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Vascular Anatomy and Variations of the Anterior Abdominal Wall – Significance in Abdominal Surgery

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Abstract: Detailed knowledge of the human anatomy is an integral part of every surgical procedure. The majority of surgery related complications are due to a failure to possess appropriate knowledge of human anatomy. However, surgeons pay less attention of the anatomy of the anterior abdominal wall. It is composed of nine abdominal layers, which are composed of fascias, muscles, nerves, and vessels. Many superficial and deep vessels and their anastomoses supply the anterior abdominal wall. Moreover, anatomical variations of these vessels are often presented. Intraoperative and postoperative complications associated with entry and closure of the anterior abdominal wall could compromise the best surgical procedure. Therefore, sound knowledge of the vascular anatomy of the anterior abdominal wall is fundamental and a prerequisite to having a favourable quality of patient care. The purpose of the present article is to describe and delineate the vascular anatomy and variations of the anterior abdominal wall and its application in abdominal surgery. Consequently, the most types of abdominal incisions and laparoscopic accesses will be discussed. Furthermore, the possibility of vessels injury related to different types of incisions and accesses will be outlined in detail. Morphological characteristics and distribution pattern of the vascular system of the anterior abdominal wall is illustrated by using figures either from open surgery, different types of imaging modalities or embalmed cadaveric dissections. Oblique skin incisions in the upper or lower abdomen such as McBurney, Chevron and Kocher are not the topic of the present article.

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Introduction

The anterior abdominal wall (AAW) is limited superiorly by the xiphoid process and costal arch, and inferiorly by the inguinal ligament, bones of the pubis and the iliac crest (Arslan, 2005). It is composed of nine abdominal layers, which consist of fascias, muscles, nerves and vessels (Mahadevan, 2006). Rich arterial and venous anastomoses from the superficial and deep vessels of the AAW are present (Gray et al., 2005; Netter, 2014). Therefore, physicians from surgical specialties regarding abdominal procedures should be familiar with the anatomy of the AAW. Moreover, surgeons should anticipate the types of surgical procedures that will be performed and possible complicated aspects related to the abdominal incision and the procedure. Knowledge of AAW anatomy is crucial to prevent iatrogenic vessels injury and to enhance repair in order to reduce the risk of incisional hernias or wound dehiscence. Additionally, the development and further evolution of the laparoscopic surgery emphasizes the essential and thorough understanding of the vascular anatomy of the AAW (Baggish and Karram, 2006). The goal of the present article is to delineate the AAW vessels anatomy and its application in abdominal surgery. Consequently, the majority of types of abdominal incisions and laparoscopic accesses will be presented. Furthermore, the possibility of vessels injury related to different types of accesses will be outlined in detail. Oblique skin incisions in the upper and lower abdomen such as McBurney, Chevron and Kocher are not the topic of the present article.

Methodology

The review and consensus process between authors was completed from March 2022 to December 2022. A comprehensive literature searches of studies (articles written in English and German) associated with AAW vessels anatomy, variations and abdominal incisions was performed. A computer-based extensive review of the MEDLINE, PubMed, EMBASE, and SciSearch databases was conducted. We used the following keywords and Medical Subject Headings (Mesh) terms: “anterior abdominal wall”, “anatomy”, “vessels”, “artery”, “vein”, “variation”, “incisions”, “trocar”, “complication”, “hematoma”. References from the selected papers were scanned for identifying other related articles. Additional information and figures from previous surgical procedures, different types of imaging modalities and anatomical studies on cadavers performed by authors were used for the preparation of the article. The anatomical terms used in the paper conform to the Terminologia Anatomica (Whitmore, 1999). Given the review nature of the article, no institutional review board or ethics committee approval was required.

Regions of the anterior abdominal wall

The AAW could be divided by into four quadrants by imaginary lines, which pass vertically and horizontally to the umbilicus (Farthing, 2018). The quadrants divide the anterior abdomen into the right and left upper and lower quadrants. Additionally,

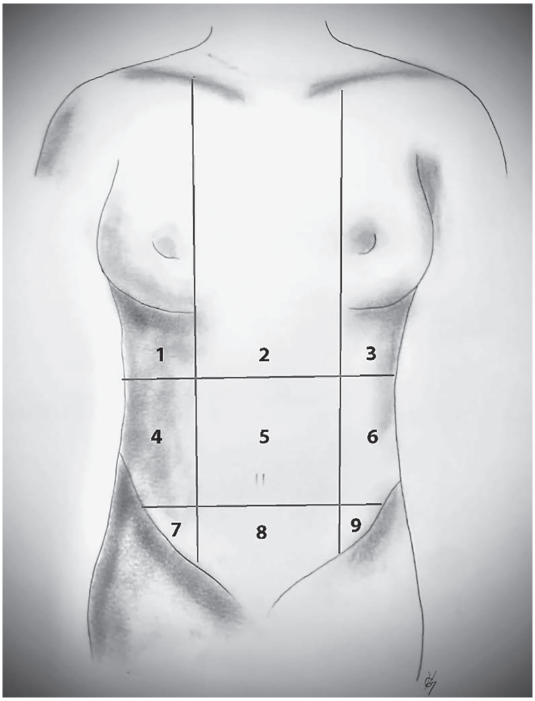

Figure 1 – The nine regions of the AAW (anterior abdominal wall). 1, 3 – right and left hypochondriac (located under the right and left costal margin). 4, 6 – right and left lumbar (on the right and left side of the abdomen). 7, 8 – right and left iliac (over the right and left iliac region). 8 – hypogastric (lower central abdomen – suprapubic). 2 – epigastric region (upper central abdomen). 5 – umbilical region.

the AAW could be separated into 9 regions, which are created by two vertical lines (through the midline of each clavicle) and two horizontal lines (one through the costal margin and one through the transtubercular plane). The regions are: right/left hypochondriac, right/left lumbar, right/left iliac, umbilical, hypogastric and epigastric (Gray et al., 2005; Netter, 2014). The nine regions are illustrated in Figure 1. This separation helps physicians accurately to describe the pathological conditions in the AAW (Arslan, 2005).

Layers of the anterior abdominal wall

The AAW from superficial to deep consists of the following nine layers: skin, subcutaneous fat, superficial fascia (Camper's fascia and Scarpa's fascia), external oblique muscle, internal oblique muscle, transversus abdominis muscle, transversalis fascia, preperitoneal adipose and areolar tissue, and parietal peritoneum (Mahadevan, 2006; Farthing, 2018). Some of the layers are shown in Figure 2.

The superficial fascia consists of two additional fascial layers – Camper's fascia and Scarpa's fascia. The Camper's fascia is a soft and movable adipose layer subjacent to the dermis, which inferior prolongation unites within the superficial fascia covering the labia majora. Additionally, the Camper's fascia passes above the inguinal ligament (without attaching to it) and continues with the superficial fascia of the thigh (Gray et al., 2005; Mahadevan, 2006; Netter, 2014; Farthing, 2018).

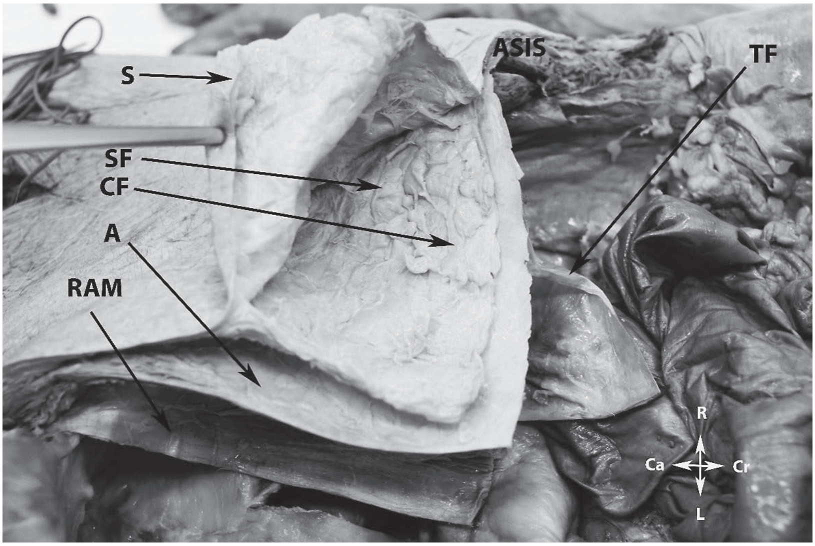

Figure 2 – The majority of the layers of anterior abdominal wall (embalmed cadaver – right pelvic sidewall). S – skin; SF – subcutaneous fat; CF – Camper's fascia; A – aponeurosis of rectus abdominis muscle; RAM – rectus abdominis muscle; TF – transversalis fascia; ASIS – anterior superior iliac spine; Cr – cranial; Ca – caudal; R – right; L – left.

Camper's fascia divides the skin from the muscles and plays an important role as a protector and an insulator to the deep organs of the abdomen (MacKay et al., 2022). Camper's fascia is often used as a marker for identifying superficial epigastric vessels, as they are located between the Scarpa's and Camper's fascia. Moreover, the latter has implication during inguinofemoral lymphadenectomy, as superficial inguinal lymph nodes are also located between these two superficial fascial layers. The incision is performed just deep to the Camper's fascia. The fascia has also applications during wound closure after cesarean section. The space between two superficial fascial layers is a potential source of postoperative wound complications such as dehiscence, seroma and fluid accumulation. Therefore, studies showed that approximation of Camper's fascia during wound closure was associated with lower rate of dehiscence and incisional hernias (Bohman et al., 1994; Hodgson et al., 2000; Mian et al., 2014).

The Scarpa's is a dense collagenous connective tissue layer, which lies below the Camper's fascia. It is thinner than Camper's fascia, especially in inferior direction. This Scarpa fascia is also known as Thompson's fascia. Superiorly, it continues with the retromammary fascia, whereas inferiorly with the superficial fascia covering the perineum. The continuation of the Scarpa's fascia to the perineum is known as Colles' fascia. The Scarpa's fascia is firmly attached to the linea alba, perineum and inguinal ligament. It passes below the ligament and continues with the fascia lata of the thigh (Reardon et al., 2004; Mahadevan, 2006; Farthing, 2018; Joshi and Duong, 2022).

A muscular-aponeurotic layer consists of the following anatomical structures – the external oblique muscles, the internal oblique muscles, the rectus abdominis muscles, the transversus abdominis muscles, the pyramidalis muscles, the rectus sheath and the linea alba. The pyramidalis muscles are inconstant and could be absent (Taylor and Daniel, 1975; Stern and Nahai, 1992; Yüksel and Yüksel, 1995; Arslan, 2005; Gagnon and Blondeell, 2006; Fukaya et al., 2011; Tubbs et al., 2016; Ogami et al., 2017; Zubler et al., 2021).

The linea alba is located at the midline (medial to the rectus abdominis muscle) from the xiphoid process to the symphysis pubis. It is formed from the aponeuroses of the external, internal and transversus abdominis muscles. The linea alba is significantly thicker above the umbilicus as the rectus abdominis muscles lie closer from one other, whereas below the umbilicus the linea alba narrows progressively as the muscles diverge from one other. At the lower AAW, the linea alba has two attachments – one to the symphysis pubis and the other behind rectus muscles to the posterior surface of the pubic crest (also known as "adminiculum lineae albae" (Arslan, 2005; Gray et al., 2005; Mahadevan, 2006; Netter, 2014).

The umbilicus is a result from the remnants of the umbilical cord. The base of the umbilicus is the thinnest part of the AAW. It is located in the linea alba, but its position depends on the body mass index of the patients. Generally, in adults it is located at the level of the disc between the 3th and 4th lumbar vertebral body. The abdominal aorta bifurcation is located 2 cm inferior to the umbilicus. The

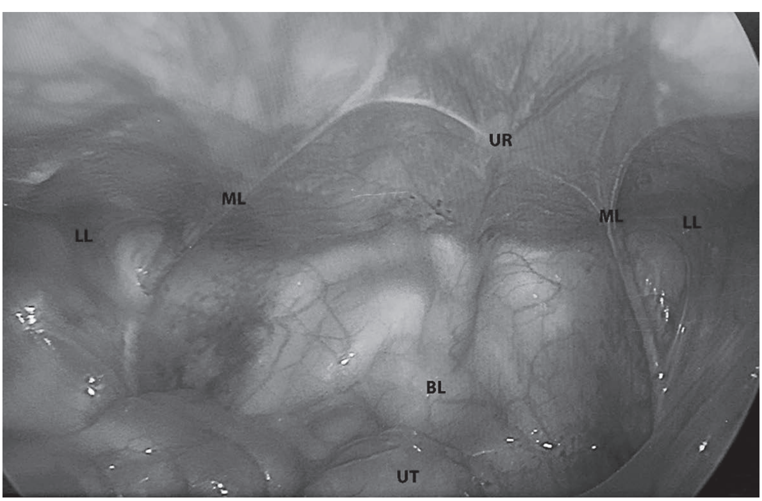

Figure 3 – Ligament of the anterior abdominal wall (laparoscopic surgery). UR – urachus remnant, median umbilical ligament; ML – medial umbilical ligament (obliterated umbilical arteries); LL – lateral ligament (inferior epigastric artery/vein); BL – bladder; UT – uterus.

following ligaments attach to the umbilicus – median (urachus remnant), medial (obliterated umbilical arteries), lateral (inferior epigastric artery/vein) and the falciforme ligament (Arslan, 2005; Gray et al., 2005; Mahadevan, 2006; Netter, 2014) (Figure 3).

The rectus sheath is an aponeurotic sheath that surrounds the rectus abdominis muscle. It is formed by two sublayers – anterior and posterior. The anterior is derived from two adherent layers – one of aponeurosis of the external oblique muscle and the other from the anterior aponeurosis of the internal oblique muscle. The posterior layer of the rectus sheath is formed from the posterior aponeurosis of the internal oblique muscle and the aponeurosis of the transversus abdominis (Arslan, 2005; Mahadevan, 2006). However, that particular layer arrangement of the rectus sheath exists only below the arcuate line (5 cm below the umbilicus). Above that line, the anterior aponeurosis of the internal oblique muscle and the aponeurosis of the transverse muscle pass completely anterior to the rectus abdominis muscle. Therefore, the posterior wall of the rectus abdominis sheath is absent above that line, and the transversalis fascia lies just below the muscle (Gray et al., 2005; Netter, 2014).

The transversalis fascia of the AAW is located between the inner surface of transversus abdominis and the preperitoneal fat. It contributes to the posterior wall of the rectus sheath. Although it is a relatively thin layer, in the lower part of the anterior abdominal wall is less expansive, especially at the level of the inguinal region, where it becomes thicker and dense. The fascia attaches to the iliac crest, the posterior margin of the inguinal ligament, to the pecten pubis and to the conjoint tendon. At the level of the deep inguinal ring, the round ligament of the uterus passes through the transversalis fascia (Arslan, 2005; Gray et al., 2005; Mahadevan, 2006; Netter, 2014).

The preperitoneal fat is located between the transversalis fascia and the parietal peritoneum. Its thickness depends on body mass index of the patient, but in the lower part of the AAW, the preperitoneal fat is always thicker. Below the umbilicus, the preperitoneal fast is divided into two layers (anterior and posterior) by the umbilical prevesical aponeurosis (fascia prevesicalis). The letter represents a triangle with a posterior broad base formed by the fascia of the bladder. The anterior vertex of the triangle fuses with the transversalis fascia at the level of the umbilicus. The space near the bladder, which is located between the umbilical prevesical aponeurosis and transversal fascia, is called Retzius space (Gray et al., 2005; Mahadevan, 2006; Netter, 2014).

The parietal peritoneum is the last posterior layer of the AAW. It is loosely attached to the AAW due to the existence of the preperitoneal fat. However, the parietal peritoneum is dense and firmly attached to the umbilicus, linea alba, inferior surface of the diagraph and the posterior wall of the inguinal canal. At the lower and posterior part of the AAW, the parietal peritoneum passes though the iliac fossa without joining to the inguinal ligament. Contrary, the transversalis fascias attaches

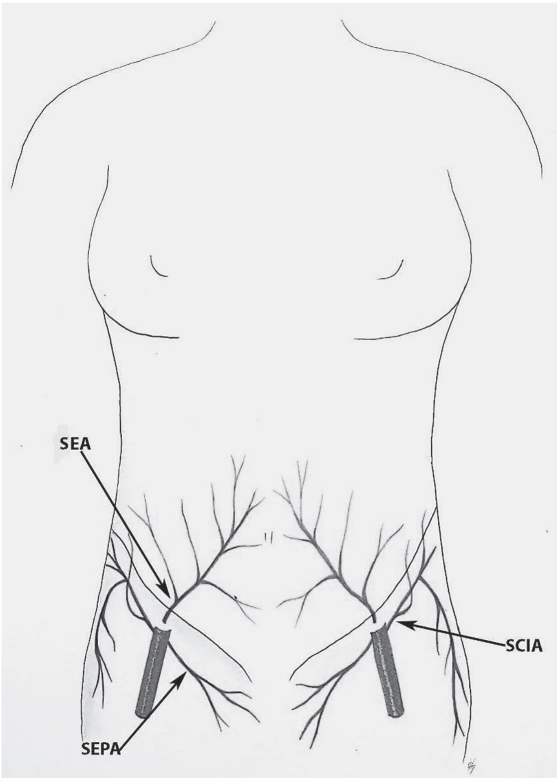

Figure 4 – Superficial arteries of the anterior abdominal wall. SEA – superficial epigastric artery; SCIA – superficial circumflex iliac artery; SEPA – superficial external pudendal artery.

to the inguinal ligament. As a result of that divergation between the fascia and the peritoneum, a potential space could be encountered – the Bogros space (Gray et al., 2005; La Falce et al., 2006; Netter, 2014).

Superficial arteries of the anterior abdominal wall

The superficial arteries of the AAW are the following: superficial epigastric artery (SEA), superficial circumflex iliac artery (SCIA), superficial external pudendal artery (SEPA). These arteries are illustrated in Figure 4.

Superficial epigastric artery

The superficial epigastric artery (SEA) arises from the common femoral artery 2–3 cm below the inguinal ligament. It then proceeds superiorly and laterally from the femoral triangle and then crosses the inguinal ligament at its midpoint. Initially it is located deep to Scarpa's fascia. Subsequently, above the inguinal ligament, the SEA is located superomedially and continues in the subcutaneous fat by piercing the Scarpa's fascia (Reardon et al., 2004; Gagnon and Blondeell, 2006). The SEA is located laterally and deeper than its venous counterpart is. The medial branches of the artery anastomose with the branches of intercostal arteries, superficial and deep circumflex iliac arteries, whereas lateral branches anastomose with the branches of superior and inferior epigastric arteries (Reardon et al., 2004).

Anatomical variations and discussion

SEA variations differ according to different anatomical studies. Fathi et al. (2008) performed 40 dissections on 20 preserved or fresh male cadavers. Authors reported that in 57.9% of the cases, the SEA originated directly from a common femoral artery. Some studies found that the SEA could be absent in approximately one third of the population (Taylor and Daniel, 1975; Gagnon and Blondeell, 2006; Fukaya et al., 2011). A large ascending branch or multiple small branches from the SCIA replaced the absent SEA (Taylor and Daniel, 1975; Stern and Nahai, 1992; Reardon et al., 2004; Gagnon and Blondeell, 2006; Fukaya et al., 2011). However, other studies reported a presence of the SEA in 90, 94 and 95% of the examined cadavers, respectively (Reardon et al., 2004; Rozen et al., 2010). SEA could arise in a common trunk with the SCIA, SEPA and deep circumflex iliac artery (Taylor and Daniel, 1975; Stern and Nahai, 1992; Reardon et al., 2004; Gagnon and Blondeell, 2006; Fukaya et al., 2011). Fukaya et al. (2011) found a common trunk between SEA and SCIA in 36.4% of cases. Reardon et al. (2004) reported that the SEA shared a common trunk with the SCIA, SEPA and deep circumflex iliac artery in 70, 35 and 20% of cases, respectively. In rare cases, the artery could arise from the pudendal artery or deep femoral artery (Yüksel and Yüksel, 1995; Tubbs et al., 2016). Yüksel and Yüksel (1995) reported a case of SCIA and SEA arising in a common stem from the deep femoral artery.

Superficial circumflex iliac artery

In the majority of cases, the SCIA originates from the lateral aspect of the femoral artery at the level of the SEA (sometimes in a common trunk) (Figure 5). It then perforates laterally the deep fascia of the thigh and proceeds parallel to the inguinal ligament. The SCIA has a lateral course forward the anterior superior iliac spine (ASIS) (Yüksel and Yüksel, 1995; Arslan, 2005). It has two branches – superficial and deep. The superficial branch pierces the deep fascia and proceeds in a latero-cranial direction to the deep fat, whereas the deep branch runs subfascially over a longer distance and supplies the deep inguinal lymph nodes, sartorius muscle and deep fascia (Zubler et al., 2021). The SCIA branches anastomose with branches of the SEA, deep circumflex iliac artery, superior gluteal and lateral femoral circumflex artery (Arslan, 2005; Tubbs et al., 2016).

Anatomical variations and discussion

Generally, the SCIA is more constant than the SEA. It could arise from the superficial or deep femoral artery or in a common stem with the SEA (Ogami et al., 2017; Zubler et al., 2021). Ogami et al. (2017) observed deep circumflex iliac artery and

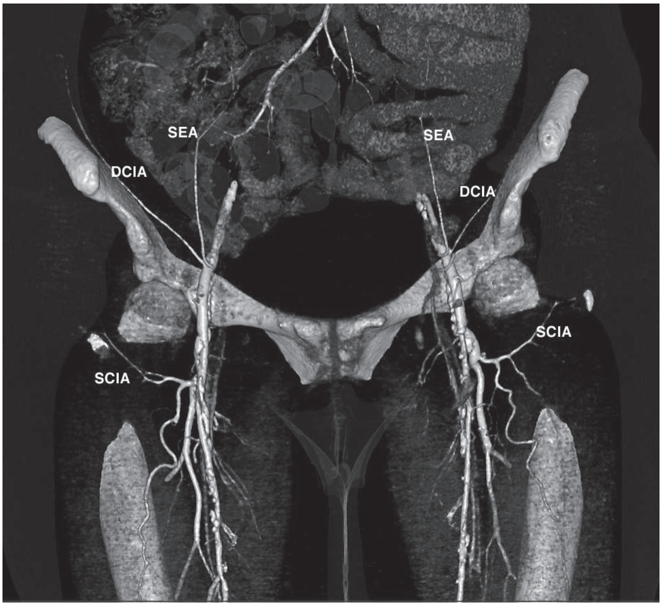

Figure 5 – Thin slice volume rendered computed tomography reconstruction of ilio-femoral vascular segment. Superficial epigastric artery (SEA), deep circumflex iliac artery (DCIA) and superficial circumflex iliac artery (SCIA) is annotated bilaterally.

SCIA in 130 femoral triangles derived from 65 formalin-fixed cadavers. Authors reported for double SCIA in 7.7% of cases. Bilateral double SCIA was identified in one cadaver. Ghassemi et al. (2013) reported for three types of variations of the SCIA. In type I, the artery had one or two branches and originated below the inguinal ligament. In type II, the artery originated from its deep counterpart. Type III variations was associated with absence of the SCIA, which was observed in 5.5% of specimens.

Superficial external pudendal artery
The SEPA arises from the femoral artery below the origin of SEA and SCIA. It continues medially, generally below the great saphenous vein and across the round ligament. Subsequently, the SEPA divides into two main branches. The superior branch supplies the symphysis pubis and the lower part of the AAW. The inferior branch supplies the skin of the labia majora. The branches of SEPA anastomose with branches of the internal pudendal artery (Gray et al., 2005).

Anatomical variations and discussion
La Falce et al. (2006) investigated the anatomy and variations of the SEPA in 50 inguinal regions of cadavers. Authors found that in the majority of cases the SEPA originated from the femoral artery – 98%. The incidence of SEPA originating from the deep femoral artery was 2%. A duplicated SEPA was found in 46% of specimens.

Superficial veins of the anterior abdominal wall

Superficial veins of the AAW are the following: superficial epigastric vein (SEV), superficial circumflex iliac vein (SCIV), superficial external pudendal vein (SEPV). These veins are shown in Figures 6 and 7.

Superficial epigastric vein

SEV drains into the great saphenous vein. It also drains in the portal vein through the paraumbilical veins. The SEV is located medial and superficial compared to the artery and forms multiple anastomoses at the superficial layer of the AAW. Venous connections between the SEV and thoracoepigastric vein form the cavo-caval anastomoses. Additionally, the anastomoses between the SEV/thoracoepigastric vein and paraumbilical veins form the portocaval anastomoses. The SEV also connects through anastomoses with the other superficial veins of the AAW (Arslan, 2005; Gray et al., 2005; Mahadevan, 2006; Fukaya et al., 2011).

Anatomical variations and discussion

In some atlases of anatomy, it was illustrated that the SEV drained into the femoral vein (Netter, 2014). It is debatable, as SEV draining in the femoral vein is rather an anatomical variation that a general draining pattern of the vein. Reardon et al. (2004) performed 22 cadaveric dissections and examined the anatomy of the SEV and SEA. Authors observed that the SEV drained into the saphenous bulb in 95.3% of cases.

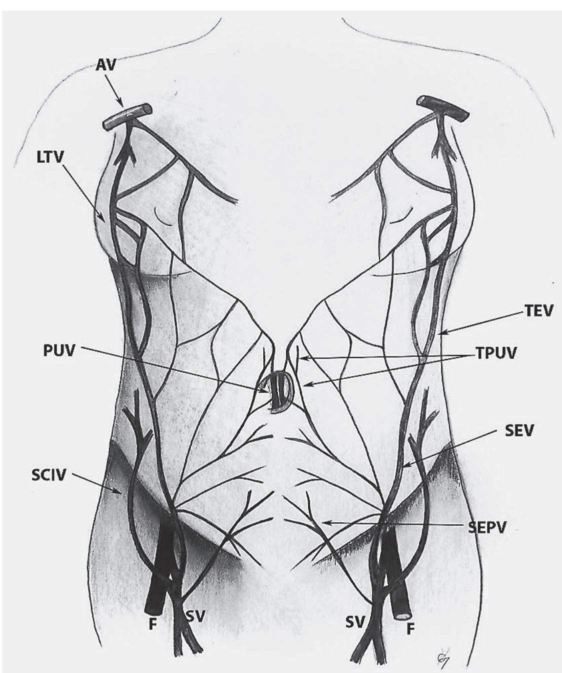

Figure 6 – Superficial veins of the AAW (anterior abdominal wall). AV – axillary vein; LTV – lateral thoracic vein; TEV – thoraco-epigastric vein; TPUV – tributaries of para-umbilical veins; PUV – para-umbilical veins; SCIV – superficial circumflex iliac vein; F – femoral vein; SV – saphenous vein; SEPV – superficial external pudendal vein; SEV – superficial epigastric vein.

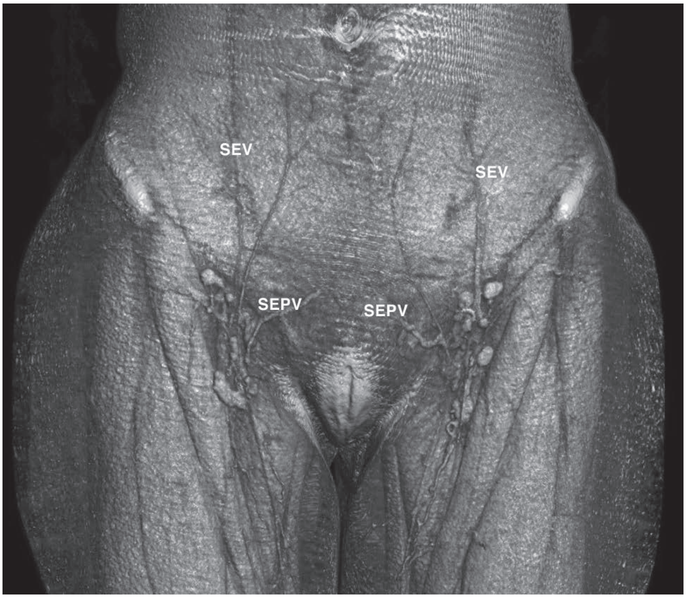

Figure 7 – Volume rendered image of computed tomography venography depicturing SEV and SEPV bilaterally (anterior view of the AAW – anterior abdominal wall). SEV – superficial epigastric vein; SEPV – superficial external pudendal vein.

The vein was absent in one case. The vein drained as an individual vein, as multiple veins, or both in 57, 38, and 4.7% of cases, respectively. Mühlberger et al. (2009) dissected 114 formalin fixed bodies with 217 great saphenous veins. Authors found that the SEV drained in the saphenous vein in 78.3% of cases. In the majority of cases, it entered the great saphenous vein 1.2 cm distally to its orifice. Contrary to these results, Rozen et al. (2009) observed that the SEV drained into the superficial

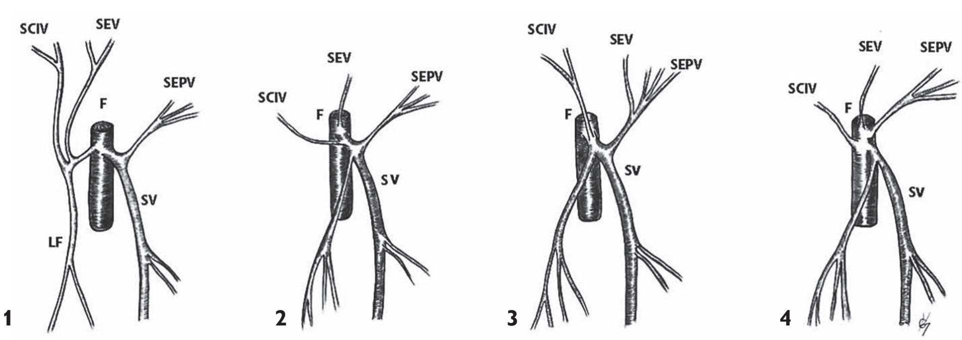

Figure 8 – Draining pattern variations of the SEV. SEPV – superficial external pudendal vein; SCIV – superficial circumflex iliac vein; SEV – superficial epigastric vein; SV – saphenous vein; LF – lateral femoral vein; F – femoral vein.
1 – SEV forms a common trunk with the lateral superficial femoral and superficial circumflex iliac vein. The drunk drain into the femoral vein. 2 – The SEV drains directly into the femoral vein. 3 – A common trunk between the SEV and superficial external pudendal vein, which drains into the saphenous vein. 4 – SEV, SEPV and SCIV drains separately into the saphenous vein.

femoral vein in 62.5% of among 200 examined sides. However, the term "superficial femoral vein" has been discarded. Terminologica anatomica did not recognized this term and replaced it with just femoral vein, as the vein is deep, not superficial (Monkhouse, 2001; Caggiati et al., 2002; Chua et al., 2017). Chun et al. (1992) investigated 249 lower limbs among Koreans and found that the SEV drained in the great saphenous vein directly or by a common trunk in 77.1% of cases. The most common draining pattern variations of the SEV are shown in Figure 8.

Superficial circumflex iliac vein

The SCIV runs parallel to the inguinal ligament following its arterial counterpart. In most cases it drains in the great saphenous vein. The SCIV collects the blood from the lateral lower part of the AAW (the area, which is located superior to the lateral part of the inguinal ligament) and the proximal region of the superficial thigh (Arslan, 2005; Gray et al., 2005; Netter, 2014). Its branches anastomose with the branches of the SEV, deep circumflex iliac vein, external pudendal vein and thoracoepigastric veins.

Anatomical variations and discussion

Mühlberger et al. (2009) examined 14 formalin fixed bodies with 217 great saphenous veins. Authors observed that the SCIV drains in the great saphenous vein in the 82.9% of cases. Glasser (1943) performed a dissection of 50 cadavers (100 lower extremities) and examined the venous variations in the fossa ovalis. Authors found that the incidence of SCIV, which drained into the femoral vein was approximately 1%. Glasser also found an incidence of 9% for the SCIV drained in a

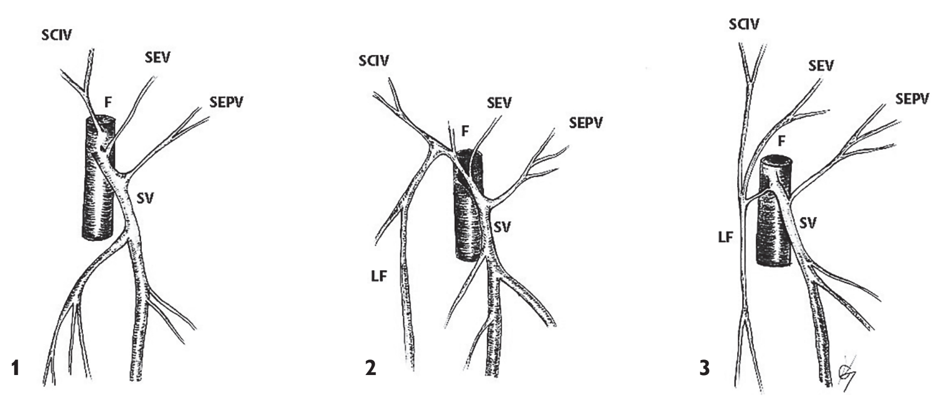

Figure 9 – Draining pattern variations of the SCIV. SEPV – superficial external pudendal vein; SCIV – superficial circumflex iliac vein; SEV – superficial epigastric vein; SV – saphenous vein; LF – lateral femoral vein; F – femoral vein.
1 – SCIV drains into the femoral vein. 2 – SCIV forms a common trunk with the lateral femoral vein. Both veins drain into the saphenous vein. 3 – SCIV, SEV and lateral femoral vein drain into the saphenous vein in a common trunk.

common trunk with lateral femoral and SCIV. A common trunk between the lateral femoral and SCIV, which drained in the great saphenous vein, was observed in 1% of cases. Actually, the term "lateral femoral vein" correspondence with the term "deep femoral vein" or "profunda femoris vein" according to Terminologica anatomica (Monkhouse, 2001; Caggiati et al., 2002). However, Glasser (1943) concluded that venous variations were not common since the venous patterns tend to be generally inconstant in the body. Penteado (1983) examined the anatomy of SCIV in 43 formalin-fixed cadavers. In only two cases the SCIV drained in the femoral vein, whereas in all other cases it entered in the great saphenous vein. In 36.3%, the SCIV and the SEV shared a common trunk and drained in the great saphenous vein. Authors also found that in 12.7% of cases the SCIV shared a common trunk with superficial accessory saphenous vein and a common trunk with the SEV and superficial accessory saphenous vein in 10.9% of cases. Rozen et al. (2011) observed a common trunk between SCIV and SEV in 21% of examined cases. Chun et al. (1992) found that the SCIV entered in the great saphenous vein either directly or in a common trunk in 83.1% of cases. Authors described 10 variant types, of which a common trunk between SCIV and lateral accessory saphenous vein was the most common – 13.3%. The most common draining pattern variations of the SCIV are shown in Figure 9.

Superficial external pudendal vein

The SEPV follows its arterial counterpart and in the majority of cases drains in the great saphenous vein. The SEPV is a continuation of the labial veins. It collects the blood from the medial lower part of the AAW and from the symphysis pubis. Its branches anastomose with the branches of deep external pudendal vein, SEV.

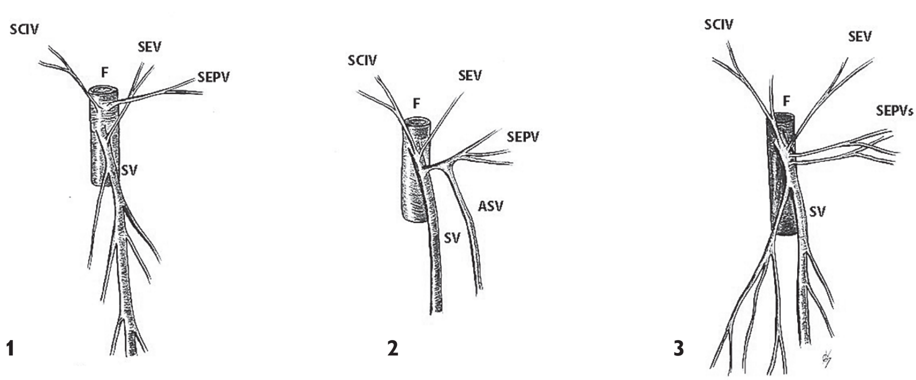

Figure 10 – Draining pattern variations of the SEPV are shown in Figure 8. SEPV – superficial external pudendal vein; SEPVs – superficial external pudendal veins; SCIV – superficial circumflex iliac vein; SEV – superficial epigastric vein; SV – saphenous vein; ASV – accessory saphenous vein; LF – lateral femoral vein; F – femoral vein. 1 – The SCIV and the SEPV drain separately into the femoral vein. 2 – An accessory saphenous vein forms a common stem with the SEPV. Both veins drain into the saphenous vein. 3 – Two SEPVs drain separately into the saphenous vein.

The bilateral superficial external pudendal veins form many anastomoses above the symphysis pubis (Gray et al., 2005; Netter, 2014).

Anatomical variations and discussion
Chun et al. (1992) found that SEPV drained in the great saphenous vein in 61.9% of cases. Glasser (1943) reported an incidence of 81% for this draining pattern. The incidence of SEPV draining in the femoral vein was 1%.

Chun et al. (1992) reported that the most frequent draining pattern variation was a common trunk between SEPV, medial accessory and SEV.

The incidence of a common trunk between SEPV and accessory saphenous vein, which drain in the great saphenous vein, is 6%. In 3% of cases, two separate SEPVs could be observed. A common trunk between SEPV and SEV is observed in 2% of the population (Glasser, 1943). Draining pattern variations of the SEPV are shown in Figure 10.

Deep arteries of the anterior abdominal wall

The deep arteries of the AAW are the following: the inferior epigastric artery (IEA), deep circumflex iliac artery (DCIA), internal thoracic artery (ITA) and superior epigastric artery (SUEA). Deep arteries of the AAW are shown in Figure 11.

Inferior epigastric artery

The IEA originates from the anteromedial aspect of the external iliac artery in the extraperitoneal connective tissue just above and the inguinal ligament (Figures 12

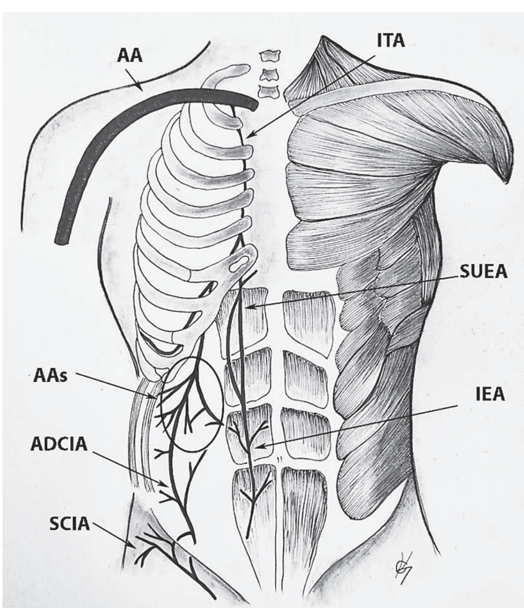

Figure 11 – Deep arteries of the AAW (anterior abdominal wall). The superficial circumflex iliac artery is also illustrated for better differentiation from the ascending branch of the deep circumflex iliac artery. AA – axillary artery; ITA – internal thoracic artery; SCIA – superficial circumflex iliac artery; ADCIA – ascending branch of the deep circumflex iliac artery; AAs – arterial anastomoses between the lower intercostal, subcostal and lumbar arteries; IEA – inferior epigastric artery; SUEA – superior epigastric artery.

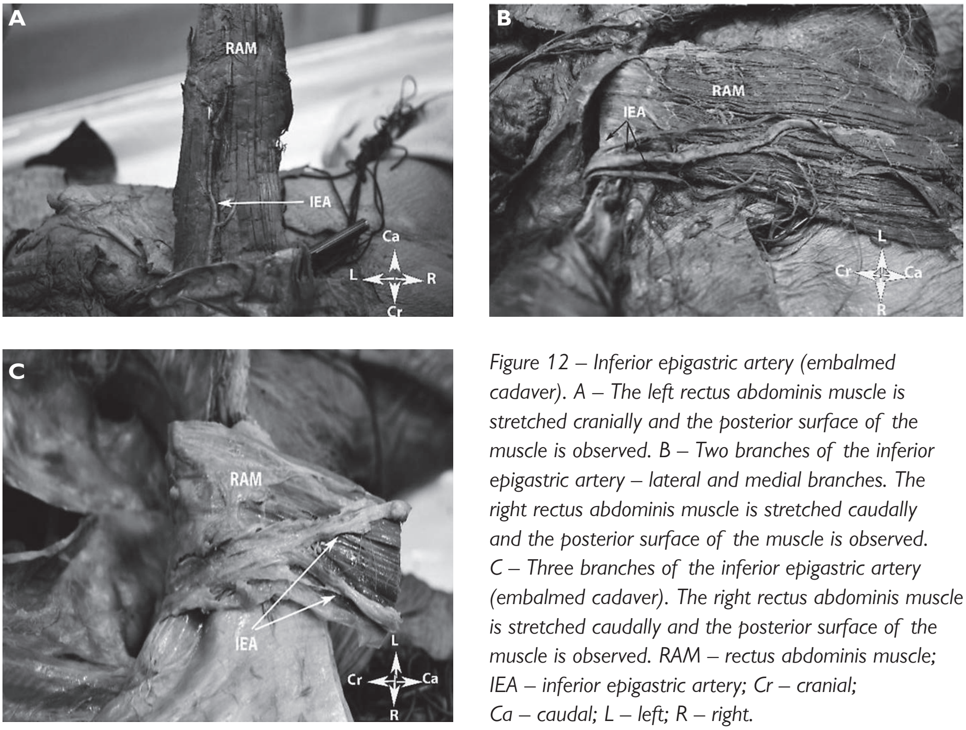

Figure 12 – Inferior epigastric artery (embalmed cadaver). A – The left rectus abdominis muscle is stretched cranially and the posterior surface of the muscle is observed. B – Two branches of the inferior epigastric artery – lateral and medial branches. The right rectus abdominis muscle is stretched caudally and the posterior surface of the muscle is observed. C – Three branches of the inferior epigastric artery (embalmed cadaver). The right rectus abdominis muscle is stretched caudally and the posterior surface of the muscle is observed. RAM – rectus abdominis muscle; IEA – inferior epigastric artery; Cr – cranial; Ca – caudal; L – left; R – right.

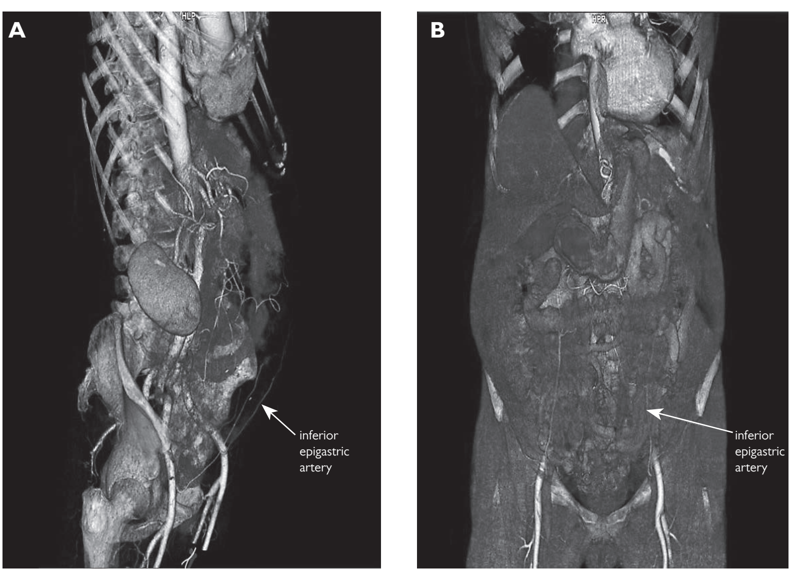

Figure 13 – Contrast enhanced computed tomography (CT) thick slice volume rendered (VR) coloured body reconstruction depicting inferior epigastric artery as annotated. A – lateral view of abdomen; B – anterior view of the anterior abdominal wall.

and 13). It then ascends on the AAW medial to the deep inguinal canal. The IEA passes posterior and medial to the round ligament. Moreover, the artery runs from lateral to medial, pierces the transversalis fascia at the level of the arcuate line and ascends between the lateral margin of the rectus abdominis muscle and the posterior rectal sheath. In some cases, it divides into two branches – lateral (dominant in 50% of cases) and medial (dominant in 7% of cases) (Gagnon and Blondeel, 2006) (Figure 12). In the lower part of the AAW, the IEA forms a fold of the parietal peritoneum known as lateral umbilical ligament. The latter is located lateral to the obliterated umbilical vessels (Anandhi et al., 2016; Joy et al., 2017; Higgins et al., 2021). The IEA participates in the formation of the Hesselbach's triangle (Baggish and Karram, 2006). Moreover, the IEA is the medial boundary of the Bogros space (Yang and Liu, 2016). The IEA gives branch to the round ligament, which is known as Sampson's artery (Sampson, 1917). The IEA gives three more branches – pubic, muscular and cutaneous (Netter, 2014).

The Sampson's artery anastomoses with the ascending branch of the uterine artery at the level of the round ligament. The pubic branch of the IEA anastomoses with a branch of the obturator artery. This anastomotic vessel is known as "Corona mortis" (Anandhi et al., 2016). The muscle branches anastomose with the ascending branch of the deep circumflex iliac artery and branches of the lumbar and intercostal arteries. Branches of the IEA anastomose with branches of the superior epigastric artery (Gray et al., 2005; Netter, 2014).

Anatomical variations and discussion

The IEA could arise from the obturator artery and femoral artery. It could also originate from the external iliac artery or internal iliac artery in a common trunk within the obturator artery (Gray et al., 2005; Tubbs et al., 2016) (Figure 14). Surgeons should know the approximate distance of the IEA from the important

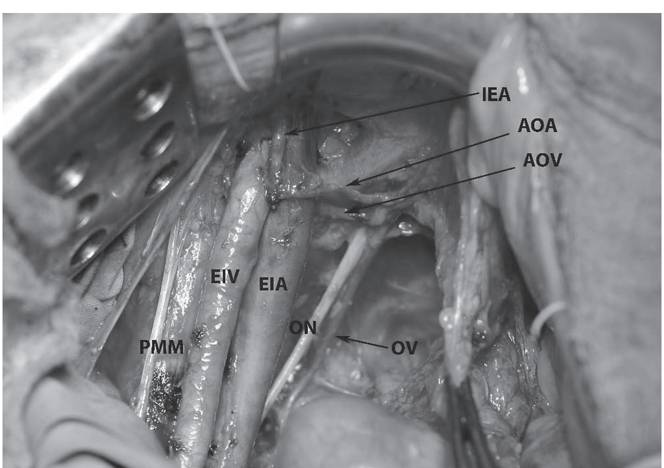

Figure 14 – A common trunk between the inferior epigastric artery and an aberrant obturator artery (open surgery – left pelvic sidewall). AOA – aberrant obturator artery; AOV – accessory obturator vein; IEA – inferior epigastric artery; ON – obturator nerve; OV – obturator vein; PMM – psoas major muscle; EIV – external iliac vein; EIA – external iliac artery.

anatomical landmarks of the AAW. Anandhi et al. (2016) examined the IEA in 50 cadaveric specimens. Authors reported that the distance of IEA from midline at the level of umbilicus was 3.6 cm on right side and 3.5 cm on the left side, respectively. The distance of IEA from the midline at the level between the umbilicus and the symphysis pubis was 3.5 on the right and 3.4 on the left. Rahn et al. (2010) examined the anatomy of IEA among 11 female cadavers. Authors found that at the level, which was 2 cm superior to symphysis pubis, the distance of the vessels from midline was 6.1 cm. Authors concluded that the IEA is located always lateral to the rectus muscle at the level above 2 cm from the symphysis pubis. Joy et al. (2017) estimated an average distance of the IEA from the midline being 4.45 ± 1.42 cm at mid-inguinal point level.

Hesselbach's triangle – Clinical significance and discussion
Hesselbach's triangle is located in the lower posterior aspect of the AAW. The German anatomist and surgeon Franz Hesselbach was the first, who described the triangle and its boundaries. It is limited medially by the lateral border of the rectus abdominis muscle, inferiorly by the inguinal ligament (also known as Poupart's ligament) and laterally by the inferior epigastric vessels (Hesselbach, 1806; Agarwal and Mukherjee, 2008; Misiakos et al., 2014). The triangle represents a potential anatomical area of weakness in the groin, where an inguinal hernia can occur. The triangle is also a part of the modern classification of inguinal hernias and separates the hernias into direct (the hernia protrudes through the triangle) and indirect (the hernia does not protrude through the triangle) (Hesselbach, 1806; Agarwal and Mukherjee, 2008; Misiakos et al., 2014).

Corona mortis – Clinical significance and discussion
Corona mortis is a heterogeneous term, which causes controversies in medical literature (Kostov et al., 2021). Some authors define corona mortis as any vessels, which passes over the superior pubic branch, regardless of whether it is a vascular anastomose or an obturator vessel related to the external iliac artery or vein (Rusu et al., 2009). The incidence according to this terminology was found to be 80% of the examined cadavers (Rusu et al., 2009) However, the majority of authors described corona mortis, as every anastomotic vessel, located behind the superior pubic ramus and on the posterior aspect of the lacunar ligament, between obturator vessels and external iliac system. Therefore, the vessels should participate in anastomoses to be stated as corona mortis (Sanna et al., 2018; Kostov et al., 2021). The anastomoses could be between external iliac/inferior epigastric vessels and obturator vessels. Other vessels, which originate from an external iliac artery or its branches, do not participate in anastomoses and pierced the obturator membrane are termed "aberrant" obturator vessels. The incidence of aberrant obturator artery originating from the inferior epigastric artery varies – 20–34% (Pick et al., 1942; Kostov et al., 2021). Sanna et al. (2018) performed a meta-analysis and estimated

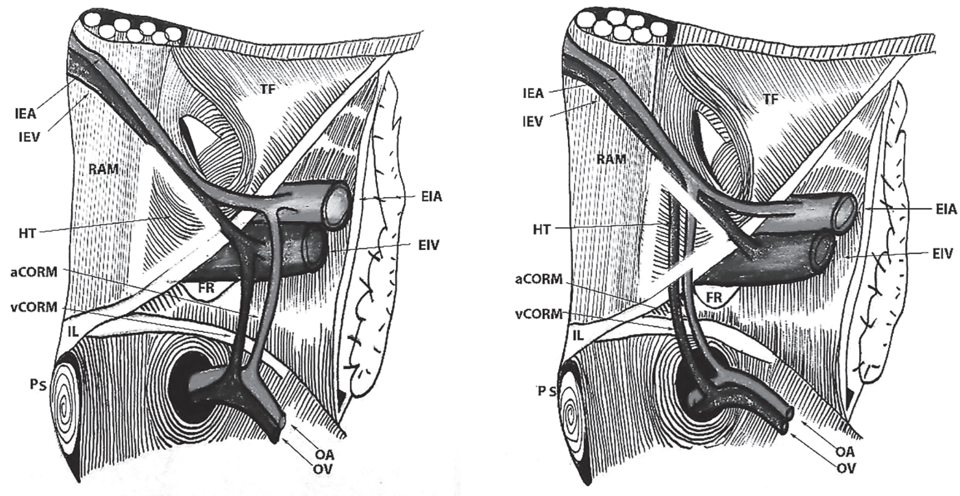

Figure 15 – The Hesselbach's triangle. A – Hesselbach triangle limits. Corona mortis passes lateral to the femoral ring and does not cross the Hesselbach's triangle. B – Corona mortis passes medial to the femoral ring (crosses the Hesselbach's triangle) and could be injured during inguinal hernia repair or urogynecological procedures. IEA – inferior epigastric artery; IEV – inferior epigastric vein; RAM – rectus abdominis muscle; HT – Hesselbach's triangle in the yellow triangle; TF – transversalis fascia; PS – pubic symphysis; EIA – external iliac artery; EIV – external iliac vein; IL – inguinal ligament; FR – femoral ring; OA – obturator artery; OV – obturator vein; vCORM – venous corona mortis; aCORM – arterial corona mortis.

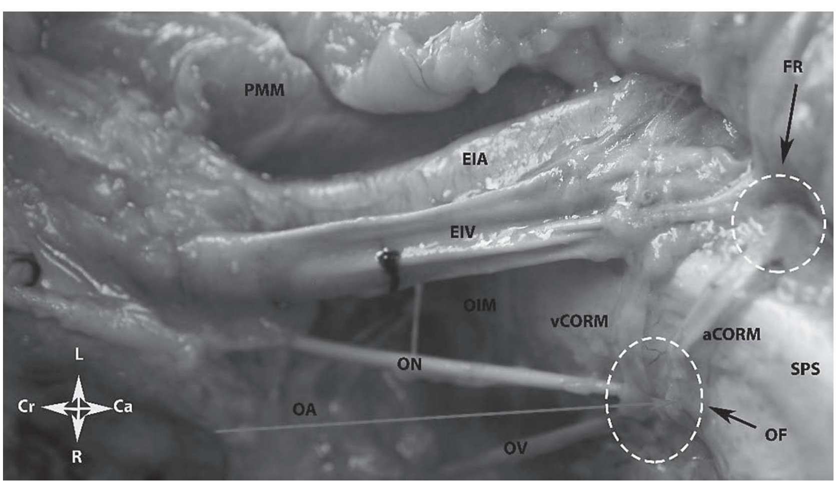

Figure 16 – Venous and arterial corona mortis (fresh cadaver – left sidewall). EIA – external iliac artery; EIV – external iliac vein; FR – femoral ring; OF – obturator foramen; PMM – psoas major muscle; OIM – obturator internus muscle; ON – obturator nerve; OA – obturator artery (injured during dissection); OV – obturator vein; SPS – superior pubis symphysis; aCORM – arterial corona mortis; vCORM – venous corona mortis; Cr – cranial; Ca – caudal; L – left; R – right.

that the real incidence of the corona mortis in hemi-pelvises was high (49.3%). Authors also reported that the rate of the venous corona mortis is higher compared to its arterial counterpart – 41.7% vs. 17.0%.

Surgeons should be familiar with the anatomy of corona mortis, as it could be injured during inguinal hernia repair, urogynecological procedures or pelvic lymphadenectomy. However, the risk of lacerations of corona mortis depends on its location regarding the femoral ring. Corona mortis lateral to the femoral ring could be damaged during pelvic lymphadenectomy. Corona mortis medial to the femoral ring might be injured during inguinal hernia repair (crosses the Hesselbach's triangle) or urogynecological procedures (Kostov et al., 2021).

The Hesselbach's triangle and its close relation with corona mortis is illustrated in Figure 15. Corona mortis is shown in Figure 16.

Bogros space – Clinical significance

The Bogros space (also known as retroinguinal space) is an extraperitoneal space, which is located lateral to the prevesical space (Retzius space). It is limited laterally by the iliac fascia, medially by the inferior epigastric vessels, anteriorly by the transversalis fascia and posteriorly by the parietal peritoneum. The Bogros space is divided into two compartments – medial (containing the femoral vessels) and lateral (provide passage of the iliopsoas muscle, allowing attachment to the femur, along with the femoral nerve). The space of Bogros is dissected during laparoscopic inguinal hernia repair in order to provide access to the iliac fossa and further easier placement of the lateral mesh (Yang and Liu, 2016; Lorenz et al., 2022).

Deep circumflex iliac artery

The DCIA arises from the lateral aspect of the external iliac artery just above the inguinal ligament. It has lateral and superior course until its branches reach the ASIS. The DCIA passes behind the inguinal ligament in a sheath, which is derived from the iliacus and transversalis fascia. It crosses the transversus abdominis muscle and proceeds between transversus and internal oblique muscle to anastomose with branches of the iliolumbar and superior gluteal artery. At the level of ASIS, a large branch of the DICA supplies both muscles and anastomoses with branches of gluteal and IEA artery (Gray et al., 2005; Netter, 2014).

Anatomical variations and discussion

The DCIA is a relatively constant artery, and its variations are extremely rare. Sarna et al. (2020) examined the anatomy of the DCIA in 52 embalmed cadavers. Authors found that the artery was bilateral and presented in all cases. Moreover, in all cases its origin was the external iliac artery.

There are many pelvic anastomoses in the pelvis, which are divided into horizontal and vertical. The internal iliac artery (IIA) is the main arterial vessel of the pelvis. IIA ligation is a lifesaving procedure in cases of severe bleeding during surgical interventions in the pelvis. Just after ligation of the IIA, the following pathophysiological mechanisms are activated – terminating the blood pressure in small arteries distal to the ligation and transforming the arterial system into a venous one. After ligation, the pelvic blood supply is maintained through three major pelvic anastomoses – 4^{th} lumbar with the iliolumbar arteries, middle sacral with lateral sacral arteries and superior rectal with middle or inferior rectal arteries. However, there are other small anastomoses, which provide the blood supply in the pelvis and prevent necrosis to the buttocks and gluteal maximus muscle. Some of these anastomoses are part of the arteries of the AAW. The DCIA anastomoses with branches of superior gluteal artery, 4^{th} lumbar artery, IEA and iliolumbal artery. The SCIA anastomoses with the superior gluteal artery (Cocq, 1966; Burchell, 1968; Keith et al., 2008; Akinwande et al., 2015). Corona mortis is also a part of the anastomoses after IIA ligation. The other anastomoses are from the femoral artery – medial circumflex femoral artery (anastomoses with branches of inferior gluteal artery and obturator artery) and lateral circumflex femoral artery (anastomoses with superior gluteal artery) (Cocq, 1966; Burchell, 1968; Keith et al., 2008; Akinwande et al., 2015).

Deep veins of the anterior abdominal wall – Inferior epigastric, deep external pudendal and deep circumflex iliac veins

Usually, two inferior epigastric veins follow its arterial counterparts and drain in the external iliac vein just above the inguinal ligament. The deep circumflex iliac vein

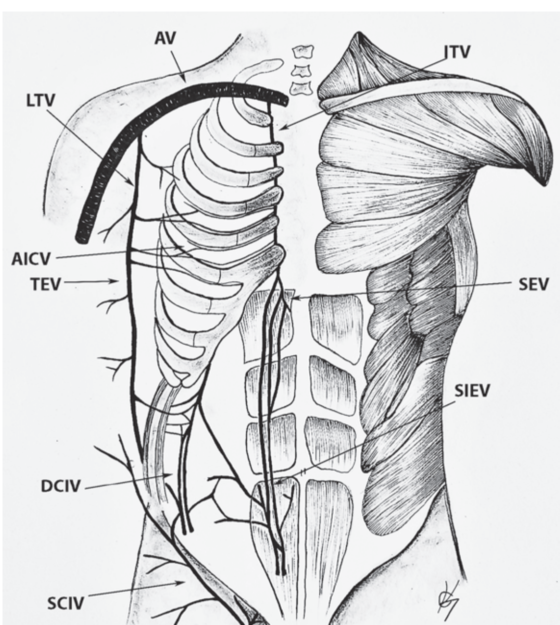

Figure 17 – Deep veins of the anterior abdominal wall. The superficial circumflex iliac vein is also shown for better differentiation from the deep circumflex iliac vein. AV – axillary vein; LTV – lateral thoracic vein; ITV – internal thoracic vein; AIVC – anterior intercostal vein; TEV – thoraco-epigastric veins; DCIV – deep circumflex iliac vein; SCIV – superficial circumflex iliac vein; IEV – inferior epigastric vein; SUEV – superior epigastric vein.

(DCIV) drains in the external iliac vein by passing anterior to the external iliac artery. It drains the blood from the lateral lower part of the AAW. In 17.5% of cases, the DCIV could pass posterior to the external iliac artery (Ghassemi et al., 2013). The deep external pudendal vein (DEPV) drains in the great saphenous vein and below the SEPV. It collects the blood from the vulvar region (Gray et al., 2005; Netter, 2014). The deep veins of the AAW are shown in Figure 17.

Less significant vessels of the AAW in abdominal surgery

The SUEA is less encountered in gynecological surgery. It arises from the internal thoracic artery and pierces the posterior layer of the rectus sheath. It proceeds in caudal direction to anastomose with the IEA at the level of the umbilicus (Figure 18). At the level of the xiphoid process, branches of SUEA anastomose with the contralateral counterpart (Gray et al., 2005; Netter, 2014). The superior epigastric vein (SUEV) accompanies the arterial counterpart and drains into the internal thoracic vein. It anastomoses with the IEV at the level of the umbilicus (cavo-caval anastomoses) (Figure 17).

The musculophrenic artery is the caudal branch of the ITA. It supplies the external, internal and transversus abdominis muscles. The artery anastomoses with the DCIA and the intercostal arteries.

The thoracoepigastric vein collects the blood from the lateral and lower part of the AAW. It drains into the lateral thoracic vein, which enters in the axillary vein. The thoracoepigastric vein communicates with the majority of veins (SUEV, SCIV, DCIV, IEV), but the most numerous anastomoses are with the SUEV and SCIV.

Branches of the posterior intercostal, subcostal and lumbar arteries anastomose with each other just above and slightly medial to the ASIS and between the

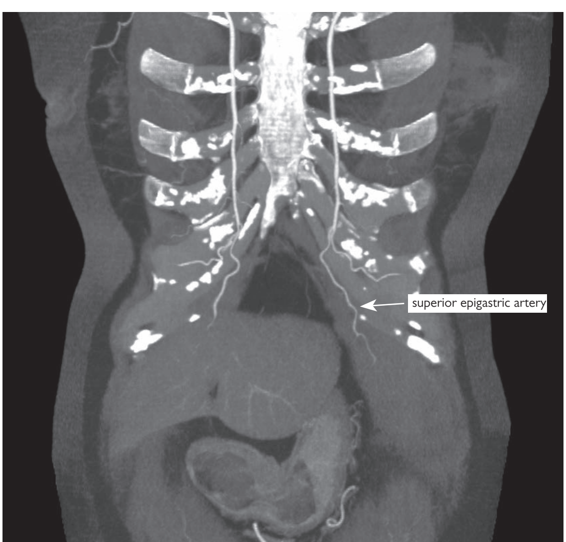

Figure 18 – Contrast enhanced computed tomography (CT) thick slice maximum intensity projection (MIP) reconstruction of anterior thoracic region depicting superior epigastric artery (SUEA).

transversalis abdominis and internal oblique muscles. Branches of these arteries also anastomose with branches of the SCIA and IEA. In the same region, there are anastomoses between the SCIV, DCIV, SEV, thoracoepigastric and subcostal vein (Gray et al., 2005; Netter, 2014).

Paraumbilical veins are formed at the level of the umbilicus. They enter at the falciforme ligament (teres ligament or round ligament of the liver contains the partly obliterated umbilical vein) and confine in a common trunk, which drains in the portal vein. The adult umbilical vein is deviated slightly to the right of the midline. Paraumbilical veins communicate with the IEV, SUEV and thoracoepigastric vein (Martin and Tudor, 1980; Arslan, 2005; Mahadevan, 2006).

Anatomical variations of these vessels are beyond the scope of this review, as their origin or draining pattern is away from the AAW.

Open surgery – Abdominal incisions

Maylard's incision

The Maylard's incision is a transverse incision, which is done approximately 3 to 8 cm superior to the symphysis pubis and 3 cm medial to the ASIS. The level of the incision depends on the type of surgery and BMI (body mass index) of the patient. The Maylard's incision should be avoided in a deep skin crease (Maylard, 1907; Burger et al., 2002; Baggish and Karram, 2006; Rock et al., 2008; Ortiz Molina et al., 2020). The transverse incision is carried down through the skin, subcutaneous fat, superficial fascia, and the aponeurosis of rectus abdominis muscle. Lateral limit is the external edge of the rectus muscles or the greater or lesser part of the aponeurosis of the oblique abdominis muscle (Baggish and Karram, 2006; Ortiz Molina et al., 2020). Consequently, the inferior epigastric vessels are identified, isolated, doubly clamped, cut and ligated. Both rectus abdominis muscles are cut between the two fingers of the surgeon, which are inserted from medial to lateral to the muscles. The underling transversalis fascia and parietal peritoneum are incised transversely along the length of the incision. During closure, an approximation of the rectus abdominis muscles is not necessary (Baggish and Karram, 2006; Ortiz Molina et al., 2020). This type of incision is suitable for radical hysterectomy, pelvic lymphadenectomy and pelvic exenteration as it provides excellent access to the pelvic retroperitoneum. It is associated with low postoperative complications (less hernia formation, better cosmetic results) compared to midline incision, especially in obese patients (Baggish and Karram, 2006; Rock et al., 2008; Ortiz Molina et al., 2020). Ortiz Molina et al. (2020) concluded that if midline laparotomy is not indicated (previous midline incision, upper abdominal surgery), the Maylard's incision is the preferable incision technique for optimal pelvic exposure.

Vascular anatomy of the AAW – Surgical consideration and discussion

As mentioned above, they inferior epigastric vessels are located lateral and posterior to the rectus abdominis muscles. Surgeons should identify vessels in the lateral aspect of the muscles. It is preferable to ligate IEA instead of using bipolar coagulation, as these are the largest vessels in the AAW. Surgeons should be aware that in some case the IEA divides into two or three arterial branches – lateral and medial (Gagnon and Blondeell, 2006). Additionally, it should be reminded that two veins accompany the arterial counterpart. The Maylard's incision and ligation of IEA must be avoided in patients with aortoiliac occlusive disease, as in such cases the collaterals between the IEA and internal thoracic artery provide blood flow to the lower extremities. Ligation of the IEA could be associated with severe leg ischemia in these particular cases (Yurdakul et al., 2006; Tada et al., 2022).

In the majority of cases, the SEA is cut and ligated. However, if it is possible, the SEA should be preserved. This artery could have a great clinical importance in plastic surgery of the AAW (abdominoplasty) in the future (Almeida et al., 2016). Moreover, the SEA flap is often used in plastic surgery, especially for breast reconstruction, as the lower abdominal skin and subcutaneous fat are preferable materials (Gagnon and Blondeell, 2006).

Pfannensteil incision

The incision is similar to the Maylard's incision. The differences are – the incision is generally performed 2–3 cm above the symphysis pubis with a convexity downward in order to preserve the blood vessels and nerves; the rectus abdominis muscles are not cut; the transversalis fascia and the parietal peritoneum are opened vertically in the midline. The Pfannensteil incision is generally 10–15 cm long, but it could be extended laterally (Burger et al., 2002; Baggish and Karram, 2006; Rock et al., 2008). In cases of lower incision, the pyramidalis muscle should be separated. As mentioned above the pyramidalis muscles are absent in about 20% of the population (range between 10 and 70%) (Lovering and Anderson, 2008). The parietal peritoneum should be incised at the upper end of the incision and after catheterization of the bladder in order to avoid its injury (Baggish and Karram, 2006; Rock et al., 2008).

Surgical considerations and discussion

Similar to the Maylard's incision, it is advisable to preserve the SEA. The incidence of hematomas at the AAW after Pfannensteil incision varies between 1.6 and 8% (van Coeverden de Groot et al., 1983; Hemsell et al., 1993; Vercellini et al., 1996; Lavoie et al., 2014). Vercellini et al. (1996) reported an incidence of 6.1% of subfascial hematomas in 131 patients who underwent Pfannensteil incision. Authors also compared postoperative hematomas after the Küstner (53 patients) and Pfannenstiel (131 patients) incision. They observed a significantly higher rate of postoperative hematomas in patients with Pfannensteil compared to Küstner incision (6.1% versus 1.9%). Lavoie et al. (2014) reported a case of 73-year-old woman with adipose tissue necrosis as a result of postoperative subcutaneous hematoma. The patient had endometrial cancer and authors performed a total abdominal hysterectomy with

Pfannensteil incision. These studies showed that although this type of incision was preferable in obstetrics and gynecology (for patient with nonmalignant conditions), it could be often associated with postoperative hematomas. Therefore, surgeons should be aware of pathways and draining pattern of the superficial epigastric, inferior epigastric and superficial external pudendal vessels. Although, the rectus abdominis muscles are not transected in this type of incision, the IEA could also be injured. The deep and superficial circumflex iliac arteries are at low risk of injury, as they are located lateral at the AAW. However, in cases of lateral extension of the Pfannensteil incision, these vessels together with their branches and anastomoses could be injured. Generally, the subfascial hematomas are due to inadequate hemostasis of the inferior epigastric vessels, whereas suprafascial hematomas are observed after laceration of the superficial epigastric and superficial external pudendal vessels. The risk of hematomas and postoperative wound complications is increased in cases of obesity, diabetes, hypertension, or previous laparotomies (Lavoie et al., 2014). The division of the pyramidalis muscles should be gentle and precious, as there are many arterial and venous anastomoses in the suprapubic region (Gray et al., 2005; Netter, 2014). Nerves of the AAW are not the topic of the present article, but it should be noted that lateral extension of the incision is associated with increased risk of ilioinguinal and iliohypogastric nerves injury (Rock et al., 2008).

Küstner incision

The Küstner incision is similar to the Pfannensteil incision. Firstly, a transverse incision of the skin, subcutaneous fat and superficial fascia is performed. The procedure is followed by an excessive superior and inferior dissection of the subcutaneous fat from the aponeurosis of the anterior muscle abdominis. Consequently, the anterior aponeurosis of the rectus abdominis, transversalis fascia and the parietal peritoneum are incised in the midline along the linea alba (Baggish and Karram, 2006; Rock et al., 2008). Surgical considerations do not differ from the Pfannensteil incision.

Cherney incision

The Cherney incision is similar to the Maylard's incision. The main difference is that incision is located lower compared to the Maylard's and the rectus abdominis muscles are separated transversely from their attachment into the symphysis pubis. The inferior epigastric vessels are cut and ligated, but it could be spared compared to Maylard's incision. The incised rectus muscles could be elevated upward in order to provide better exposure (Baggish and Karram, 2006; Lee et al., 2008; Rock et al., 2008). During closure of the abdominal incision, the rectus muscles are approximated to the symphysis pubis. The Cherney incision provides access to the Retzius space, maximizes exposure to the pelvic sidewall and retroperitoneum in patient with high BMI. Lee et al. (2008) compared modified Cherney incision and vertical midline incision for management of early stage cancer of the uterine cervix. Authors observed no clinical differences between both groups and equal number of removed lymph nodes among both groups. Authors concluded that the Cherney incision is preferable in young patients, who underwent surgery for cervical cancer.

Surgical considerations and discussion
During separation of the rectus abdominis muscles and dissection of the Retzius space, surgeons should be aware of the presence of the following vessels and their anastomoses (Gray et al., 2005; Netter, 2014; Kostov et al., 2020):

- SEA/SEV – anastomose with the SEPA/SEPV;
- SEPA/SEPV – the SEPV anastomoses with the collateral venous counterpart and forms a rich suprapubic collateral connection. These vessels also anastomose with superficial epigastric vessels; the SEPA/SEIV anastomose with the Sampson artery just above the round ligament;
- anastomoses between the retropubic branches of both obturator arteries;
- anastomoses between the suprapubic branches of both inferior epigastric arteries;
- anastomoses between the retropubic and suprapubic branches of the obturator artery and the IEA;
- arterial branches of the internal pudendal artery;
- dorsal vein of the clitoris and its anastomoses with the majority of veins in the suprapubic region.

Midline incision

The midline incision is commonly used in abdominal surgery. It is also useful for emergency procedures, as it provides the most rapid entry and the lowest amount of incisional bleeding. Moreover, the midline incision gives the best exposure to the abdominal cavity. Additionally, this type of incision spares the nerves. It is obvious that the incision has many advantages. However, its disadvantages are that dehiscence and hernias are more frequent (Burger et al., 2002; Baggish and Karram, 2006; Rock et al., 2008). The midline incision starts at the level of the symphysis pubis to the level of the umbilicus. Its long is different and depends on the surgical procedure. Extension of the midline incision could be made superiorly by passing around the umbilicus and exceeding to the level of the xiphoid process. The curve of the incision around the umbilicus should be performed on the left side of the midline in order to spare the falciforme ligament and to avoid bleeding from the umbilical veins (Burger et al., 2002; Baggish and Karram, 2006; Rock et al., 2008). The following structure of the AAW are incised vertically – skin, subcutaneous fat, superficial fascia, aponeurosis of rectus abdominis muscle, linea alba, transversalis fascial, preperitoneal fat and parietal peritoneum. The incision provides minimal blood loss due to the avascular plane in the linea alba (Burger et al., 2002).

Surgical consideration and discussion
Dissection should be meticulous near the suprapubic region due to the presence of many vessels and their anastomoses, which have been clearly described above.

Paramedian incision
The paramedian incision is an alternative to the midline incision and could be separated into lateral and medial. The most commonly used is the lateral, where a lateral vertical incision is performed on the lateral aspect of the rectus muscle (approximately 3 cm lateral to the midline). The anterior rectus sheath is incised and separated from the muscle. The latter is retracted laterally, and inferior epigastric vessels are preserved. The posterior rectal sheath, the transversalis fascia and the parietal peritoneum are incised in vertical direction. The extension of the paramedian incision in cranial direction is limited by the costal margin. This incision provides access to the left or right pelvic sidewall depending on the incision side. It is also used for extraperitoneal or transperitoneal pelvic lymphadenectomy (Köse et al., 2017). It is associated with lower hernia rates compare to midline incision (Rock et al., 2008).

Surgical considerations and discussion
Gentle and meticulous dissection between the aponeurosis and the rectus abdominis muscle will prevent injury to the inferior epigastric vessels. Peripheral branches of these vessels will be encountered during dissection and should be precisely dissected and ligated. The chance of injury of the iliohypogastric and ilioinguinal nerve is higher compared to midline incision. Mandelkow and Loeweneck (1988) reported that injury of the iliohypogastric nerve will be avoided if the incision was performed at least 5 cm cranial to the inguinal ligament. Avsar et al. (2002) examined 12 adult cadavers and tried to determine the distances of ilioinguinal and iliohypogastric nerves to McBurney's and paramedian incisions. Authors concluded that the paramedian incision was safer compared to McBurney's regardless nerve injury. Avsar et al. (2002) also reported that the incidence injury (if both incisions are performed) of at least one of the two nerves on the right was 75% and 41.66% on the left. Authors concluded that by measuring the distance of both nerves according to both incisions. The incidence of total nerves being in the dangerous region was 43.18%.

Surgical procedures at the anterior abdominal wall
Abdominal paracentesis
The remaining question is the placement location of the ascitic drains in the AAW in cases of absence of the ultrasound guidance. The British Society of Gastroenterology (2021) recommended that the point of puncture should be located no less than 8 cm from the midline and 5 cm superior to the symphysis pubis. Authors concluded that this point of puncture would prevent injury to

the inferior epigastric vessels, spleen or liver (Aithal et al., 2021). However, Siau et al. (2021) disagreed and reported that the use of absolute measurement was controversial as it varied and depended on obesity, age, amount of ascites or distortion due to chronic ascites. Authors offered the contralateral McBurney's point guided by abdominal percussion and patient in a supine position. They concluded that the contralateral (left) McBurney's point was preferable as the AAW was thinner and the sigma was more mobile than the caecum. Sakai et al. (2005) measured the thickness of the AAW by ultrasound in 52 patients with cirrhosis and ascites. Authors reported that the left lower quadrant was the preferable point of puncture, as the AAW was significantly thinner and the deep of ascites greater in that particular region.

Safety zones of the anterior abdominal wall for intraoperative draining placement
These zones are similar to the placement of second trocars during laparoscopy. There are only few reports, which described vascular injuries to the AAW during drainage placement. Ng et al. (2016) reported for vessel injury of the AAW caused by drain insertion after anterior lumbar spine fusion. Authors concluded that the danger zone for vessel injury is located just superior to the level of the umbilicus and roughly from 4 cm to 8 cm lateral from the midline.

Surgical consideration and discussion
That particular area is rich of anastomotic branches of the lumbar, intercostal, subcostal and the ascending branch of the DCIA. The advisable point of drain insertion should be located below the umbilicus and at least 8 cm lateral from the midline (Sakai et al., 2005; Ng et al., 2016; Siau et al., 2021).

Laparoscopic surgery
Primary trocar placement and vascular injury of the AAW are rare as they are located in an avascular plane – either at the umbilicus or cranial and caudal to it (at linea alba) (Watrowski et al., 2021). However, in cases of previous abdominal surgery, there is an increased risk of injuries to the gastrointestinal tracts. Therefore, new access points (Palmer's point, Jain's pont, Lee-Huang point) for primary trocar placement should be considered (Palmer, 1974; Jain et al., 2016). The Jain point is located at the level of the umbilicus just between abdominal regions 5 and 6, in a straight line, which is drawn vertically upward from a point 2.5 cm medial to ASIS (Jain et al., 2016). The Palmer's point is located 3 cm below the left subcostal margin in the mid-clavicular line (Palmer, 1974). Additionally, the Palmer's point is also used in cases of large ovarian tumours or uterine fibroids (Granata et al., 2010). The Jain point is the preferable point of entry in cases of previous splenic or gastric surgery, where the Palmer's point has to be excluded. Moreover, by using these two points of entry, there is no risk of injury of major retroperitoneal vessels. Jain et al. (2016) used the Jain point as a laparoscopic entry site in 623 patients. Authors reported no

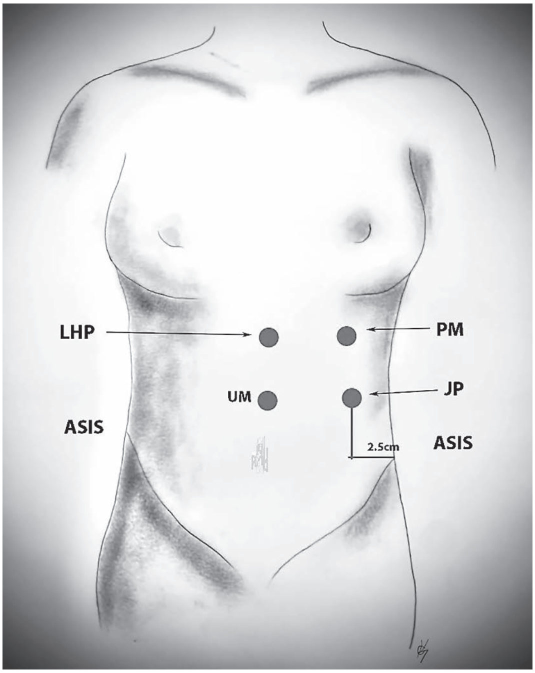

Figure 19 – Different laparoscopic primary trocar entry points. UM – umbilicus; ASIS – anterior superior iliac spine; PM – Palmer's point; JP – Jain point; LHP – Lee Huang point.

cases of injuries to superficial or deep vessels of anterior abdominal wall. Therefore, the Jain point could be also used for intraoperative draining placement, if draining the abdomen is necessary in cases of surgery at the upper abdomen.

The Lee-Huang point is located in the middle upper abdomen (abdominal region 2) between the xiphoid process and the umbilicus. It is used for patient with high risk of subumbilicus adhesions due to previous surgery. It is also preferable point of laparoscopic primary entry in cases of gynecological malignancies or large abdominal masses. Contraindication for Lee-Huang point is previous surgery at the supra-umbilical region (Lee et al., 2001; Thepsuwan et al., 2013). The three primary points of laparoscopic trocar entry are shown in Figure 19.

Vascular injury of the anterior abdominal wall in secondary trocar placement

Injury of the SEA/SEV, SCIA/SCIV of the AAW could be avoided by transilluminating the AAW before secondary trocar placement. Similarly, to the superficial vessels of the AAW, injury of IEA/IEV could be avoided by identification of these vessels by direct laparoscopic vision. The inferior epigastric vessels are located at the lateral umbilical ligament, which is slightly lateral to the medial umbilical ligament (obliterated umbilical arteries). However, in the majority of cases the superficial and deep vessels of the AAW are hardly visible by laparoscopy, especially in obese patients or in cases with previous abdominal incision (Watrowski et al., 2021). Moreover, although the abdominal wall vessels injuries are usually preventable, one third of trocar-related complications are observed during secondary trocar insertion (de Rosnay et al., 2011). Therefore, many articles, either anatomical or surgical, tried to establish the safety zone of the second trocar placement in the AAW (Rahn et al., 2010; Mohammadhosseini and Shirani, 2011).

Injury of the inferior epigastric vessels occurs in approximately 2% of laparoscopic procedures at the abdomen. The laceration of these vessels could lead to severe haemorrhage (requiring hemotransfusion), hematoma or abscess formation (Hurd et al., 1994; Saber et al., 2004).

Hurd et al. (1994) investigated the location of the IEA, DIEAD and SCIA in 21 women by using CT (computed tomography) images. Authors concluded that the ideal location of secondary trocars insertion was at least 5 cm above the symphysis pubis (SP) and 8 cm from the midline. There were two alternative locations – the first was 3 cm above the SP and 4 cm from midline, and the second was at the level of the umbilicus and 8 cm from midline (Shawki, 2004).

Saber et al. (2004) investigated the location of the inferior epigastric vessels among 100 patients by using CT scan. Authors concluded that these vessels are located in the area between 4 and 8 cm from the midline, regardless of the level of the AAW. Saber et al. (2004) also observed that in obese patients (BMI ≥ 26.3) the inferior epigastric vessels are located more laterally from the midline.

Baggish and Karram (2006) reported that the distance from the linea alba to the inferior epigastric vessels (superior to the upper margin of the SP) was 6–7 cm.

Anandhi et al. (2016) examined the anatomy of the inferior epigastric vessels in 50 specimens. Authors concluded that the danger zone was located between 3 cm and 8 cm from the midline.

Shawki (2004) examined the IEA, SEA and SCIA among 30 women who underwent diagnostic laparoscopy. The author examined the distance of the IEA, SEA and SCIA from the midline and either 3 cm or 5 cm above the SP. Shawki (2004) concluded that lateral secondary trocar placement 3 cm above the SP was related with increased risk of vessels injury, as the distance between laterally located SCIA and IEA/SEA was usually less than 1 cm. Contrary, lateral trocar insertion 5 cm above the SP was a safer zone as the distance between the more laterally located SCIA and IEA/SEA was more than 4 cm.

However, other studies reported different findings. Joy et al. (2017) examined the location of 60 inferior epigastric arteries among 30 adult cadavers. Authors observed that the safe zone was located 5.5 cm from the linea alba. Rahn et al. (2010) investigated the anatomy of IEA in 11 female cadavers. Authors found that IEA and the ilioinguinal and iliohypogastric nerves would be sacrificed if the secondary trocars were inserted above the ASIS and 6 cm from the midline. Moreover, Balzer et al. (1999) investigated the anatomy of the IEA and the ascending branch of the DCIA in 21 human cadavers. Authors reported that half of the recommended trocar sites placements in the medical literature were within the range of the IEA and the DCIA. They concluded that the safe zone should be located at the line alba or 5 cm from the lateral aspect of the rectus abdominis muscle. Epstein et al. (2004) examined the anatomy of the IEA among 30 fresh cadavers. Authors defined two safety zone in the AAW – 1) the linea alba, 2) more than two-thirds of the distance along a horizontal line, which was located between the midline and the ASIS.

Logically, the danger zone (3–8 cm from the midline) for the superior epigastric vessels is the same as the inferior counterparts, as they lie in the same axis. Bhatti et al. (2008) investigated the anatomy of the superior epigastric vessels and estimated that the danger zone was located 4–7.5 cm from the midline at the level between the xiphoid process and the umbilicus and 3.9–4.8 cm from the midline at the level of the xiphoid process.

Anatomical variations

In should be noted that the IEA could have two or more branches. Epstein et al. (2004) found that a large median branch of the IEA was presented in 60% of cases. In more than two third of cases the IEA had at least one branch > 1 mm diameter that raised from the lateral aspect of the rectus sheath. Joy et al. (2017) reported for an average of 3.3 branches per IEA. Authors found a large medial branch of 20% of cases.

Bowness et al. (2019) observed the anatomy of the IEA in 100 patients by a CT scan. Authors noticed that the IEA generally lied within the rectus abdominis muscle, despite that most studies reported that the IEA lies within the posterior aponeurosis of the rectus sheath. In some cases, the IEA could be absent (Tregaskiss et al., 2007; Bowness et al., 2019).

Unfortunately, there is a huge variety of the morphology, course and orientation of the perforator arterial branches of the AAW (El-Mrakby and Milner, 2002). Tregaskiss et al. (2007) examined arterial supply of the AAW among 10 fresh cadavers. Authors found that the perforators of the superior epigastric artery (SEA) were constant compared to the IEA, which varied noticeably. Tregaskiss et al. (2007) estimated an average number of seven perforators in each hemiabdomen. In their research, the SEA was absent in half of cases. The branches of the IEA were less extensive when the SEA was noticed in the specimens. El-Mrakby and Milner (2002) performed a microdissection of the IEA in 20 cadavers. Authors found that perforators of the lateral branch of the IEA were more prevalent and constant compared to medial ones. The average number of perforators, which was dissected in each specimen were 5.4. These two studies showed that the perforator branches of the IEA did not follow any particular pattern. Therefore, knowledge of their anatomical location of the AAW is impossible. Moreover, in the lateral AAW and just above the ASIS there are many anastomoses between the deep/superficial circumflex, superficial epigastric, lumbar, intercostal and subcostal arteries. Possible injuries of such anastomoses or perforators are unavoidable, as they could have different course in the AAW. Fortunately, injuries of such small vessels are not associated with severe bleeding or huge hematomas.

It could be concluded that the lateral secondary trocar placement should be inserted 5 cm above the SP and 8 cm lateral to the midline due to the possibility of anatomical variations, especially of the IEA (two or three branches). The safety zone of the medial secondary trocar insertion is located between the linea alba and 3 cm laterally (Epstein et al., 2004; Rahn et al., 2010; Joy et al., 2017).

Conclusion

Detailed knowledge of the human anatomy is an integral part of many surgical procedures. The anatomy of the AAW is complex as it is a layered structure, which is rich in vessels and their anastomoses. Nevertheless, anatomical variations of the vessels of the AAW are often observed. Intraoperative and postoperative complications associated with entry and closure of the AAW could compromise the best surgical procedure. Therefore, sound knowledge of the vascular anatomy of the AAW is fundamental and a prerequisite to having a favourable quality of patient care.

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