SURGICAL ANATOMY OF ABDOMINAL WALL

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GENERAL CONSIDERATION

The abdominal cavity, situated between the diaphragm above and the pelvic strait below, is surrounded by a wall that consist of an antero-lateral part and a posterior (lumbo-iliac) part. The skeletal part of the wall consists of the five lumbar vertebrae, the upper parts of the pelvic bones, and the bony components of the lower chest wall. The muscular elements are arranged in the following manner: posteriorly, the quadratus lumborum, psoas major, and iliac muscles are located; laterally, there are three muscular layers, namely the external oblique (EO), internal oblique (IO), and transversus abdominis (TA); anteriorly, the rectus abdominis (RA) muscle covers the distance between the lower chest wall and pelvis on each side. The diaphragm separates the thoracic cavity from the abdominal cavity. It is the primary muscle of respiration and has three openings that act as conduits for vessels that pass between the thoracic and abdominal cavities: the esophageal opening (T10 level), the aortic opening (T12 level), and the caval opening (T8 level). The abdominal wall constitutes of posterior, lateral, and anterior parts, which are structurally interconnected by flat tendinous laminae (aponeuroses) derived from the lateral wall muscles. The anterior abdominal wall is more flexible than the posterior wall, and it plays a crucial role in supporting lateral bending, flexion, extension, protrusion, and twisting, as well as in maintaining posture, increasing intrabdominal pressure, parturition, and micturition.[1]

The eight muscles present in the antero-lateral abdominal wall are responsible for performing a wide range of functions. The complex interactions between bones, nerves, muscles, and fascias give rise to the dynamic of the antero-lateral abdominal wall. The abdominal muscle architecture is critical in predicting the muscle's functional ca-

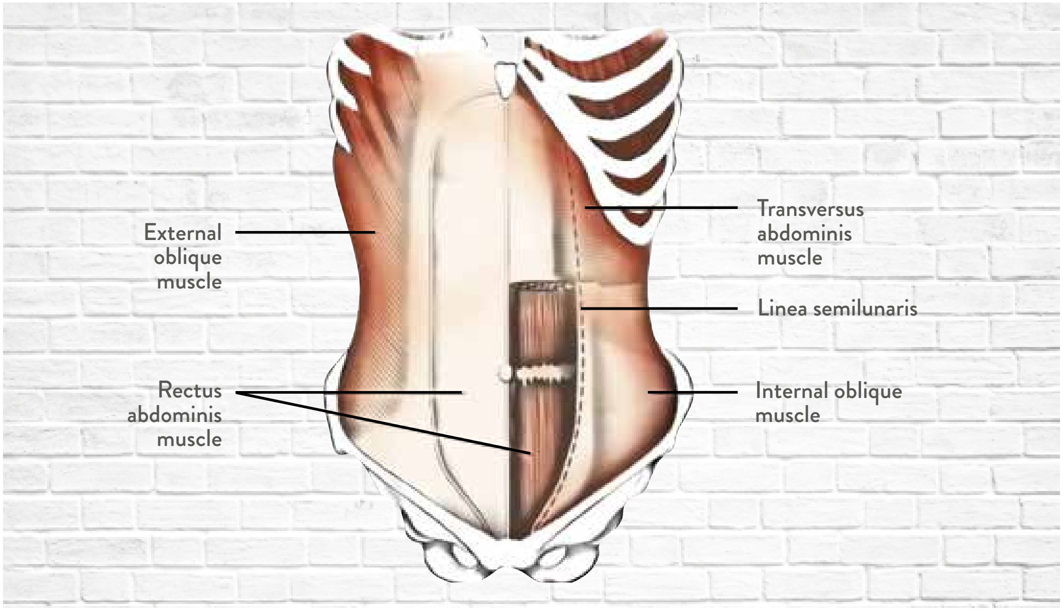

Figure 1.1. Frontal view of the anterolateral layers of the abdominal wall.

pacity. The physiologic cross-sectional area represents the number of force-generating sarcomeres arranged in parallel and predicts its maximum isometric force-generating capability.[2]

From a topographical perspective, the antero-lateral wall can be divided into an anterior region (sternum-costo-pubic), which includes the umbilical area, and two lateral regions (costo-iliac and inguino-abdominal). However, this subdivision is outdated and must be replaced by a new unitary anatomo-functional conception based on common embryological derivation from mesoderm, the presence of a myoaponeurotic system in which fascias, muscles, aponeuroses, and sheaths act in synergy, a common vascularization and innervation, and the need to restore wall continuity in the presence of parietal defects to ensure adequate functioning of the musculofascial system.[3]

ABDOMINAL WALL ANATOMY

The antero-lateral abdominal wall runs superiorly from the xiphoid process and costal cartilages of the 7th, 8th, 9th and 10th ribs to the iliac crest, inguinal ligament, and pubic symphysis inferiorly. It is divided into three layers: superficial, middle and deep (**Figure 1.1**).[4]

Superficial layer

The superficial layer of the abdominal wall is the most external and is composed of skin, subcutaneous tissue, and the superficial fascia. The superficial fascia contains mainly adipose tissue. The superficial epigastric and superficial circumflex iliac arteries mainly provide the blood supply to the superficial layer of the abdominal wall.

Middle layer

In the middle myoaponeurotic layer, there is a lateral muscular system, consisting of EO, IO and TA, with its aponeurotic insertion apparatus that unites the anterior and lateral regions, and a medial muscular system, formed by rectus and pyramidal muscles enveloped by the rectus sheath. The lateral system consists of large muscles that originate at the level of the bony scaffold of the abdominal wall and are directed in the mid-caudal direction, transforming into the extended tendinous planes, which form the rectus sheath and the linea alba.

The most superficial and thickest EO originates from the lower eight ribs and courses in an inferomedial direction.

Below the anterior-superior iliac spine (ASIS), the muscle becomes entirely aponeurotic: at the level of the linea alba, the tendinous fibers intertwine with those of the IO and TA muscles of the opposite side, while in the inguinal area they form the inguinal ligament of Falloppio-Poupart, the lacunar ligament of Gimbernat and the pillars (Colles reflected ligament) of the external inguinal ring. The contraction of the EO flexes the vertebral column, helps to rotate the thorax and pelvis, and depresses the thorax in expiration.

The IO originates from the thoracolumbar fascia, anterior two thirds of the iliac crest, and lateral half of the inguinal ligament. It inserts on the inferior and posterior borders of the tenth through twelfth ribs superiorly and runs in a superomedial direction, perpendicular to the EO. Its aponeurosis splits medially above the arcuate line to form part of the rectus sheath and, below the arcuate line, does not split and form the anterior rectus sheath. Bilateral contraction of the EO, in conjunction with the IO and rectus abdominis, produces flexion of the vertebral column. Ipsilateral contraction of the EO and IO muscles produces abduction of the trunk.

The TA, fleshy in the middle part and tendinous in its extremities, originates from the inner surface of the last six ribs, from the thoraco-lumbar fascia, the iliac crest and the iliopsoas fascia, but not from the inguinal ligament. From these sites, the muscle fibers move medially and become aponeurotic along the semilunar line of Spigelio, which extends from the IX costal cartilage to the pubic tubercle, describing an arch with a medial concavity and crossing the muscle-tendon line of the oblique abdominis muscles externally. The TA extends more medially than both internal and external obliques muscles (Figure 1.2). It is a tensor of the wall, the corset of the abdomen, acting as a girdle, and a depressor of the ribs as it receives intense impulses from the central expiratory neurons. The aponeurosis of the TA contributes to the formation of the rectus sheath and the linea alba; in the inguinal area, as arcus transversus abdominis and as component of the conjoined area, it plays the important role in the parietal resistance (Figure 1.3).

The semilunar line of Spigelio is formed by fusion of the EO, IO, and TA aponeuroses at the lateral border of the rectus abdominis and is extended from the cartilage of the ninth rib to the pubic tubercle. The portion of aponeurosis located between the semilunar line laterally and the external edge of the rectus abdominis muscle medially is called the Spi-

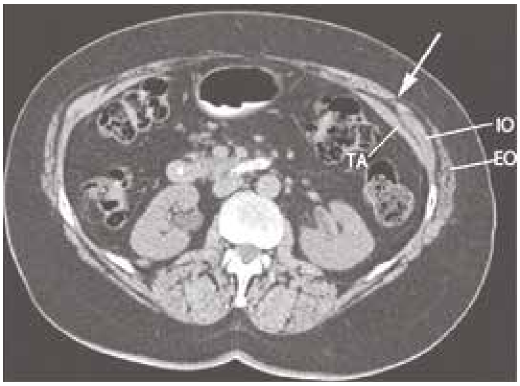

Figure 1.2. CT scan of the upper abdomen. The TA muscle does not insert into the lateral boarder of the rectus muscle, but rather passes medial to the linea semilunaris (arrow) and posterior to the rectus itself in the upper one-third of the abdomen.

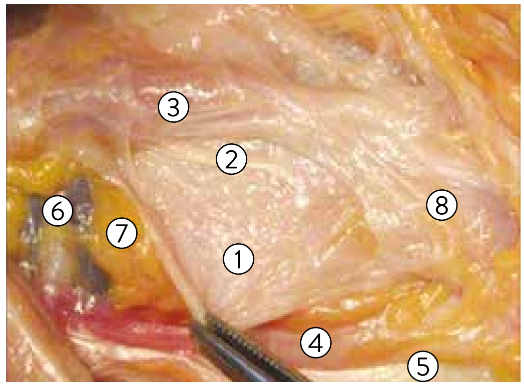

Figure 1.3. Myoaponeurotic transverse arch – conjoined area. 1) Cooper's transversalis fascia; 2, 3) myoaponeurotic transversus arch; 4) iliopubic tract; 5) inguinal ligament; 6) inferior epigastric vessels; 7) Bogros space; 8) conjoined area.

gelian fascia and presents a weakness area between the outer margin of the rectus and the spino-umbilical line of Monro, interspinous line of Lanzmann, semilunar line of Spigelio and arcuate line of Douglas (Figure 1.4).[5] Thin connective covering laminae separate the three large muscles and their aponeuroses. The most internal is Cooper's transversalis fascia (FT), which is part of the endoabdominopelvic fascia. The rectus abdominis (RA) muscles originate from the pubic symphysis and pubic crest and insert on the anterior surfaces of the fifth, sixth, and seventh costal cartilages and the xiphoid process. Laterally, the rectus sheath merges with the EO aponeurosis to form the linea semilunaris (Figure 1.4).[5] The RA is a metameric, polygastric muscle, with four muscle bellies separated by three tendinous intersections (*inscriptiones*), tightly attached to the anterior leaflet of its sheath, corresponding to its embryonic segmentation. This adherent arrangement explains how hematomas or sheath abscesses extend mainly to the posterior face of the muscle.

The intercostal nerves reach the RA coming from the lateral side in the layer between the transversus abdominis and the internal oblique. The paired rectus abdominis muscles are the principal flexors of the anterior abdominal wall and also protect the abdominal organs and help in forced expiration. Above the arcuate line, the IO aponeurosis splits to contribute to both the anterior and posterior rectus sheaths. Below the arcuate line, a semicircular line corresponding to the midpoint between navel and pubis, clearly visible when examining the abdominal wall from the inner face, the aponeurosis does not split but rather fuses with the external oblique fascia to form the anterior rectus sheath alone (Figure 1.5).[6]

The absence of the posterior layer of the sheath is probably the cause of the particular weakness in the distal tract of the linea alba, which nonetheless presents a strong, resistant reinforcement fascicle behind the rectus abdominis muscle, the *adminiculum lineae albae*.

The rectus sheath and the linea alba are composed of collagen fibers arranged in an

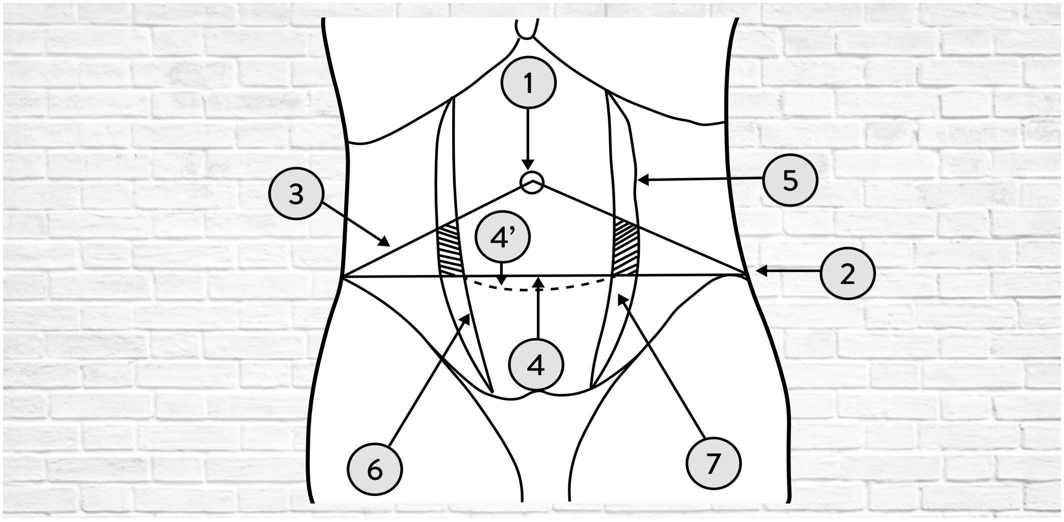

Figure 1.4. The Spigelian fascia and its weak area: 1) umbilicus; 2) anterosuperior iliac spine; 3) spino-umbilical line; 4) interspinous line; 4') arcuate line; 5) semilunar line; 6) external edge of the rectus sheath; 7) Spigelian fascia; ///) weak area (modified from Mosca et al.[5]).

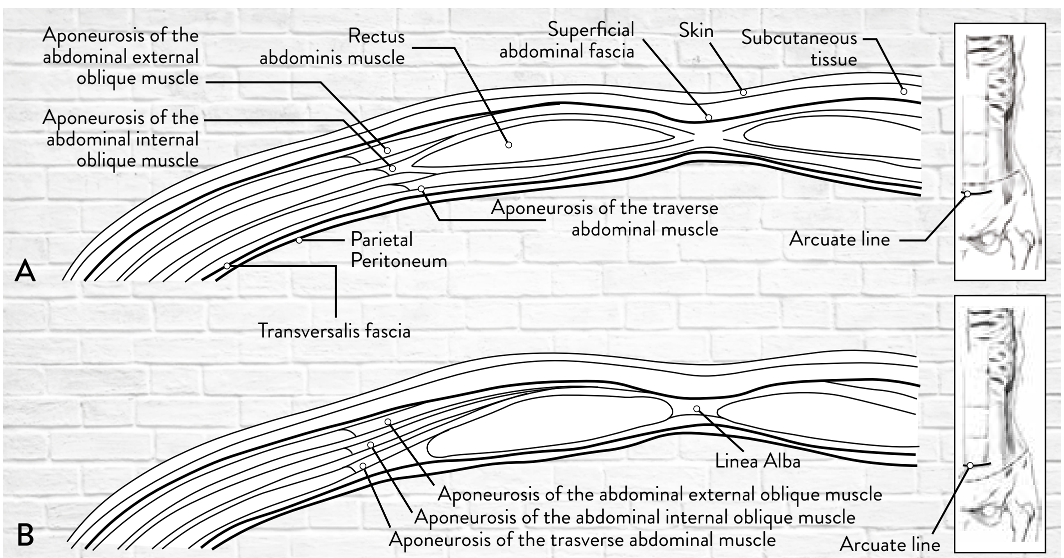

Figure 1.5. Constitution of the sheath of rectus muscles – linea alba: sectional view of the abdominal wall above (A) and below (B) the arcuate line of Douglas (modified from Askar *et al.*[6]).

"interwoven lattice" pattern. The width and thickness of these structures vary along the surface of the anterior abdominal wall and are related to the distance from the umbilicus.

The wall defects mainly develop in correspondence with the linea alba, whose architecture - in fluorescence microscopy - shows an *anisotropic behavior*, *i.e.*, a different mechanical behavior according to the direction of stress of the fibers. With the same applied force, the deformation is greater, approximately double, in the longitudinal direction.

The most compliant axis of the biomaterial should be oriented in the craniocaudal, or "longitudinal", direction, and the strongest axis of the biomaterial should be oriented in the medial-lateral, or "transverse," direction.[7] The aponeuroses of the flat muscles that form the rectus sheath and the linea alba play a crucial role in maintaining the integrity of the abdominal wall. These fascial structures provide resistance in the transverse direction, preventing the rectus muscles, which have a longitudinal course, from being deflected outwards by any transverse force. The flat muscles work in synergy to ensure the effectiveness of the medial muscle system, which is joined by the linea alba and the median tendinous raphe formed by the crossing of the bilaminar aponeuroses of the lateral muscle system. Failure of the central tendinous plane can result in the insufficiency of the rectus muscle, which is known as the "master muscle of the abdominal wall."[4]

Deep parietal layer

The deep parietal layer of the abdominal wall comprises the FT, loose preperitoneal connective tissue, and the parietal peritoneum. The FT covers the internal surface of the TA aponeurotic plane and merges with the anterior lamina of the thoracolumbar fascia. The transversalis fascia, a membranous layer of loose connective tissue, is more solid in the sub-umbilical area and doubled in the inguinal region to delimit a space in which the inferior epigastric vessels run. The easily avascular inter-fascial plane between the FT and preperitoneal fascia/fat is important during laparoscopic preperitoneal hernia repair.[8, 9]

The Retzius (preperitoneal) space

The Retzius space is located in the midline of the lower abdomen, with the superficial transverse fascia and the pubic bone anteriorly, the bladder posteriorly, the umbilicus level superiorly, the pelvic floor muscles inferiorly, and the inferior epigastric arteries laterally. The surgeon needs to incise the deep transverse fascia that is attached to the pubic bone and enters the visceral space to obtain a more capacious preperitoneal retropubic space, considered to be equivalent to the space of Retzius, during an endoscopic hernia repair.[10, 11]

Bogros space and preperitoneal spaces

The parietal peritoneum delimits the Bogros space, located between the inguinocrural and internal iliac regions and limited by the fascia transversalis anteriorly, the peritoneum posteriorly and the iliac fascia laterally. The retropubic space of Retzius and the preperitoneal space of Bogros are potential non-natural cavities under the lower anterior abdominal wall. The expert laparoscopic hernia surgeons have different opinions about the proper anatomical planes for dissection and the mesh placement during laparoscopic hernioplasty. An easily avascular inter-fascial plane exists between the FT and the preperitoneal fascia/fat, which is the real surgical preperitoneal space suitable for straightforward safe dissection and mesh placement during the laparoscopic preperitoneal hernia repair.

Important structures in the abdominal cavity during laparoscopic inguinal hernia repair

During laparoscopic inguinal hernia repair, it is important to recognize important structures in the abdominal cavity, including the median umbilical fold, the medial umbilical fold, the lateral umbilical fold, Hesselbach's triangle, the internal inguinal ring and the femoral ring, pubic symphysis, Cooper's ligament, the corona mortis, the inferior epigastric vessels, the vas deferens/the round ligament of the uterus, the testicular vessels, the iliopubic tract, the triangle of doom and the triangle of pain.[10, 11]

Weak area of the wall in the inguinal area

The inguinal area is divided into the inguino-abdominal and inguino-crural regions. The weak area of the wall is defined by the myopectineal orifice (MPO) of Fruchaud, a potential site of the various types of hernias and delimited above by the arches of IO and TA muscles, laterally from iliopsoas muscle, medially from the lateral margin of the RA muscle, inferiorly from Cooper's ligament (shiny white cordlike formation; Figure 1.6, Figure 1.7).[12, 13] The inguinal ligament divides the myopectineal orifice into two regions: the suprainguinal region and the subinguinal region. The spermatic cord or the round ligament of the uterus runs through the suprainguinal region, while the femoral nerve, the femoral artery, the femoral vein and the femoral canal run through the subinguinal region.

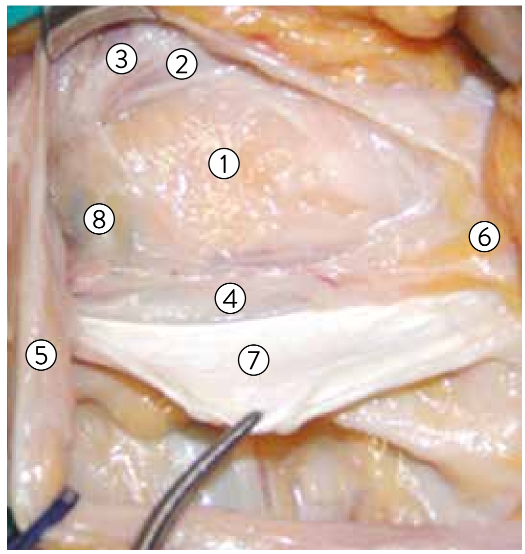

Figure 1.6. Fascia transversalis (Cooper) and myoaponeurotic transversus arch (Condon). 1) FT; 2) myoaponeurotic transversus layer; 3) IO muscle arch; 4) iliopubic tract; 5) spermatic cord; 6) conjoined area; 7) inguinal ligament; 8) inferior epigastric vessels.

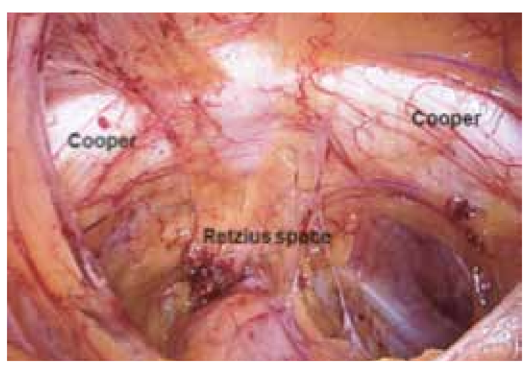

Figure 1.7. Retromuscular dissection of the space of Retzius. Exposure of the pubis and the Cooper's ligaments.

SURGICAL ANATOMY FOR RECONSTRUCTIVE SURGERY

Abdominal wall

The abdominal wall reconstructive procedures, which typically include separation of the abdominal wall layers and release of one or more myofascial planes, require a clear understanding of the anatomy of the abdominal wall.

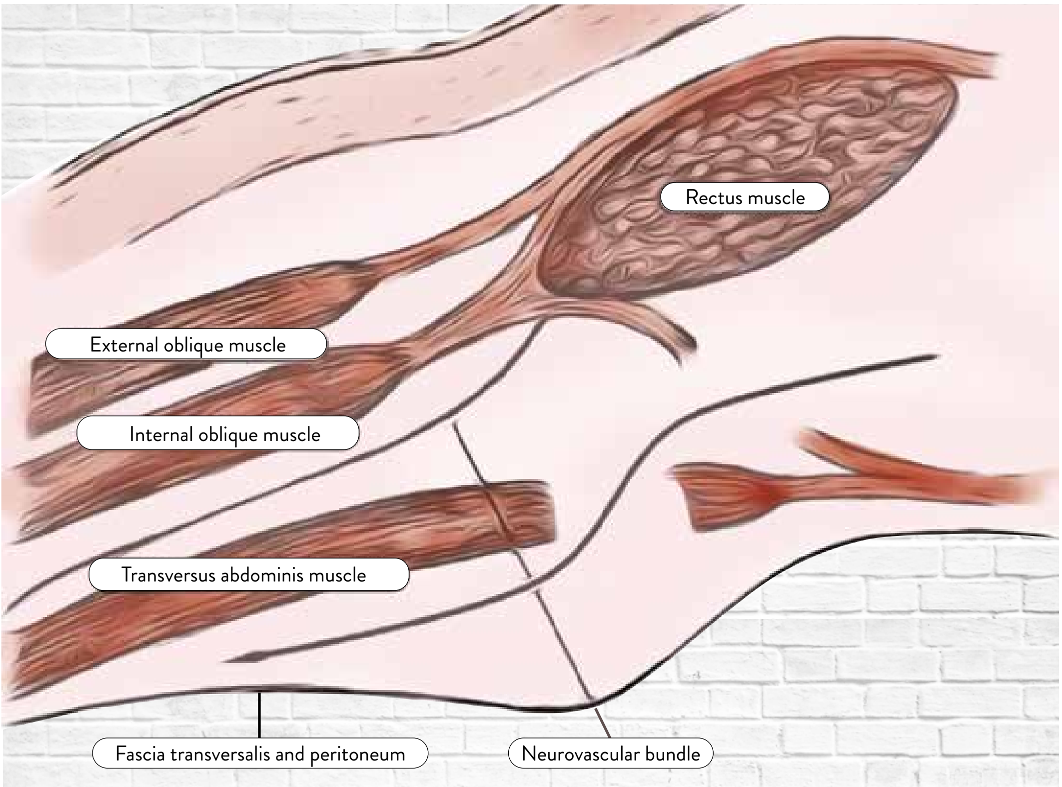

Figure 1.8. Preservation of the neurovascular bundles during the PCS/TAR. Location of the intercostal nerves passing thorough IO and TA muscles and entering in the retrorectus plane. The transversal fascia or the posterior lamella of the internal oblique is transected just medial to the nerves.

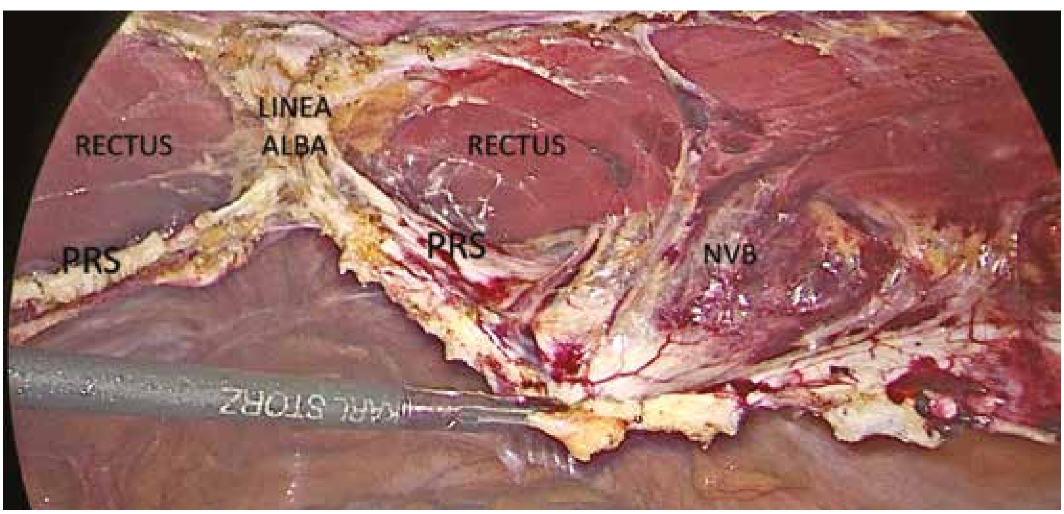

Figure 1.9. Extended totally extraperitoneal approach. Courtesy of Dr. Nadav Nevo and Dr. Youri Mnouskin. Vision from bottom to up of the line alba.
PRS: posterior rectus sheath; NVB: neurovascular bundle.