Clinical anatomy of the abdominal wall: hernia surgery

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Abstract
Introduction
The surgeon’s understanding of the anatomy of the anterior abdominal wall is critical for successful hernia repair. Although the clinical anatomy of the inguinal region has traditionally been a focus for hernia surgeons, increasing attention is now applied to abdominal wall clinical anatomy for abdominal wall reconstruction. The abdominal wall comprises several different layers encompassing skin, subcutaneous tissue, fascia, muscle and peritoneum. This review focuses on a discussion of the anatomy and neurovascular supply of the abdominal wall with a special emphasis on hernia repair techniques based on anatomical considerations. Techniques to aid in fascial closure and anatomic planes for placement of mesh are reviewed.

Conclusion
Knowledge of abdominal anatomy facilitates operative decision making based on the type of repair that best fits the patient’s anatomy and type of hernia. Evolution of hernia repair techniques continues as knowledge of anatomy and function of the abdominal wall increases.

Introduction
Knowledge of the anatomy and function of the abdominal wall is the cornerstone for successful hernia repairs based on restoring abdominal wall form and function.

The anterior abdominal wall is a hexagon-shaped area. The superior border is the costal margin and xiphoïd process with the lateral borders being the midaxillary lines. The inferior borders are the symphysis pubis, pubic tubercle, inguinal ligaments, anterior iliac crest, and anterior superior iliac spines and iliac crests. The layers of the abdominal wall include skin, subcutaneous tissues, superficial fascia, deep fascia, muscle, extraperitoneal fascia and peritoneum. The aim of this review was to discuss clinical anatomy of the abdominal wall in hernia surgery.

Discussion
The authors have referenced some of their own studies in this review. These referenced studies have been conducted in accordance with the Declaration of Helsinki (1964) and the protocols of these studies have been approved by the relevant ethics committees related to the institution in which they were performed. All human subjects, in these referenced studies, gave informed consent to participate in these studies.

Clinical anatomy
The layers of the abdominal wall include soft tissue and muscle. The superficial fascial layers differ above and below the umbilicus. Above the umbilicus, a single layer consists of the fused Camper and Scarpa fascia; below the umbilicus, these layers are separated. Camper fascia is the fatty outer layer and is continuous inferiorly with the superficial thigh fascia and extends inferiorly into the labia majora in females and the scrotum in males. Scarpa fascia is the membranous inner layer that fuses inferiorly with the fascia lata of the thigh and continues posteriorly to the perineum where it is called Colles fascia.

The deep fascial layers include the external oblique, internal oblique, transversus abdominis and parietal peritoneum. These structures help form the rectus sheath and transitions at the arcuate line. The arcuate line is located midway between the umbilicus and symphysis pubis. The anterior rectus sheath above the arcuate line is comprised of the external oblique and part of the internal oblique. The posterior rectus sheath is comprised of the internal oblique and transversalis fascia. Below the arcuate line, the external and internal oblique muscles fuse to form the anterior rectus sheath with the posterior rectus sheath being made up of only transversus abdominis (Figure 1).

The anterior and posterior rectus sheets surround and support the rectus muscle, and these layers are often used and manipulated for abdominal hernia repair and reconstruction. The linea alba and linea semilunares are important surgical landmarks. The linea alba runs in the midline from the xiphoïd process to the symphysis pubis and is comprised of a fusion of the anterior and posterior rectus sheath. The linea alba is often used for surgical incisions, because it allows quick and easy access to the abdominal cavity. The linea semilunaris is the lateral boundary of the rectus muscle and is comprised of the fusion of the external and internal oblique muscles and the transversus abdominis.

The main muscles of the abdominal wall include the rectus abdominis, external oblique, internal oblique, transversus abdominis and pyramidalis. The rectus abdominis muscles are paired and are in the midline. They serve multiple functions and are the principle flexors of the abdominal wall. They stabilise the pelvis while walking, protect the abdominal viscera and help in forced expiration.

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expiration. The rectus originates from the pubic symphysis and crest, and inserts on the anterior surfaces of the fifth, sixth and seventh costal cartilages and the xiphoid process. Three to four tendinous inscriptions run in a lateral direction, adhere to the anterior rectus sheath and interrupt the rectus abdominis.

The lateral muscles of the abdominal wall include the external and internal oblique muscles and transversus abdominis. The most superficial muscle and thickest of these muscles is the external oblique, which originates from the lower eight ribs, attaches medially to the pubic crest and courses in an inferomedial direction. Inferiorly, the external oblique forms the inguinal ligament extending between the anterior superior iliac spine and pubic tubercle. The internal oblique muscle runs in a superomedial direction, deep and perpendicular to the external oblique. It inserts on the inferior and posterior borders of the tenth through twelfth ribs superiorly and originates from the thoracolumbar fascia, anterior two-thirds of the iliac crest and lateral half of the inguinal ligament. Inferiorly, the internal oblique fuses with the transversus abdominis forming the conjoined tendon, which inserts on the pubic crest. The transversus abdominis runs in a horizontal direction and is the deepest of the lateral muscles. It originates from the anterior three-fourths of the iliac crest, lateral third of the inguinal ligament, inner surface of the lower six costal cartilages and interdigitates with fibres from the diaphragm. Below the arcuate line, it inserts into the pubic crest and pectineal line forming the conjoined tendon with the internal oblique. The pyramidalis muscle, absent in about 20% of people, is a small triangular muscle anterior to the inferior aspect of the rectus abdominis. The muscles of the abdominal wall are shown in Figure 2.

Abdominal wall blood supply and innervation
Understanding the blood supply and innervation of the anterior abdominal wall is important for safe hernia repair. The blood supply to the abdominal wall is complex but can be simplified by breaking it down into three zones (Figure 3).

Zone I consists of the upper and mid-central portions of the abdominal wall and is bordered superiorly by the xiphosternal process and medial costal margins, laterally by the linea semilunaris and inferiorly by the inferior edge of the umbilicus. The blood supply for this zone consists of the deep superior and deep inferior epigastric arteries, which converge at a point between the xiphoid and the umbilicus; the inferior artery is the dominant vessel of the two. The superior epigastric artery originates as the lateral thoracic artery and bifurcates at roughly the sixth rib level. The deep inferior epigastric artery originates from the external iliac artery before it courses medially, passing through the posterior rectus sheath mid-way between the pubis and the arcuate line.

The superior and deep inferior epigastric arteries both run deep to the rectus abdominis muscle, anterior to the posterior rectus sheath, and provide blood supply to the muscle and the overlying skin and subcutaneous tissue through musculocutaneous perforators. These perforators can be subdivided into medial and lateral perforators. They exist as longitudinal rows that run parallel to the abdominal wall. Medial perforators tend to have a broader vascular territory as they cross the midline, whereas the lateral perforators are localised to their specific side of the abdomen. Understanding these perforators is important when selecting an incision type and choosing a method of repair. The common midline incision will disrupt the medial perforators that cross midline, limiting the collaterals in zone I. When
the subcutaneous tissue is separated from the anterior rectus sheath, such as during an external component separation, the blood supply to this anterior tissue is undermined, because much of the blood supply to this region relies on these musculocutaneous perforators.

Zone II consists of the inferior abdominal wall. It is bordered superiorly by the inferior edge of the umbilicus (the inferior border of zone I) and runs the length of the anterior abdominal wall to its lateral border at the midaxillary line. Its inferior border is the inferior edge of the abdominal cavity. The blood supply for this zone consists of the epigastric arcade, superficial inferior epigastric, superficial external pudendal and superficial circumflex iliac arteries. A major component of the zone II blood supply, the deep circumflex iliac artery, has perforators that supply a portion of skin in zone II. This area is posterior and cephalad to the anterior superior iliac spine.

Zone III consists of the lateral abdominal wall and is bordered superiorly by the costal margin, medially by the linea semilunaris and laterally by the midaxillary line. The blood supply to this zone consists of the musculophrenic, lumbar and lower intercostal arteries; the latter is derived from the deep circumflex iliac artery. The musculophrenic artery is the second branch of the internal thoracic artery at its bifurcation. It passes inferolaterally behind the seventh, eighth and ninth ribs, providing large branches to the intercostal arteries and eventually joining the lumbar artery, supplying the lateral abdominal wall. The lumbar and lower intercostal arteries lie in the plane between the transversalis and internal oblique muscles.

Innervation of the anterior abdominal wall follows a segmental and dermatomal pattern and includes nerves originating from the ventral rami of T7-L1. These segmental nerves have important sensory and motor functions. Specifically, the anterior and lateral cutaneous branches of the intercostal nerves T7-11, subcostal nerve T12 and iliohypogastric and ilioinguinal branches of L1 are involved in these processes. With the exception of the iliohypogastric and ilioinguinal branches, these nerves run in the same plane as the intercostal and lumbar arteries between the internal oblique and transversalis muscles. At the midline, the T7-9 branches supply the superior abdominal wall from just below the xiphoid process to the superior edge of the umbilicus, T10 innervates the area around the umbilicus and T11-L1 supply the lower abdominal wall. Laterally, T7-12 branches provide sensory innervation. The ilioinguinal and iliohypogastric nerves also provide sensation to the inner thigh and scrotum or labia majora. These two nerves pierce through the internal oblique muscle and run between this and the external oblique muscle.

Motor innervation of the musculature of the abdominal wall follows a similar pattern. The rectus abdominis muscle is innervated by the lower six intercostal nerves. The external oblique, internal oblique and transversus abdominis muscles are innervated by the lower intercostal, the subcostal, and the iliohypogastric and ilioinguinal nerves. The nerves of the abdominal wall are shown in Figure 4.

Abdominal wall hernias and relevant surgical techniques
A ventral hernia is a disruption or hole in the abdominal wall and can be classified as primary, occurring de novo or incisional (hernias caused by previous incision and surgery). The majority of hernias form in the weaker areas of the abdominal wall where there is no muscle present and typically occur in the linea alba.

However, incisional hernias can occur anywhere in the abdomen. The risk factors for developing an incisional hernia include several technical and patient factors. The two major surgical techniques described for repair of a ventral hernia are laparoscopic and open approaches. Mesh use decreases the recurrence rate in ventral hernias, so mesh should be used in most cases.

An open ventral hernias repair is usually needed because of the location of the mesh required or when the repair requires separations or releases of any of the abdominal wall components. Mesh repairs are generally classified as onlay, bridge or sublay repairs, and the type of repair is determined by where the mesh is placed in relation to the hernia. While there is ongoing debate regarding the benefits of the onlay and sublay techniques, most surgeons agree that bridge repairs with mesh have an unacceptable hernia recurrence rate and should only be used in special circumstances.

The onlay repair (placing the mesh above the hernia defect and fixing it to the external oblique and/or the anterior rectus sheath) has several potential benefits: it can be technically easier, faster and its use may avoid entering the abdominal cavity and injury to the viscera. An important principle of hernia repair relates to wide mesh overlap of the defect and adequate fixation. A good onlay repair typically involves raising subcutaneous flaps to allow placement of mesh. Another tenet of hernia repair is that, when possible, mesh should be used as a buttress to repair the midline/linea alba should be closed and the rectus muscles reaproximated. Important techniques can be used to aid in midline closure in large or complex hernias and are typically referred to as component separations or myocutaneous or myofascial releases. The most notable of these was first described by Ramirez et al. and involves cutting of the posterior rectus sheath, dissecting the subcutaneous tissue off the external oblique and incising the external oblique lateral to the semilunar line (Figure 5). Although this technique is likely the most widely known, there are many myocutaneous and myofascial releases based on the anatomy of the abdominal wall that can be used to achieve midline closure.

The sublay repair is based on the theory that placement of mesh below the hernia defect and muscles will allow the abdominal forces to help keep the mesh in place and is largely based on the retrorectus repair popularised by Rives et al., Wantz and Stoppa. The retrorectus repair was described by Rives and is thought to be one of the best repair methods for ventral hernias. In this repair, the posterior rectus sheath is cut just off the linea alba (Figure 6), and the rectus muscle is dissected off the posterior rectus sheath. The posterior rectus sheath is then sewn together in the midline allowing for the mesh to be placed in this space and excluding its contact with the viscera (Figure 7). One drawback of the Rives repair is that the posterior rectus sheath is a finite sheath and limits the amount of mesh that can be placed laterally as the sheath ends. Thorough knowledge of the anatomy of the abdominal wall demonstrates that there are several planes that can be used for retromuscular mesh placement.

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**Figure 3:** The blood supply to the abdomen divided into three zones. Reprinted with permission from Chim H, Evans KK, Salgado CJ, Mardini S. In: Rosen M, editor. Atlas of abdominal wall reconstruction. New York, NY: Elsevier; 2012.

placement to facilitate the placement of larger meshes that can extend beyond the borders of the posterior rectus sheath. Three of these techniques have recently been described. The preperitoneal repair involves cutting the peritoneum in the midline and developing the plane laterally as needed (Figure 8). The benefit of this technique is that it allows for wide mesh overlap of the hernia defect; however, the drawbacks are that it can be a difficult technical dissection and may not allow for a myofascial release. Two modifications of the Rives repair have been proposed to potentially help with not being able to place mesh laterally to the semilunar line in the retrorectus repair. The first described by Carbonell and colleagues involves incising the lateral border of the posterior rectus sheath and dividing the posterior aponeurosis of the internal oblique. The dissection proceeds laterally between the internal oblique and the transversus abdominis muscle allowing for a large space to place mesh. One criticism of this repair is that the dissection and the division in these planes at the lateral border of the posterior rectus sheath typically require the need for ligation of the neurovascular bundles supplying the rectus muscle. Although there have been no objective studies defining the effect this has on abdominal wall

Figure 5: Open repair of ventral hernia with placement of mesh in the retrorectus space. Component separation/incision of the external oblique has been done lateral to the semilunar line to allow for midline closure without undue tension over the mesh.

Figure 6: Open ventral hernia repair showing a laparotomy incision with opening of the posterior rectus sheath just off the midline. Dissection of this plane on both sides of the incision will allow for closure of the posterior rectus sheath and placement of a retrorectus mesh for hernia repair (Rives).
Figure 7: Open retrorectus (Rives) repair of ventral hernia with dissection and closure of the posterior rectus sheath. The mesh is placed in this space so it will not have contact with the viscera, and the anterior fascia is closed over the mesh.

Figure 8: Laparotomy incision with the peritoneum dissected off of the posterior rectus sheath. Dissection of the preperitoneal space on both sides of the incision allows for closure of the peritoneum in the midline and large mesh placement that can go lateral to the semilunar line.

Figure 9: The transversus abdominis involves incising the posterior rectus sheath just medial to the neurovascular supply and then incising the transversus abdominis muscle. This allows for wider mesh placement into the preperitoneal space, sparing of the neurovascular bundle and decreases the tension on the abdominal closure.

Figure 8: The transversus abdominis muscle is then divided and released allowing access to the preperitoneal space (Figure 9). The proposed benefits of this technique are that it spares the neurovascular supply to the rectus muscle and allows for wide mesh placement lateral to the semilunar line in the preperitoneal space.

The laparoscopic approach is based on the retrorectus repair popularised by Rives\textsuperscript{12}, and the mesh is placed intra-abdominally. Since the mesh is placed intra-abdominally, mesh should be carefully chosen to ensure the compatibility with intra-abdominal placement. Intra-abdominal meshes generally are coated polypropylene, polyester meshes or expanded polytetrafluoroethylene\textsuperscript{15}. One potential drawback of the traditional laparoscopic repair is that, although the hernia is being repaired and the potential for incarcerated or strangulated hernias is fixed, this is a bridging-type repair and does not truly reconstruct the abdominal wall.

This drawback has been addressed by the use of laparoscopic defect closure described by Novitsky et al.\textsuperscript{16} and involves incising the posterior rectus sheath just medial to the semilunar line proximal to where the nerves insert into the rectus muscle. The transversus abdominis muscle is then divided and released allowing access to the preperitoneal space\textsuperscript{14} (Figure 9). The proposed benefits of this technique are that it spares the neurovascular supply to the rectus muscle and allows for wide mesh placement lateral to the semilunar line in the preperitoneal space.

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**Conclusion**

The anatomy of the abdominal wall is complex, and thorough knowledge of anatomy including blood supply and innervation will help the hernia surgeon choose the best repair technique and most advantageous mesh placement. Many recent hernia repair techniques focus on restoring abdominal wall anatomy and function rather than simply repairing the hole in the abdominal wall, and these repair techniques are based on anatomical considerations.

**Conflict of interests**

Dr Hope declares Bard consulting and Ethicon research support as potential conflicts of interest. Drs Von and Johnson have no competing interests or conflicts of interest to disclose.

**References**