

# New techniques in ventral hernia surgery – an evolution of minimally-invasive hernia repairs

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## ABSTRACT:

Incisional ventral hernia occurs after almost every fourth laparotomy. Still, both simple suturing of the hernia defect and open mesh repair, lead to a high incidence of infections and recurrences. In recent years, we have observed a further evolution of operational techniques used in order to reduce the number of complications. The search for effective repair methods is currently going in two directions: on the one hand, techniques to reduce tissue tension in the suture line are being developed and disseminated (including modifications to the so-called Ramirez technique); on the other hand, minimally invasive techniques are introduced that allow placement of large synthetic meshes without the need for extensive tissue dissection using open repair. In the first group of presented techniques, emphasis is put on basics and access in the following repair method: original Ramirez technique, modified Ramirez technique, anterior component separation with periumbilical perforator-sparing, endoscopic anterior component separation and transversus abdominis release. In the second part of the manuscript, attention is drawn to the following hernia repair techniques: eTEP, reversed TEP, MILOS/eMILOS, stapler repair, TAPP, TARUP, TESLA, SCOLA, REPA, LIRA, IPOM, IPOM-plus. When choosing the optimal technique for a given patient, the surgeon should first of all be guided by technical feasibility, availability of materials, their own experience, as well as the characteristics of the patient and overall burdens. Nevertheless, surgeons undertaking reconstruction of the abdominal wall in the case of hernias should know different surgical accesses and individual spaces of the abdominal integument, in which a synthetic material may be placed. However, it should be emphasized that poor ergonomics of novel techniques, complex anatomy and complicated dissection of space, as well as the need for laparoscopic suturing in a difficult arrangement of tissue layers and in a narrow space, without a full triangulation of instruments, make these operations a challenge even for a surgeon experienced in minimally invasive surgeries.

## KEYWORDS:

component separation, eTEP, hernia repair, mesh, sublay, surgery, ventral hernia

## ABBREVIATIONS

**ACS** – anterior component separation  
**CST** – component separation technique  
**ELAR** – endoscopic-assisted linea alba reconstruction  
**EMIOS** – endoscopic mini/less-open sublay  
**IPOM** – intraperitoneal onlay mesh  
**LIRA** – laparoscopic intracorporeal rectus aponeuroplasty  
**MILOS** – mini/less-open sublay  
**PCS** – posterior component separation  
**REPA** – preaponeurotic endoscopic repair  
**SCOLA [TESLA]** – subcutaneous onlay laparoscopic approach  
**TAPP** – transabdominal preperitoneal hernia repair  
**TAR** – transversus abdominis release  
**TARM** – transabdominal retromuscular  
**TARUP** – transabdominal retromuscular umbilical prosthetic hernia repair  
**TEP** – extended/enhanced view totally extraperitoneal  
**TES** – Totally Endoscopic Sublay

## INTRODUCTION

Incisional ventral hernia occurs after almost every fourth laparotomy [1]. Unfortunately, the still used simple suturing of edges of the hernia defect, leads to recurrence in as many as 25–54% of cases [2–4]. Even placement of a synthetic mesh during reconstructive surgery does not guarantee an efficient repair, and recurrence noted in those cases still reaches the level of 32% in open anterior

repairs [5]. Hence, the best method for surgical repair of ventral hernia is still being sought [6]. Effective and durable reconstruction of the abdominal wall, regardless of whether performed due to a small umbilical hernia or midline epigastric hernia, or extensive incisional ventral hernia, must meet four basic conditions: protect abdominal organs from getting outside the abdominal cavity, provide dynamic support for abdominal muscle function, keep an adequate margin for soft tissue coverage and avoid tension in the supply area (tension-free repair) [7]. Numerous repair methods meeting those requirements have been developed (e.g. the Rives-Stoppa method), but still a high rate of complications leading to poor treatment outcomes is observed [8]. In the case of significant abdominal wall defects, it is necessary to place a large synthetic implant in the abdominal wall to ensure effective repair. No tension between the synthetic patch and the abdominal wall can be obtained by increasing the implant size. Then, the support of the wall takes place mainly tangentially over the entire surface of the mesh, and not pointwise, as it is in case of attachment of a too small implant with sutures or staples (tackers). Unfortunately, placing a large mesh requires extensive dissection of myofascial spaces of the abdominal wall. This carries the risk of damaging the neurovascular bundles that supply individual muscles, mainly the rectus abdominis [9]. Nerve damage leads to functional atrophy of the supplied muscle and its sagging, which in turn leads to a lack of functional support of the implant and may cause further deformations of the abdominal wall. On the other hand, vascular damage may result in impaired blood supply, which in turn can lead to necrosis in the supplied area and, consequently, to infection and loss of the implant.

In recent years we observe a further evolution of the operational techniques used in order to reduce the number of complications. The search for effective repair methods is currently moving in two directions: on the one hand, techniques to reduce tissue tension in the suture line are being developed and disseminated (including modifications to the so-called Ramirez technique); on the other hand, minimally invasive techniques are introduced that allow placement of large synthetic meshes without the need for extensive tissue dissection using the open method (analogous to endolaparoscopic methods in inguinal hernia repairs).

## COMPONENT SEPARATION TECHNIQUES (CST) (TAB. I.)

### The classic Ramirez technique

The original Ramirez technique described in 1990 consisted in releasing the medial muscle complex (including the rectus abdominis) by making a longitudinal cut on the medial edge of the external oblique muscle aponeurosis outside (by about 1 cm) the lateral margin of the rectus sheath (semilunar line) [10]. At this stage it is extremely important to make sure that the cut is made laterally from the semilunar line. In this case, adipose tissue is visible after the incision in aponeurosis is made. If a short test incision leads to the exposure of longitudinally extending muscle fibers, this may indicate an incorrect incision of the anterior sheath of the rectus muscle. In this case the incision should be made even more laterally. In addition, the Ramirez technique involves a longitudinal and medial cut of the posterior sheath of the rectus muscle, which allows further medialization of the muscle complex and closing of the medial defect.

### The modified anterior component separation (modified Ramirez technique; modified ACS)

Soon, it turned out that the application of the above maneuvers increases the possibility of approximating edges of the linea alba and facilitates its suturing. However, the number of hernia recurrences was not significantly reduced. Therefore, the original method was modified by additional placement of a synthetic mesh in the retro-muscular space (so-called, modified Ramirez method). This technique draws attention to the need for broad lateral release of the external oblique muscle from the underlying internal oblique muscle. It is a non-vascular space and it is quite easy to make this maneuver, reaching as far as the lateral margin of the iliolumbar muscle. In addition, the Ramirez maneuver, i.e. incision of the aponeurosis of the external oblique muscle along its entire length, that is from the inguinal canal (paying attention to protection of structures inside the inguinal canal) up to a height of about 5 cm above the costal margin (in the upper part the aponeurosis gradually passes into muscle fibers and becomes thicker) has to be performed. With those maneuvers, a possible medial displacement of the rectus abdominal muscle by up to 8–10 cm per side at the level of the umbilicus and 4–6 cm in the epigastrium and lower abdomen can be achieved.

Perforator-sparing anterior component separation (modified Ramirez technique with preservation of periumbilical vessels).

Unfortunately, making such a long release of the medial attachment of the external oblique muscle is associated with necessary extensive dissection of space in the subcutaneous tissue. Expos-

ing the entire length of the lateral edge of the rectus abdominis requires the formation of a wide cutaneous and subcutaneous flap and raising it upwards. As a result, numerous perforating vessels located in the umbilical area are cut or damaged. Those vessels pass perpendicularly from the anterior sheath of the rectus muscle and supply blood to the skin and subcutaneous tissue of the anterior abdominal wall. Cutting these vessels may lead to soft tissue ischemia and promote infection, which may lead to formation of wounds and skin fistulas that are difficult to heal, including consequential hernia recurrence and/or necessary mesh removal. The rate of wound healing complications may reach as high as 40% [11, 12]. To protect the skin against ischemia during the so-called Ramirez maneuver, two more modifications of the original method were developed. The first involves a narrow, laterally directed tunnel in the subcutaneous tissue of the abdomen at the level of the umbilicus. This allows the use of narrow hooks with long blades to get access to the semilunar line. From this site, preserving periumbilical perforators, it is possible to cut the external oblique muscle aponeurosis in both cranial and caudal directions. When surgery is performed on particularly tall patients (or with a large distance between the costal margin and the inguinal ligament), the aponeurosis may be cut by accessing the semilunar line through two tunnels – one in the epigastrium, and the other in the lower abdomen. Then, vessels located around the umbilicus in the subcutaneous tissue will not be damaged as well.

### Endoscopic anterior component separation

Another modification allowing the preservation of an intact periumbilical vessel complex is to use endoscopic access. Two techniques for endoscopic cut of the aponeurosis of the oblique external muscle have been described. Rosen et al. proposed the insertion of a laparoscopic camera above the costal margin between the external and internal oblique muscles, and then, under visual control, cutting the aponeurosis of the external oblique muscle at its attachment in the caudal direction [12]. A few years later, Daes et al. described the technique of introducing a laparoscopic camera into the subcutaneous tissue in the lower abdomen and, after dissection of the pre-fascial space, incision of the aponeurosis of the external oblique muscle in the cranial direction [13]. In both techniques, the use of a trocar with an expanding balloon facilitates creating the space necessary for dissection. In both methods the camera trocar may be placed either within the lower abdomen, or over the costal arch.

It should be borne in mind that the above-mentioned techniques of releasing the external oblique muscle aponeurosis (ACS) are applicable primarily to patients with an abdominal wall defect of a maximum width of 6–15 cm, with a hernia defect longer than the width of the defect, with no signs of skin damage, without losing the possibility of draining the contents of the hernia into the abdominal cavity after reconstruction of the defect (loss of domain), without ongoing infection, without numerous previous reconstruction attempts, with/without implantation of a mesh, and in the case of suspected massive intraperitoneal adhesions [14]. In those circumstances and in other advanced cases of extensive hernia, posterior component separation (PCS) is recommended.

### Transversus abdominis release (TAR)

The use of the classic method of retromuscular placement of a synthetic mesh between the posterior surface of the rectus muscles

**Tab. I.** Component separation techniques in repairs of large ventral hernias.

	NAME	PRINCIPLES OF THE METHOD	ADVANTAGES	DISADVANTAGES
	original Ramirez method	longitudinal incision of the aponeurosis of the external oblique muscle and the posterior sheath of the rectus abdominis muscle	medialization of the rectus muscle complex (approx. 6–10 cm per side)	absence of mesh results in a high percentage of hernia recurrences
	modified Ramirez technique	as above, but with additional mesh placement	the use of an additional mesh reduces hernia recurrence rates	extensive dissection of cutaneous and subcutaneous flaps disturbs their blood supply
anterior component separation (ACS)	perforator sparing component separation	access to the aponeurosis incision line is obtained by creating narrow tunnels in the subcutaneous tissue	the preservation of the periumbilical perforators reduces the percentage of complications	limited access to the semilunar line increases technical difficulty in cutting the aponeurosis along the entire required length
	endoscopic anterior component separation (e-ACS)	minimally invasive, subcutaneous or intramuscular access to the attachment of the aponeurosis	no extensive dissection in the subcutaneous tissue by open access	the use of a balloon increases the cost of the procedure (however, it is also possible to perform the maneuver without a balloon)
posterior component separation (PCS)	release of the transverse muscle (TAR)	cutting of the medial attachment of the transverse abdominal muscle	gaining access to the extensive extraperitoneal space with simultaneous medialization of the rectus abdominis muscle complex	complicated anatomy; probable loss of the torso stabilization function with change in the shape of the abdomen's cross-section of the

and the posterior sheath of the rectus abdominis muscle allows implantation of a mesh with a maximum width corresponding to the width of both sheaths of rectus muscles (usually about 14–17 cm in total). Unfortunately, in cases of hernia with very wide orifice (over 15 cm), a mesh of this width cannot provide a permanent repair. The inability to approximate edges of the defect without creating an excessive tension in the suture line is an additional problem. In this case sutures cut the tissues, resulting in recurrence. In order to enable the use of an even wider mesh, methods have been developed for the dissection of an additional space laterally from the semilunar line in the pre-peritoneal space, below or above the transverse abdominal muscle (posterior component separation; PCS) [15]. Unfortunately, due to the specific location of neurovascular bundles near the semilunar line, some of the PCS techniques inevitably led to denervation of the rectus muscle and to partial or complete loss of its function. The method currently considered the gold standard of posterior myofascial release is the technique of transversus abdominis release developed by Novitzki et al. [16]. This method involves the longitudinal incision of the posterior sheath of the rectus abdominis muscle medially from the semilunar line at a distance of about 1 cm, which ensures protection of neurovascular bundles. Then, the underlying transverse muscle fibers are cut and gradually disappear in the caudal direction, forming the transverse fascia. Performing this maneuver allows for the creation of an extremely wide space extending from the tendinous center of the diaphragm, over the posterior surface of the costal arches, laterally to the retroperitoneal space and in caudal direction to the Retzius space behind the pubic symphysis. The obtained space is connected with the space behind rectus muscles. That, with the bilateral release of the transverse muscle, allows for the placement of a mesh with an area of up to 4500 cm<sup>2</sup> (even several tens of centimeters in width and length), and nearly circular wrapping the abdominal cavity with an implant [17]. This method is especially recommended in cases of extensive hernia, hernias beyond the median line, peristomal hernias, defects located close to osseous structures (costal margin, sternum xiphoid process, iliac ala), recurrent hernias, and after ineffective release of the aponeurosis of the external oblique muscle. In 2011, Wegdam et al. reviewed the literature published in the past six years, since the introduction of the TAR technique (total 646 patients), and found that complications associated to wound healing occurred in

the TAR technique at a similar rate as in the case of ACS (15% vs. 20%). However, significantly less hernia recurrences were found following the TAR procedure (4% vs. 13%) [18].

When using fascial compartment release techniques described above, an excellent knowledge of the abdominal wall anatomy is extremely important. Incorrect identification of the intersection and dissection carried out in an inappropriate layer leads to complete and irreversible destabilization of the abdominal wall and to permanent disability.

Among additional methods leading to increased susceptibility of the abdominal cavity before a planned repair surgery, the possibility of using botulinum toxin and a gradual increase of the abdominal volume by preoperative peritoneal pneumothorax, should also be mentioned. However, both methods are merely supplementary to the techniques described above, and their clinical value is still being studied.

## MINIINVASIVE TECHNIQUES

Implantation of synthetic material necessary for permanent reconstruction of the abdominal wall in the case of extensive incisional ventral hernias increases the risk of complications in wound healing, particularly of surgical site infections and seromas. If the fact is additionally taken into account that the implantation of material is carried out in patients with numerous risk factors of delayed wound healing, especially those with diabetes, overweight and obese, in cigarette smokers, in patients with COPD, the need for techniques that reduce risk of complications becomes crucial. Experience gained in laparoscopic surgery, used in other surgical conditions, has influenced the interest in minimally invasive methods applicable also to reconstructive surgery of the abdominal wall in patients with hernias. Unfortunately, despite the initial enthusiasm of surgeons, first attempts of laparoscopic hernia treatment with implantation of an adhesive mesh directly under the hernia defect, inside the peritoneal cavity (intraperitoneal onlay mesh; IPOM) soon proved to be ineffective and led to frequent recurrences, bulging, and formation of intraperitoneal adhesions [19]. The desire to avoid extensive (and favoring infections) dis-

section in the subcutaneous tissue, combined with the possibility of minimally invasive access to the abdominal wall has resulted in the recent introduction of many novel surgical techniques for treatment of hernias and abdominal wall defects. The majority of reported methods point to obtaining a minimally invasive access to the retromuscular space, with placement of an extensive sheet of synthetic mesh. Due to different assumptions made for individual methods, and different ways of accessing and creating space for the mesh, the authors of these methods introduced complex names, commonly used in the form of acronyms. For easier distinction of these methods, a table has been included below, summarizing the differences between individual techniques (Tab. II.).

### Retromuscular techniques (behind the rectus abdominis muscle)

#### eTEP

Inguinal hernia repairs using the totally extraperitoneal (TEP) approach are characterized by low ergonomics resulting in the forced position of a surgeon and dissection carried out in a narrow space. In order to overcome these limitations, Daes introduced the eTEP (extended/enhanced view totally extraperitoneal) technique consisting in the introduction of trocars laterally from the linea alba and at a much greater distance from the dissected space [20]. The use of this technique aroused surgeons' interest in further dissection of the retromuscular space, and has encouraged them to use this method also in repairs of midline ventral hernias. For this purpose, the non-vascular space behind the rectus muscle on the side of introduced trocars is first dissected. Then, the connection of the anterior and posterior sheath of the rectus muscle is very precisely identified along the linea alba, and only the posterior sheath is incised longitudinally just over this connection. This opens an access to the next preperitoneal space, leaving the preperitoneal adipose tissue at the bottom, and the intact linea alba at the top of the dissected space. In the next stage, the medial edge of the posterior sheath plate is incised longitudinally on the opposite side, thus reaching the third space, i.e. the retromuscular space on the opposite side. Then, these three open spaces are dissected in the cranial or caudal direction, around the hernia defect, from which the hernial sac with contents is removed. The defect itself is sutured, and an extensive flat mesh is laid in the resulting space. Fixing of the mesh is optional. In the case of epigastric hernias, trocars are inserted into the lower abdomen, while for umbilical and lower abdomen hernias, ports are positioned under the costal arch. Belyansky, as the main promoter of this method, reported results of a multicenter study with a low incidence of complications. Seromas occurred in only 2.5% of patients, while recurrence in nearly one-year follow-up occurred in 1.3% of patients [21].

#### Reversed TEP (Totally Endoscopic Sublay; TES)

Bittner proposed another modification of the TEP method, involving the introduction of the first optical trocar in the area of the navel and into the retromuscular space, similarly to the TEP technique in inguinal hernia repair [22]. Next, the retromuscular space is bluntly dissected with an optical trocar (optionally, an expandable balloon) up to the Retzius space lying behind the pubic symphysis. After creating an adequate space, the operator stands between the patient's legs and introduces three more trocars (one optical and two operating ones), while the port is removed from the navel area, and the wound is closed with sutures. Further dis-

section of this space occurs in the cranial direction, analogously to the eTEP method. After dissection and suturing of the hernia defect, the space is filled with a flat mesh, usually about 30-cm long. Bittner observed no hernia recurrence in any of the operated patients within an average of nine months of follow-up, while seromas developed in 7.7% of patients [22].

### MILOS/EMILOS

The search for a surgical method that would reduce the need for extensive incisions and wide-open dissection of cutaneous and muscular flaps has resulted in the development of another retromuscular technique by Reinpold [23]. The author proposed to gain access to the retromuscular space through a small incision directly over the hernial sac (MILOS; mini/less open sublay). According to Reinpold, the applied technique may be referred as MILOS if the incision length does not exceed  $\frac{1}{4}$  of the diameter of the implanted mesh. After reaching the sheath of the rectus muscle, the hernia defect is circularly incised and the peritoneum is dissected free at a distance of at least 2 cm. In addition, the peritoneum is separated from the linea alba. Then, after exposure of posterior sheaths of the rectus muscle, they are incised longitudinally at a distance of about 1 cm from the linea alba, followed by dissection of the retromuscular space in all directions, i.e. laterally, cranially and caudally around the hernia defect. For small and medium hernias, it is sufficient to use long narrow hooks and cut the posterior sheath longitudinally from the linea alba using laparoscopic tools under direct visual control. For large hernias, dissection is much easier using a camera (EMILOS; Endoscopic mini/less open sublay). For the purpose of this operation, the author uses a specially prepared optics, inside of which there is a tunnel for the laparoscopic tool (Endotorch) [24]. In the group of 1074 patients surgically treated using this method for primary incisional hernias and midline epigastric hernias, Reinpold et al. observed recurrences in only 0.5% of patients with epigastric hernia and no recurrences after umbilical hernia surgeries during the first year after the surgery. Only 1.2% of patients suffered from seromas, and 0.2% of patients experienced wound infection [25].

### MIC Rives Stoppa Stapler Repair

Technical difficulties associated with laparoendoscopic suturing of hernia defect and margins of stretch of rectus muscles may be overcome by the use of a linear stapler. Chen proposed a technique based on laparoscopic release of peritoneal adhesions around the hernia defect, followed by the introduction of trocars into the retromuscular space under visual control [26]. Dissection of the space inside sheaths of rectus muscles is carried in the same way as in the eTEP method, but without cutting of the medial part of posterior sheaths. Then, a linear cutting stapler is introduced into the lower abdomen, to cover posterior sheaths on both sides, near the linea alba. When the stapler is started, posterior sheaths become connected along the linea alba. To create space along the entire length of the linea alba, 3–4 stapler cartridges are usually used. This creates an extensive space behind both rectus muscles. A synthetic mesh is laid in that space. The author of the method suggests using a self-fastening mesh fitted to the surface of the entire dissected space [27]. Chen found no infections in patients subjected to that technique, and seromas occurred in 9.5% of cases. After the six-month follow-up there were no hernia recurrences, although one

patient (4.8%) required revision surgery due to a palpable subcutaneous thickening corresponding to the suprafascial hernia sac [26]. Despite the use of a stapler, this technique is still more cost effective compared to IPOM repairs with anti-adhesive mesh.

## TAPP

Very good results of TAPP inguinal hernia repair (transabdominal preperitoneal mesh placement) encouraged surgeons to use this technique in ventral hernia repair. In the TAPP technique applied to midline hernia repair, three trocars are inserted in the anterior axillary line (optical port and two operating ones), similarly to the IPOM method. Then the posterior sheath of the rectus muscle is incised longitudinally on the side of introduced trocars, slightly medially from the semilunar line, where neuromuscular bundles pass towards the rectus muscle. The retromuscular space is dissected until the anterior and posterior sheaths are joined in the region of the linea alba. At this point, only the posterior sheath should be incised longitudinally, without damaging the linea alba. This ensures access to the medial preperitoneal space and the posterior sheath is exposed on the opposite side. The sheath is also incised longitudinally to open the retromuscular space. After reduction of the hernia sac with its contents, the hernia defect is sutured and a flat synthetic mesh is placed directly behind the rectus muscle. When withdrawing the tools, the posterior sheath on the side of introduced trocars has to be sutured tightly [28]. The TAPP method is also recommended for repair of hernias left by trocars and for hernias beyond the midline.

## TARUP

A variation of the TAPP method intended for repairs of umbilical hernia with a defect size below 4 cm is the technique of transabdominal retromuscular umbilical prosthetic hernia repair – TARUP. This technique involves the placement of a 15 x 15 cm mesh around the wall defect. Due to technical difficulties associated with suturing of the hernia defect, followed by suturing of the incised posterior sheath of the rectus muscle, Muysoms applies the robotic technique (rTARUP). In the analyzed group, he reported a low percentage of post-surgical complications. Skin infection in the navel area occurred in 2.4% of patients, intramuscular hematoma in 2.4% and seroma in 4.9% [29]. TARM is another type of this repair with retromuscular mesh for other midline ventral hernias.

### *Supra-aponeurotic methods (in subcutaneous tissue)*

## TESLA/SCOLA/REPA

In the treatment of stretch of recti muscles, particularly with concomitant hernias (umbilical and linea alba), it is recommended to use methods that restore the function of the anterior abdominal wall [30]. Hence, in these situations, surgery only for a hernia with unattended stretch of recti muscles, may lead to recurrence of hernia in as many as one patient per three [31]. Macroporous meshes (pore size of 2–4 mm) placed in the subcutaneous (preaponeurotic) space, despite the surgeons' previous concerns, do not increase the risk of surgical site infections. However, in these situations, seromas are more likely to occur [32]. Long-term use of drains (for up to two weeks or until drainage reduction down to 30–50 ml/day is achieved) reduces the risk of seroma formation. In addition, the use of sutures attaching the cutaneous-subcutaneous flap to the

fascia (quilting sutures) and the use of adhesives for fixing the mesh and subcutaneous tissue, also reduces the incidence rate of this complication. In the methods of supra-aponeurotic hernia repair accompanied by a stretch of recti muscles, an attempt is made to reconstruct the linea alba. For this purpose, edges of the stretch (medial edges of the sheaths of recti muscles) are sutured longitudinally with a continuous seam over the entire length of the linea alba, and then the suture line is reinforced with a macroporous mesh strip with a 4–8 cm margin. The mesh is fixed with sutures to the sheath of the rectus muscle.

However, it is worth noting that the supra-aponeurotic method is recommended primarily for women with postpartum insufficiency of the anterior abdominal wall, particularly those who pay more attention to restoration of the abdominal wall function rather than to cosmetic appearance. In patients with significant excess of the skin, a classical repair with abdominoplasty should be considered. In addition, separation of the cutaneous-subcutaneous flap affects sensory function of the skin [33].

The described technique was used by various authors, hence several names of the same method are mentioned in the literature (REPA, SCOLA, TESLA). According to Juarez Muas, the use of REPA (preaponeurotic endoscopic repair) should be expected to be associated with the development of seroma in 12% of patients, but he found no recurrence after 18 months of follow-up [34]. Similar results were presented by Claus in patients undergoing the SCOLA [TESLA] surgery (subcutaneous onlay laparoscopic approach). The reported incidence of seromas was 13.7%, and hernia recurrence occurred in 2% of patients [32].

## ELAR

In 2016 Köckerling described his own technique of minimally invasive repair of abdominal recti muscles stretch in patients with concomitant umbilical hernia or midline epigastric hernia [35]. The procedure begins with a longitudinal cut surrounding the navel on the left side, over the length of about 3 cm. After separating the subcutaneous tissue from the sheath of the rectus abdominis muscle around the navel, the hernia sac is opened and its content are evacuated. Then, the excessive peritoneum is cut off. Further dissection takes place in the subcutaneous tissue using a videoendoscope (laparoscopic optics and laparoscopic instruments). Anterior sheaths of recti muscles are incised longitudinally at a distance of 2–3 cm from the medial edge and over their entire length, i.e. from the xiphoid process to the area below the navel. Cut medial edges are sutured with a non-absorbable continuous suture, recreating the linea alba in a new shape. This way, recti muscles previously lying at a certain distance of each other are shifted towards the midline. Then, the fascia defect formed on the anterior surface of exposed recti muscles is covered with a synthetic mesh, fixed peripherally to the edges of the lateral fragment of the previously cut anterior sheaths of recti muscles. No recurrences were reported in preliminary results presented by the author in a group of 40 treated patients. Complications associated with the formation of seroma or navel necrosis occurred in a single patient [35]. This method comprises a further evolution of the technique used several decades earlier by Chevrel, who also used a fragment of the anterior sheath of the rectus muscle to recreate the linea alba, but he did not use any synthetic material to cover the defect at the time [36].

**Tab. II.** Minimally invasive techniques used for ventral hernia repairs.

	ACRONYM	NAME	PRINCIPLES OF THE METHOD
retromuscular methods	eTEP	extended (enhanced view) totally extraperitoneal	trocars introduced retromuscular into the sheath of the rectus abdominis muscle, then this space is connected with the sheath on the opposite side passing under the linea alba through the preperitoneal layer an extensive mesh is placed behind the rectus muscle after suturing the hernia/linea alba
	reversed TEP TES	reversed TEP Totally Endoscopic Sublay	similarly to the TEP method, an optical trocar is introduced in the area of the navel and the retromuscular space is dissected in the caudal direction up to the retropubic space of Retzius then the optics and operating trocars are introduced into the lower abdomen and the retromuscular space is dissected towards the head, a flat mesh is then placed
	MILOS	mini or less open sublay	incision with a length not exceeding ¼ of the diameter of implanted mesh, directly above the hernia defect dissection of the retromuscular space takes place from the hernia defect peripherally with cutting posterior sheaths of recti muscles
	eMILOS	endoscopic MILOS	similarly to the MILOS method, but in order to better visualize the operating field, instead of long hooks laparoscopic optics is used
	MIC Rives Stapler Repair	stapler repair of the linea alba	after dissection of the retromuscular space in sheaths of recti muscles, posterior sheaths are connected with a stapler and cut off a flat, self-fixing mesh is placed in the created space
	TAPP	transabdominal preperitoneal	after the pneumoperitoneum is formed, the peritoneum is incised, gaining access to the preperitoneal space on both sides a flat, semi-synthetic mesh is placed directly behind sheaths of rectus muscles, below sutured hernia defect
	TARUP TARM	transabdominal retromuscular umbilical prosthesis transabdominal retromuscular	a variety of the TAPP method used for umbilical/midline hernia repairs
suprafascial method	TESLA SCOLA REPA	totally endoscopic supra-aponeurotic linea alba reconstruction subcutaneous onlay laparoscopic approach preaponeurotic endoscopic repair	endoscopic separation of the subcutaneous tissue from anterior sheaths of recti muscles reconstruction of the linea alba by preaponeurotic suturing of edges of stretched recti muscles placement of a flat, macroporous, synthetic mesh in the subcutaneous space long-term subcutaneous drainage
	ELAR	endoscopic-assisted linea alba reconstruction	cutting anterior sheaths of the recti muscles over their entire length and recreating the linea alba by suturing them together the fascial defect over exposed recti muscles is covered with synthetic mesh
intraperitoneal methods	IPOM	intraperitoneal onlay mesh	placing an anti-adhesive synthetic mesh intraperitoneally around the hernia defect with peripheral fixation to the abdominal wall with sutures or staples
	IPOM-plus	intraperitoneal onlay mesh	as in the IPOM technique, with additional suturing of the hernia defect, to support the mesh in place of the original defect
	LIRA	laparoscopic intracorporeal rectus aponeuroplasty	cutting posterior sheaths of recti muscles over their entire length and recreating the linea alba by their laparoscopic suturing together the fascial defect over exposed recti muscles is covered intraperitoneally with anti-adhesive synthetic mesh

### Intraperitoneal methods

#### IPOM

The method of intraperitoneal placement of a synthetic mesh was supposed to be a response to technical difficulties associated with the dissection of a vast space for mesh implantation in open methods, which was also associated with a threefold increased risk of in-site infections (3.4% vs. 10.5%;  $p < 0.001$ ) [37]. Placement of a flat mesh on the inner surface of the peritoneum, around the wall defect, is technically simpler, assuming that intestinal or greater omentum adhesions with a hernia sac are safely released [38]. The mesh is fastened around the perimeter with metal non-absorbable staples or absorbent polymeric tacks. Mesh fixing may also be done with the use of transfascial sutures, which, however, is associated with a more frequent occurrence of pain. By design, both the mesh surface directed towards viscera, and staples should not cause adhesions with abdominal organs, and consequential development of fistulas. Unfortunately, despite the use of various non-adhesive materials by mesh manufacturers, intraperitoneal adhesions are still encountered after IPOM operations, which, among other things, has now resulted in surgeons' lesser interest in this method. Currently, the IPOM method is recommended for patients with numerous small and medium hernia defects, in whom open access would be associated with extensive dissection of the integument [39, 40]. The method is also recommended for patients in whom, for general health reasons,

a prolonged surgery associated with a significant interference with the abdominal wall would be too heavy a burden [41].

In the initial period of using the IPOM method, it was noticed that covering the hernia defect with a mesh, without closing the defect, promotes the incidence of recurrence and bulging of the abdominal content [42]. After the surgery, patients still reported bulging at the site of the previously repaired hernia, often combined with physical discomfort. For this reason, for hernias with defect diameters greater than 1–2 cm, closing the defect with sutures may be considered. As a result, the synthetic mesh is supported over its entire surface and does not become bulged at the site of the wall defect. The modification consisting in closing the defect is called the IPOM-plus (mesh augmentation) as opposed to the original IPOM technique (standard IPOM; sIPOM) with the mesh placed under the defect (bridging). Edges of the defect may be sutured intraperitoneally using a laparoscopic holder or suture-passer with thread binding inside the peritoneum or outside the body. IPOM-plus method is associated with fewer recurrences, seromas and bulging, compared to sIPOM ( $p < 0.05$ ) [43].

#### LIRA

In intraperitoneal techniques, the closure of extensive hernia defect creates the risk of pain, recurrence, and may require the use of

techniques for release of muscles in lateral parts of the abdomen. In some cases, the application of those techniques may even be technically impossible [44]. At the same time, coverage of open hernia defect with a mesh creates a high risk of bulging, recurrence and seroma. Morales-Conde suggested to use a fragment of the posterior sheath of the rectus abdominis muscle to close the defect in hernia defect. In the case of hernias with defects of 4–10 cm, the posterior sheath of the rectus muscle is incised longitudinally on both sides. Thus obtained medial fascial flaps are sutured together along their entire length to recreate the linea alba [45]. The exposed posterior surface of recti muscles is covered with an intraperitoneal non-adhesive mesh and fixed with tacks around the perimeter. According to the author, the main advantage of the LIRA technique is the possibility of ensuring the absence of tension in the suture line, which results in significantly less pain. In one-year follow-up the authors found no cases of recurrence of hernia [45].

The last decade in hernia surgery has primarily been focused on an attempt to combine the concept of open Rives-Stoppa retromuscular mesh placement with benefits of the laparoscopic IPOM surgery. Those attempts have resulted in the development of a number of new methods allowing the reduction of the number of recurrences, restoration of the function of the abdominal wall, avoiding contact

of synthetic material with abdominal organs, reduction in the number of infections and complications associated with wound healing, and reduction of postoperative pain. Modern surgical medicine offers a number of ventral hernia repair techniques. However, a single, universal treatment method has not yet been identified. The literature regarding the methods described above still applies to small groups of patients, and the follow-up period rarely exceeds twelve months. When choosing the optimal technique for a given patient, a surgeon should first of all be guided by technical feasibility, availability of materials, their own experience, as well as the characteristics of the patient and overall burdens. Further research and analysis of long-term treatment results may influence the determination of indications for the use of specific methods in particular clinical situations. Nevertheless, surgeons undertaking reconstruction of the abdominal wall in hernias should know different surgical accesses and individual spaces of the abdominal integument, in which a synthetic material may be placed. However, it should be emphasized that the poor ergonomics of novel techniques, complex anatomy and complicated dissection of space, as well as the need for laparoscopic suturing in a difficult arrangement of tissue layers and in a narrow space, without a full triangulation of instruments, make these operations a challenge even for a surgeon experienced in minimally invasive operations.

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