11 Computed Tomography and Gross Anatomy of the Abdominal Wall (Including Planes for Mesh Hernia Repair)

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Anatomy of the Abdominal Wall

Comprehensive knowledge of the abdominal wall anatomy is essential for the management of ventral hernias. As the population ages and surgical therapies expand, herniorrhaphy incidence and complexity have increased. Complex hernias come in the form of medically challenging patients, multiply recurrent hernias, tissue loss, infected fields, prior component separations, and enterostomies [1]. These complexities necessitate a thorough and comprehensive understanding of the abdominal wall structure both on physical examination and radiographically.

Myofascial Anatomy

The myofascial anatomy creates the bulk and structural integrity of the abdominal wall, and the complex layering is naturally adapted to hernia prevention. Three muscles create the lateral bulk of the abdominal wall. Beginning posterior in the paraspinous region, the transversus abdominis, internal oblique, and external oblique muscles wrap medially and converge at the lateral border of the rectus abdominis muscle creating the *linea semilunaris*.

The transversus abdominis muscle fibers orient transversely and contribute to the posterior rectus sheath in the upper one-third of the abdomen. In the lower two–thirds of the abdomen, the muscle fibers stop lateral to the rectus, and the transversalis fascia alone contributes to the posterior rectus sheath (Fig. 11.1). It is a common misconception that the transversus abdominis fibers stop lateral to the *linea semilunaris* due to incorrect drawings in popular anatomic texts. However, the presence of

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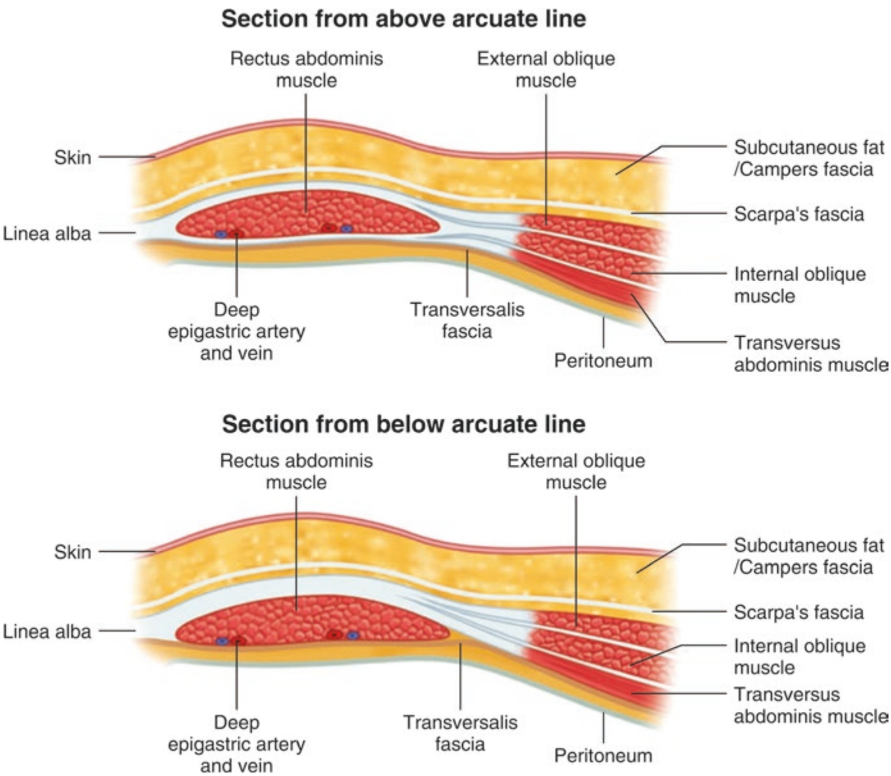

Fig. 11.1 Contribution of the transversus abdominis muscle to the posterior rectus sheath above and below arcuate line. *Novitsky, YW (2016). Hernia Surgery: current principles. Switzerland: Springer*

fibers medial to the *linea semilunaris* is the basis of a transversus abdominis release (TAR) posterior component separation (Fig. 11.2).

The internal oblique muscle fibers are obliquely oriented in a cephalad fashion and abruptly truncate at the linea semilunaris. The anterior and posterior fascial layers of the internal oblique muscle continue to become the anterior and posterior rectus sheath in the upper two–thirds of the abdomen. In the lower one–third of the abdomen below the level of the arcuate line (also called the linea semicircularis or the line of Douglas), the posterior component transitions anterior to the rectus abdominis muscles leaving only the transversalis fascial layer as the posterior rectus sheath (Fig. 11.3).

The external oblique muscle fibers are oriented perpendicular to the internal oblique fibers to further strengthen the lateral abdominal wall. Like the internal oblique muscle, external oblique muscle fibers end at the *linea semilunaris*, and the investing fascia creates part of the anterior rectus sheath. Below the arcuate line, the anterior rectus sheath is comprised of both the internal and external oblique fascia.

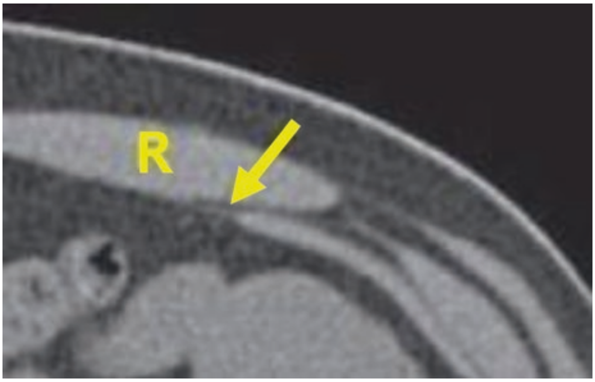

Fig. 11.2 CT imaging demonstrating transversus abdominis muscle fibers (arrow) extending beyond the *linea semilunaris* contributing to the posterior sheath of rectus muscle (R) in the upper abdomen

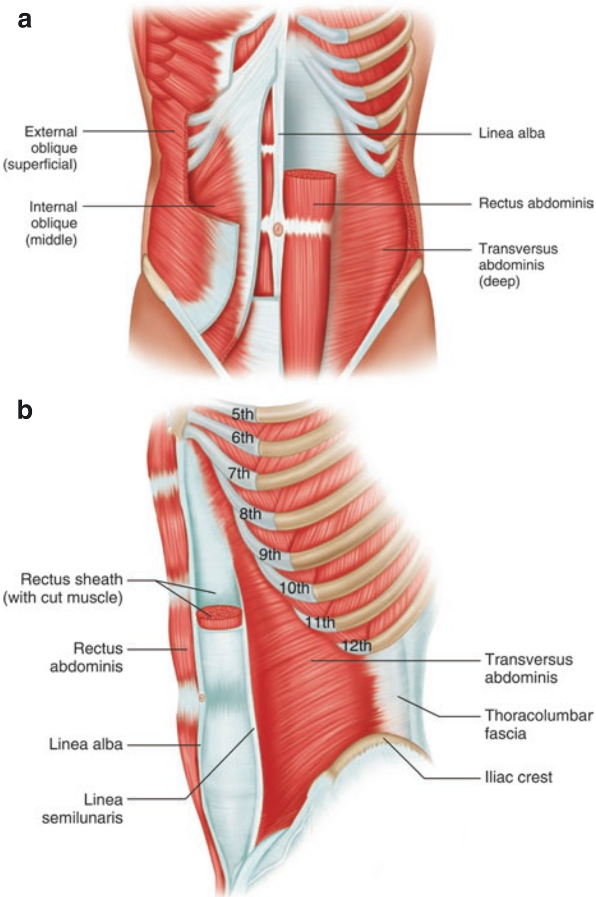

Fig. 11.3 Abdominal wall musculature. *Novitsky, YW (2016). Hernia Surgery: current principles. Switzerland: Springer*

The rectus abdominis muscles create the central core of the abdomen. As paired parallel muscles, they are bound laterally by the *linea semilunaris* and separated medially by the linea alba. They originate at the xyphoid and costal margin superiorly and insert at the pubic symphysis. The anterior and posterior rectus sheaths are created by the continuation of the external and internal oblique muscles as previously described.

The pyramidalis muscles are small paired triangular muscles that originate on the pubic crest and insert on the linea alba. They run anterior to the rectus muscle, but within the rectus sheath. They are rudimentary muscles in humans, absent in more than 20% of individuals, and are of virtually no clinical relevance for hernia repair [2].

Neurovascular Anatomy

While the neurovascular anatomy of the abdominal wall is not readily apparent, physiologically it supports the myofascial planes, and failure to pay attention to these structures can lead to denervation and devascularization of the myofascial and lipocutaneous structures, with resultant wound breakdown and other postsurgical complications (Fig. 11.4).

Fig. 11.4 (**a**) Wound ischemia and deep surgical site infection following anterior component separation with external oblique release (Photo courtesy of Dr. Luis J. Garcia, University of Iowa). *Novitsky, YW (2016). Hernia Surgery: current principles. Switzerland: Springer*. (**b**) Complications of tissue ischemia following abdominal wall reconstruction with compromised blood supply. *Novitsky, YW (2016). Hernia Surgery: current principles. Switzerland: Springer*

Vascular anatomy of the abdominal wall is divided into three zones based on the origin of the blood supply (Fig. 11.5).

Zone 1 is the central upper abdomen. Superiorly it receives blood supply from the descending superior epigastric artery, a branch of the internal mammary artery. Inferiorly it is supplied by the ascending inferior epigastric artery, a branch of the external iliac artery. As the superior and inferior epigastric arteries run posterior to the rectus abdominis muscle, they supply musculocutaneous perforating vessels (the so-called periumbilical perforator vessels) to the overlying tissues. The superior and inferior epigastric arteries converge in the supraumbilical region.

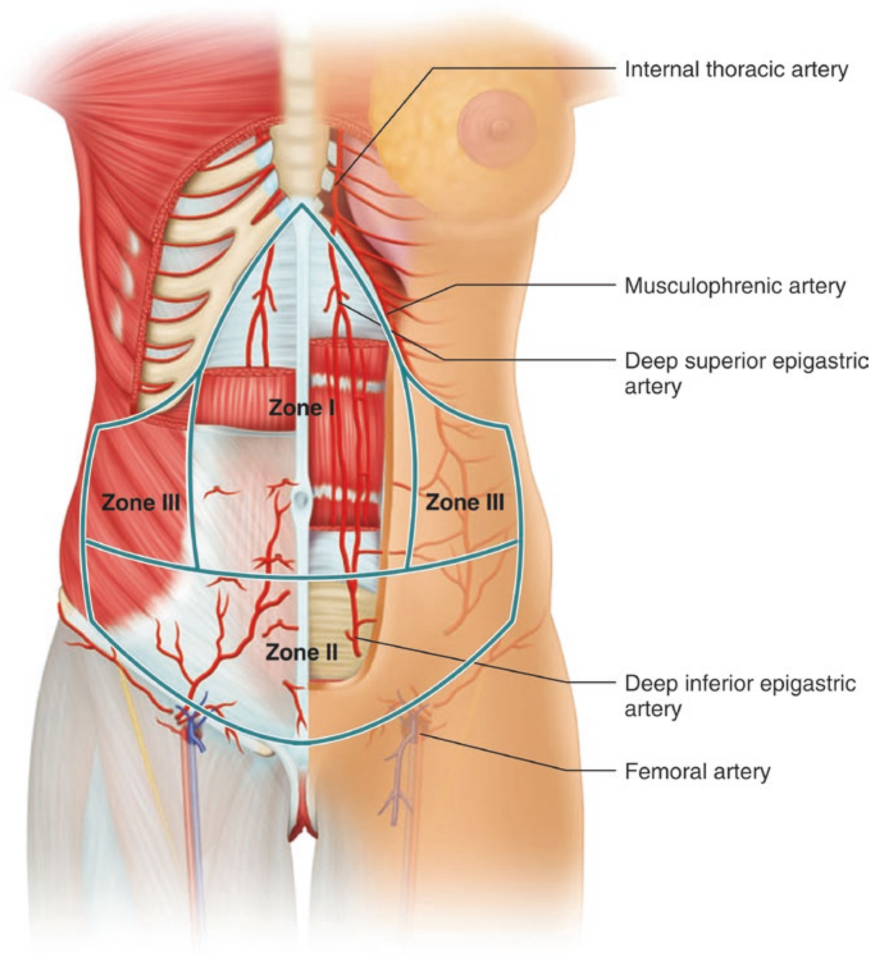

Fig. 11.5 Abdominal wall vascular anatomy by zones. *Novitsky, YW (2016). Hernia Surgery: current principles. Switzerland: Springer*

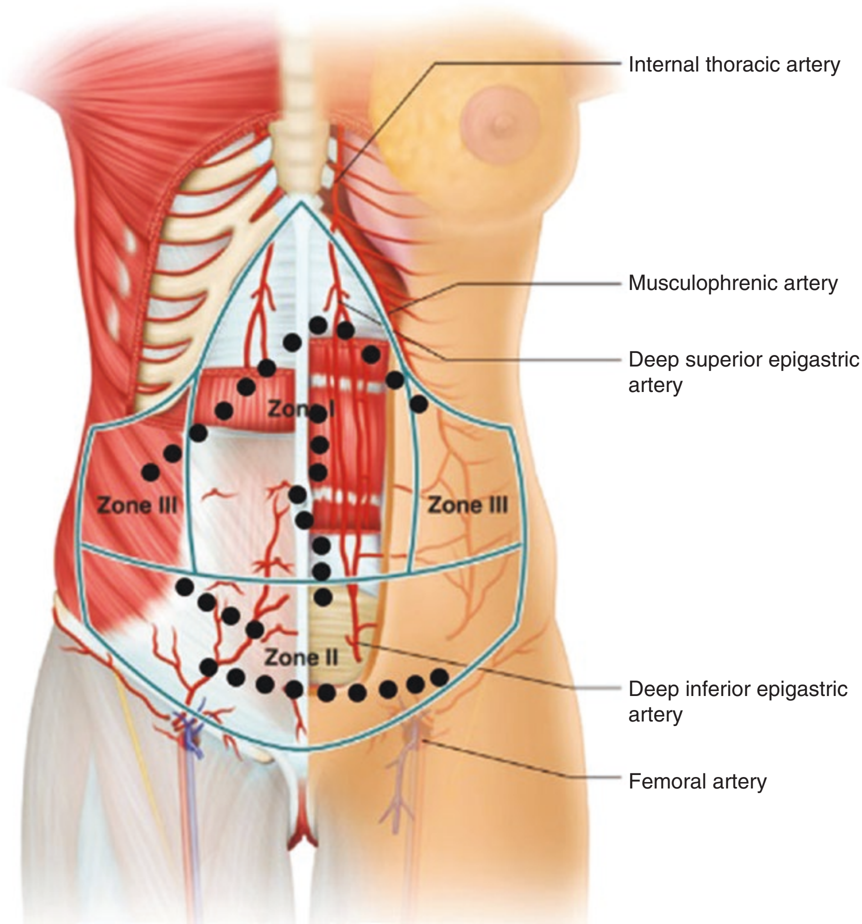

Fig. 11.6 Prior surgical incisions compromising abdominal wall vascular anatomy. *Novitsky, YW (2016). Hernia Surgery: current principles. Switzerland: Springer*

Zone 2 encompasses the suprapubic area below the arcuate line. The area is supplied medially by the superficial and deep branches of the inferior epigastric artery. Laterally, blood supply comes from the superficial circumflex iliac artery as a branch of the external iliac.

Zone 3 is the area superior the arcuate line and lateral to the *linea semilunaris*. It is perfused inferiorly by the deep circumflex iliac artery and superiorly by the musculophrenic artery as a lateral branch of the internal mammary artery.

When evaluating a patient who requires ventral herniorrhaphy, the blood supply to each zone should be considered as it may be comprised by prior surgical incisions (such as a panniculectomy or paramedian incision) or prior surgical procedure (such as epigastric ligation or abdominal aortic aneurysm repair) (Fig. 11.6).

Zones 1 and 3: Kocher and Chevron incisions generally divide the right and potentially left superior epigastric artery and must be considered in patients who have had open cholecystectomy, liver resection, or liver transplantation. In addition, patients who have had the internal mammary artery harvested for coronary bypass grafting, mediastinal dissection, or mediastinal chest tubes can disrupt the internal mammary, superior epigastric artery, or musculophrenic blood supply to Zones 1 and 3.

Zone 2: blood supply is at risk with prior paramedian, Mcburney, Rockey-Davis, and Pfannenstiel incisions.

Additionally the periumbilical region is a watershed area with tenuous blood supply in patients with large umbilical hernias and previous midline scars. Failure to excise compromised skin or scar can lead to wound breakdown and surgical site infections.

The nerves that innervate the abdominal wall run in the plane between the transversus abdominis and internal oblique muscles. Superiorly these nerves come from spinal roots T6-T12. Inferiorly, L1 nerve root provides innervation through the ilioinguinal and iliohypogastric nerves (Fig. 11.7). During a posterior separation of components, efforts should be made to preserve these nerves to avoid denervation injuries to the abdominal wall which can lead to unwanted laxity and poor function (Fig. 11.8).

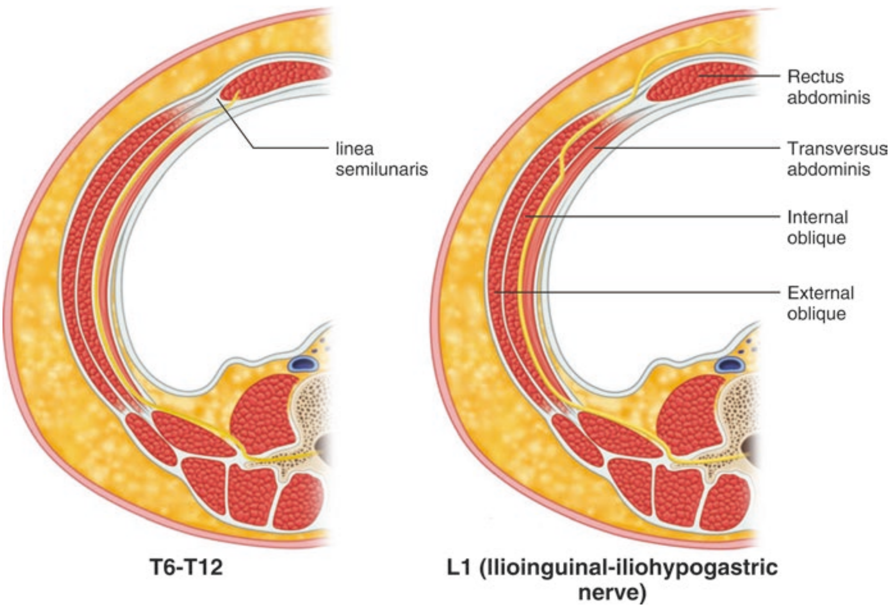

Fig. 11.7 Neurovascular anatomy of the abdominal wall. *Novitsky, YW (2016). Hernia Surgery: current principles. Switzerland: Springer*

Fig. 11.8 Denervated left rectus muscle with atrophy in comparison to a normal right rectus abdominis muscle as a result of injury to the nerves traversing the *linea semilunaris*

CT Imaging in Ventral Hernia

Computed tomography (CT) imaging is widely used for preoperative evaluation of ventral hernias. As a commonly used imaging modality for other abdominal pathologies, surgeons are often well versed in the interpretation of the images. CT imaging is ideal as it provides good visualization of the abdominal wall tissue planes as well as underlying viscera and is relatively inexpensive compared with magnetic resonance imaging (MRI) [3]. Studies have described the use of ultrasound in the diagnosis and surveillance of incisional hernias with good results [4]. Ultrasound is an attractive imaging modality because it is relatively inexpensive and minimizes radiation exposure in a patient population that is often frequently irradiated. Unfortunately, ultrasound is highly user dependent, cannot estimate the size of larger hernias, and cannot help in the assessment of other findings (mesh location, bowel patterns, occult hernias) [5, 6]. While the application of CT imaging in ventral hernias is extremely common, the techniques for image acquisition, interpretation, and reporting are not standardized.

Characteristics of the hernia location, size, and type (incisional versus primary versus recurrent) are all pertinent to the preoperative evaluation but are rarely directly reported. Multiple classification systems have been proposed in the literature to aid the discussion [6–10]. A system proposed by the European Hernia Society is based on the defect location, size, and type (primary versus incisional) [6, 11]. Medial zones (located in the midline and within the rectus muscle itself) are labeled "M" and numbered 1–5 from superior to inferior. The xyphoid, umbilicus, and pubic bone act as landmarks to define boundaries. The linea semilunaris are considered the lateral borders of the medial zone. The lateral zones are labeled "L" and numbered 1–3 from superior to inferior at the lateral border of the rectus. Zone L4 represents posterolateral hernias such as Grynfeltt-Lesshaft and Petit lumbar hernias (Fig. 11.9).

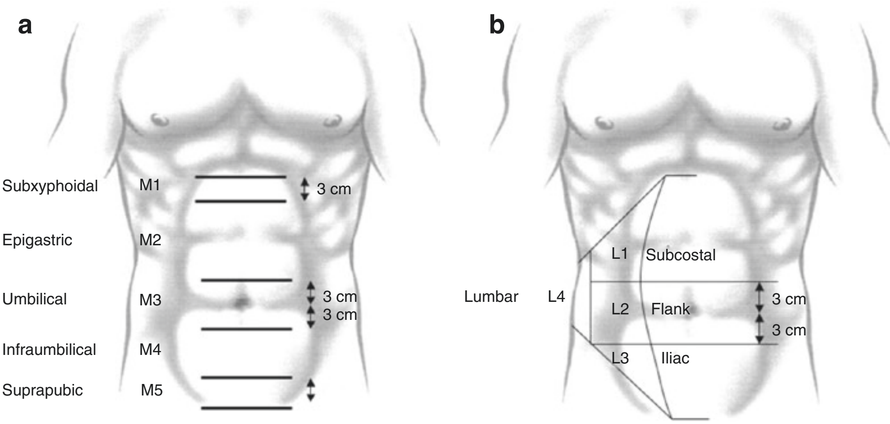

Fig. 11.9 Primary and incisional abdominal wall hernia naming guideline. *Muysoms FE*, et al. *Classification of primary and incisional abdominal wall hernias. Hernia. 2009 Aug;13 (4):407–14*

While this system was primarily developed to describe intraoperative findings, it is easily applicable to abdominal wall defects found on preoperative imaging. The EHS classification can provide an initial radiographic hernia diagnosis which can then be modified based on intraoperative findings.

Preoperative Planning

Physical examination alone is demonstrated to miss 20–30% of ventral hernias and has been shown to be inferior to radiologic imaging for the diagnosis of ventral hernias [12]. As the resolution of modern imaging modalities improves, the ability to visualize abdominal wall musculature, fascial planes, and even surgical mesh has improved [13]. The ability to preoperatively evaluate CT imaging and plan the most ideal herniorrhaphy based on CT findings represents a significant advancement in modern hernia care, but without concise definitions and standardized CT reporting of hernias, it is still a skill largely based on surgeon experience.

CT imaging can be used to predict both the complexity of repair required and potential for complications [14–16]. The width of the hernia defect is typically used to predict when fascial defects can be closed primarily or require separation of components to approximate the rectus muscles. Hernia width >8.3 cm or defect measuring >164 cm^2 was more likely to require separation of components to achieve midline closure [14]. This knowledge has substantial implications on operative planning as component separation represents a far more challenging and time-consuming operation than ventral herniorrhaphy without separation of components. Additionally, CT measurements of abdominal wall thickness have been correlated with increased postoperative complications similar to other biometrics such as obesity, hyperglycemia, and smoking and could potentially be used for patient risk stratification [14].

Surgeon Versus Radiologists Image Interpretation

The lack of a standardized protocol for the interpretation and reporting of ventral hernias on CT scans creates a divide between surgeons and radiologists who approach patients from different vantage points. Interobserver variation in the assessment of CT images for ventral hernia recurrence demonstrated a greater than 70% rate of discordance at initial review by radiologists and surgeons [17]. Surgeons augment CT imaging with physical exam, operative experience, and knowledge of prior surgical procedures (including previous mesh placement). In contrast, radiologists' access to operative reports, operative experience, and physical examination is limited [18].

A retrospective review of completed radiology reports demonstrated that abdominal wall/ventral hernias were the second most common structure to be inaccurately reported on CT imaging and were the most commonly missed findings [18]. This disparity highlights the underappreciated complexity of abdominal wall anatomy. The comprehensive knowledge of both abdominal wall anatomy and the anticipated postoperative appearance of hernia repairs results in an advantage for surgeons when interpreting images. These findings highlight the importance of multidisciplinary management of patients with ventral hernias. Some have suggested that surgeon CT review in concert with the radiologist can lead to greater concordance as the majority of corrections to initial reports came after the provision of additional surgical history, as well as direct discussion with the ordering physician.

Our preference is to review the CT images without the radiologist's interpretation, to then compare old operative notes to the CT images in an attempt to locate mesh, to then examine the patient with the images available for immediate clinical correlation, and finally to review the radiologist report (primarily for non-hernia related but clinically relevant findings). In the event of gross discrepancy between surgeon impression and radiologist interpretation, we call the reading physician to discuss any concerns in the CT report (Appendix: CT Atlas).

Planes for Mesh Repair

Mesh reinforcement is the gold standard for ventral hernia repair as it provides the lowest rate of recurrence and best long-term outcomes [19, 20]. A number of techniques have been described for mesh placement based on the layers of the abdominal wall often with subtle differences. Each technique has merit, but the wide array of planes and an even wider array of terminology complicate the discussion of hernia surgeries. To strengthen the quality of data and unify reporting of hernia surgeries, several authors have proposed definitions for hernia repair based upon the

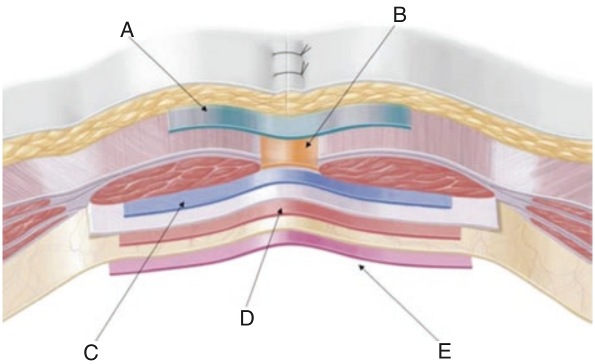

Fig. 11.10 International Hernia Collaboration consensus naming guidelines for mesh position. A. Onlay. B. Inlay. C. Retrorectus or retromuscular. D. Preperitoneal. E. Intraperitoneal. *Muysoms F, Jacob B. International Hernia Collaboration Consensus on Nomenclature of Abdominal Wall Hernia Repair. World J Surg. 2017 Jul 17*

location of mesh implantation [11, 21]. These efforts, unfortunately, have still resulted in confusion within the literature.

The International Hernia Collaboration, comprised of more than 3500 hernia surgeons, recently created a consensus naming guide for mesh position in hernia repair [11, 22] (Fig. 11.10). Mesh placed above the anterior rectus sheath is referred to as onlay. Mesh that is placed to bridge a gap between the rectus abdominis muscles is an *inlay* repair. Mesh placed behind the rectus muscles but anterior to the posterior rectus sheath is a *retrorectus* repair. When the mesh extends lateral to the *linea semilunaris* within this plane (by means of a posterior component separation), the term *retromuscular* is applied. Mesh that is placed behind the transversalis fascia but above the peritoneum is a *preperitoneal* repair, and mesh that is placed below the peritoneum in the abdominal cavity is an *intraperitoneal* repair.

Identifying Mesh on CT Scans

Mesh reinforced herniorrhaphy is the gold standard operative technique for ventral hernias [19]. This has led to a dramatic increase in the number of the different types of mesh available [23]. Despite the frequency of mesh use in ventral herniorrhaphy, there are few studies describing the appearance of different types of mesh on radiographic imaging [3, 13, 24]. Identifying indwelling mesh is an important step in preoperative planning for patients with recurrent ventral hernias as the type and location of mesh can significantly impact the complexity of the operation performed.

The appearance of mesh on CT radiologic imaging is in part determined by intrinsic mesh characteristics such as the base mesh material, mesh thickness, and presence or absence of mesh coatings [13]. Meshes that are thick, dense, coated, and reactive have increased radiopacity, aiding in the preoperative identification of mesh

Table 11.1 Visibility of common mesh types for ventral herniorrhaphy on CT imaging [3, 13, 24, 25]

Visible	Expanded PTFE mesh—thick, high-density material (>1 mm)	Thick contiguous radiopaque line	e.g., DUALMESH, DUALMESH PLUS
Intermittently visible	Coated, thin PTFE mesh (<1 mm)	Difficult to regularly identify. Correlation with operative report aides identification of subtle mesh appearance on imaging	e.g., Composix, Ventralex, Intramesh T1, Dulex
Indirectly visible	Coated polypropylene, polyester mesh	Isoattenuated—visibility determined by local tissue reaction to mesh coating rather than direct visualization of mesh	e.g. Parietex composite, Proceed, Sepramesh, Intramesh W3, Dynamesh, TiMesh, BardMesh, Prolene
Poorly visible	Lightweight polypropylene mesh	Isoattenuated, low inflammatory response makes identification difficult	e.g., Ultrapro, Vypro, Physiomesh

in plane. In cases of radiolucent mesh, a review of the operative report and direct discussion with the reviewing radiologist with special attention to the insertion plane can improve identification (Table 11.1). The appearance of biologic mesh on CT imaging is even less defined, and no reports were found on review of available literature for ventral hernias.

Mesh appearance on CT scan is also dependent in part to the tissue density surrounding the mesh. Mesh is most visible when it has fat contrast surrounding it (as opposed to direct contact with muscle and fascia) or when it has wrinkles that create clearly visible, nonanatomic lines within the patient. Radiopaque methods of mesh fixation (such as permanent metal tacks or staples) can also be used to locate the boundaries of previously implanted mesh (Appendix: CT Atlas).

Conclusion

Ventral hernia surgery has evolved as surgeons have improved upon and perfected various techniques of herniorrhaphy. The advances in hernia surgery can largely be attributed to a better understanding of abdominal wall anatomy and function combined with high-resolution CT imaging. These factors have optimized surgeon's preoperative planning, thus allowing the development of complex reconstructive procedures. In order to effectively treat ventral hernias, surgeons need to be well versed in abdominal wall anatomy and CT imaging. This chapter is meant to provide a comprehensive review of pertinent anatomy and physiology for hernia surgeons to improve the technique of ventral herniorrhaphy.

Appendix: CT Atlas

1. Wrinkled coated heavyweight polypropylene mesh (intermittently visible) is best identified where it is in contact with preperitoneal fat and as a result of the wrinkles from mesh contracture.
2. Thin expanded polytetrafluoroethylene mesh (small arrow), recurrent hernia in the midline (large arrow), and laparoscopic tacks (opaque dots).
3. Onlay mesh easily visible above the anterior rectus sheath due to interposed fat between the mesh and the fascia as well as by the presence of skin staples that were used to secure the mesh.
4. Laparoscopically placed left inguinal hernia mesh (lightweight polypropylene) visualized by fat density surrounding the mesh as well as by the metal tacks used to secure it.
5. Retromuscular polyethylene poorly visualized when in contact with the rectus muscle but that are visualized when adjacent to preperitoneal fat. Metal clips within the posterior sheet also hint as to the location in which dissection has occurred.
6. Heavyweight mesh visible on the abdominal wall and seen free floating in the abdominal cavity after failed ventral incisional hernia repair.

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