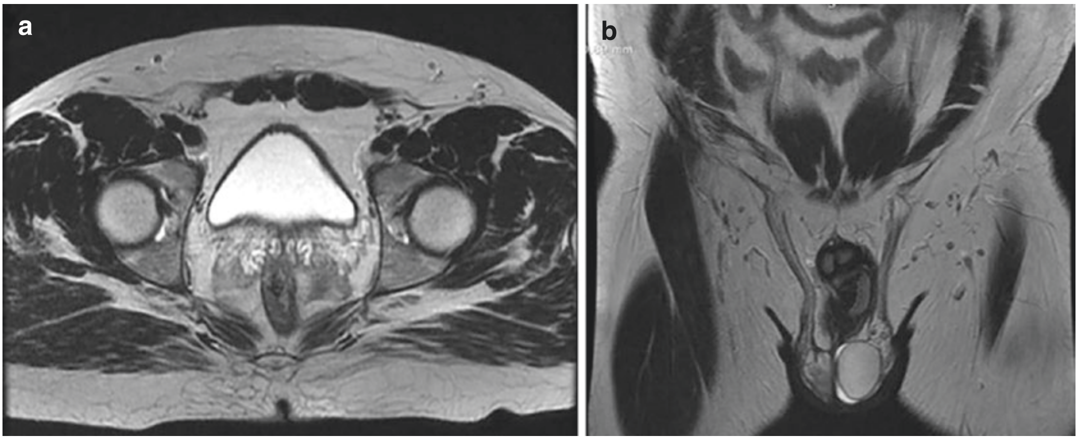

Fig. 5.19 MR image of fat-containing right inguinal hernia in T2 axial (**a**) and coronal (**b**) views. Note the smaller fat-containing left inguinal hernia as well

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Conclusion

When evaluating the abdominal wall several modalities are available at the surgeon's discretion. While initially an ultrasound is an appropriate first step, it is often not sufficient in cases with obesity and/or complicated abdominal surgery history and distorted planes. CT imaging is an appropriate second modality to evaluate abdominal wall pathology and is often utilized for preoperative evaluation and planning. MRI is essentially a last resort imaging modality often times reserved for cases where a CT is inadequate and a strong clinical suspicion remains for abdominal wall pathology.

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