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REVIEW

Mini-invasive surgery for *diastasis recti*: an overview on different approaches

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ABSTRACT

Diastasis recti abdominis (DRA) is an acquired condition defined by a widening of the linea alba exceeding 2 cm and the subsequent separation between the two medial margins of the rectus muscles, accompanied by a laxity of the ventral abdominal muscles, and often by ventral midline hernias. It is a quite common problem in women after pregnancy. In addition to the aesthetic implications resulting from the swelling of the anterior abdominal wall in the case of increased pressure within the abdominal cavity, DRA leads to several physical functional disorders, including muscle weakness, prolapses of the pelvic organs, urinary and fecal incontinence, low back and pelvic pain and sexual dysfunction. The management of *diastasis recti* can be conservative, with physiotherapy and specific physical exercises, but, especially in case of concomitant hernia, surgery can be considered as the first choice of treatment in order to restore the midline and repair the hernia. Through recent years, a large amount of mini-invasive surgical techniques has been proposed, approaching the abdominal differently, and to date there is still lack of evidence on the optimal choice for surgeons and patients. So, the present review aims to give the reader an overview on the different techniques proposed, focusing on the three main categories of approaches (pre-aponeurotic, retro-muscular and pre-peritoneal), their specific features and results, with a view on the newly proposed robotic approaches that can theoretically reproduce each single technique.

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KEY WORDS: *Diastasis recti* and weakness of the linea alba; Minimally invasive surgical procedures; Hernia; Robotics.

Diastasis recti abdominis (DRA) is an acquired condition defined by a widening of the Linea alba exceeding 2 cm and the subsequent separation between the two medial margins of the rectus muscles, accompanied by a laxity of the ventral abdominal muscles.[1]

It has been established that obesity, collagen disease and pregnancy increases the risk of developing DRA.[2, 3] Indeed, maternal age, multiparity, caesarean section, macrosomia and multiple gestations increase the chances for persistent DRA.[4]

During pregnancy, the volumetric expansion of the uterus results in a tensile strain on the connective tissue of the Linea alba. This results in a stretching of the rectus abdominis muscles, accompanied by an increase in the distance between the medial edges of the rectus abdominis muscles.[5]

The typical remodeling process of the DRA lasts approximately six to eight weeks, with the possibility of extension up to 12 months post-pregnancy. In the event of incomplete remodeling, a diastatic defect may persist in 39-52% of women following pregnancy.[2, 6, 7]

In addition to the aesthetic implications resulting from the swelling of the anterior abdominal wall in the case of increased pressure within the abdominal cavity, DRA leads to a number of physical functional disorders, including muscle weakness, prolapses of the pelvic organs, urinary and fecal incontinence, low back and pelvic pain and sexual dysfunction.[4, 8-12]

Furthermore, diastasis of the rectus abdominis predisposes to associated hernia defects due to stretching and thinning of the linea alba.[13]

Various methods of measuring the width of the linea alba are used in clinical practice. DRA can be diagnosed by clinical examination with the "finger width" method, particularly during the Valsalva maneuver highlighting a midline bulging depending on the size of the diastasis.[14] Other diagnostic methods include calipers, ultrasound or CT scan.[1]

Several classification systems have been put forth over the years. In the initial proposal, Ranney *et al.*[15] suggested a classification system based exclusively on the width of the DRA, delineating three categories: mild (<3 cm), moderate (3-5 cm), and severe (≥5 cm). However, the proposal did not specify the location, length and presence of concomitant hernias. Subsequently, Reinpold *et al.*[16] proposed a refinement of this concept, with a focus on position, dividing them from M1 to M5, according to the width of the diastasis (W1: <3 cm, W2: 3 ≤5 cm, W3: >5 cm) and length. A novel classification system, based on rectus muscle width, postpartum status, and the presence of concomitant hernias, has recently been proposed by the European Hernia Society (EHS).[1]

Conservative treatment of DRA can be attempt before surgery.[1] This includes exercise programs to strengthen the abdominal wall or physiotherapy, although it is not possible to recommend a specific non-surgical treatment for DRA.[1]

When DRA fails conservative treatment and patients experience severe functional or aesthetic impairment, surgery is the treatment of choice.[17]

In the absence of a concomitant midline hernia, the Guidelines recommend plication of the linea alba for the treatment of DRA with optional mesh positioning. In the event of a midline hernia measuring >1 cm in diameter, mesh placement is also advised.[1]

In the context of an abdominal wall hernia, it is important to consider the treatment of DRA. Abdominal hernia repair alone has been found to result in a high recurrence rate.[18] The International Endo Hernia Society (IEHS) guidelines state that the risk of recurrence of abdominal wall hernia in the absence of treatment for DRA is 31% compared to 8% when DRA is treated.[17] Furthermore, the mesh size should be expanded to the size of the complete line of closure along the linea alba, and the preferred suture should be non-absorbable monofilament in all of its length[17]. The selection of the appropriate therapeutic techniques is an essential aspect of the patient treatment process. Nowadays, numerous surgical techniques are available that allow the repair of DRA associated or not with ventral/incisional hernias, including minimally invasive surgery (MIS). The advantages of MIS are numerous, including a reduction in postoperative pain, a faster recovery period, a shorter hospital stay, and a more rapid introduction of postoperative oral nutrition. There are a variety of techniques to performing MIS. These may involve different types of surgical access (sub-cutaneous, retromuscular, intraperitoneal) and different locations for mesh positioning (onlay, sublay and preperitoneal). The indications for MIS are variable and not standardized across the various authors. However, it needs to be considered that that surgical treatment of DRA is a shared decision-making process between the surgeon and the patient. The choice of treatment must be made based on patient's needs,[1] avoiding the use of minimally invasive techniques in the presence of prior hernia repair, laparotomy, and need for abdominoplasty.[17] It was, in fact, observed that the outcomes of minimally invasive techniques for the repair of post pregnancy DRA are comparable to those of open techniques in terms of postoperative complications, readmission rates and recurrences.[19] Both approaches are therefore considered valid option, particularly in the presence of excess skin, with an open approach with abdominoplasty being the preferred option.[19] This review will endeavor to provide a comprehensive analysis of MIS techniques currently available for the treatment of DRA associated or not with abdominal wall hernias. It will attempt to provide indications for specific techniques and outline their respective strengths and limitations, as well as complications.

Search strategy

The literature review study was carried out according to current ethical standard.

Searches were conducted for all English language full-text articles published until June 2024. The following database sources were searched: PubMed (MEDLINE), Scopus, Cochrane Library, EMBASE, Web of Science. The following terms were used: mini-invasive surgery, laparoscopy, laparoscopic surgery, robotic surgery, endoscopic surgery, diastasis recti, rectus diastasis. Records were screened for relevance based on their title and abstract and successively the full text of the remaining articles was analyzed. Furthermore, the references list of each selected article was analyzed to identify additional relevant studies.

Inclusion criteria

The types of studies eligible for inclusion were only original articles (retrospective, prospective, randomized clinical trials). Criteria of inclusion of potential studies in this review were cohort studies or case series that investigated the minimally invasive approaches for the treatment of *diastasis recti*.

Endpoint

The endpoint of this review was to identify and synthetically describe the different surgical approach to *diastasis recti* in combination with ventral hernia.

Pre-aponeurotic techniques

Endoscopic-assisted linea alba reconstruction

The endoscopic-assisted linea alba reconstruction (ELAR)[20] can be defined as a hybrid surgical procedure that is recommended for the repair of DRA associated with abdominal hernias.

The patient is positioned supine, with the surgeon situated to the right of the patient and the video-endoscopic equipment positioned in front of him. The initial open phase comprises a supraumbilical incision surrounding the umbilicus on the left side and extending cranially for approximately 3 cm. This is accompanied by the isolation and reduction of any potential ventral or incisional hernias.

Subsequently, a dissection of the pre-aponeurotic space (PAS) extending from the xiphoid process superiorly to the sub umbilical area inferiorly is conducted with the video-endoscopic equipment. The dissection then extends laterally for approximately 4-5 cm from the midline. The subsequent step is the incision of the anterior rectus sheat (ARS) at approximately 2 cm from the medial margin of the rectus abdominis muscles, along the cranio-caudal extension of the dissection. This is to reduce the tension on the midline. The incised margins of the ARS and hernia defect are then sutured together with non-absorbable loop sutures, thus recreating the linea alba. A shaped polypropylene mesh is placed in onlay position and fixed to ARS using continuous non-absorbable suturing material. Finally, a drain is placed between the mesh and subcutaneous tissue.

Minimal invasive linea alba reconstruction

Minimal invasive linea alba reconstruction (MILAR)[21] is an effective surgical technique for patients presenting with DRA>2 cm and symptomatic primary midline hernia between 1 and 4 cm. This technique shares similarities with ELAR, including the type of periumbilical incision to gain PAS and the incision of the ARS to decrease tension in the midline. However, in contrast to ELAR, the surgeon assumes a position between the patient's legs and does not necessitate the use of endoscopic equipment. Indeed, the use of special adaptable light retractors enables the visualization of the subcutaneous space, thereby creating a workspace extending from the xiphoid process to the sub-umbilical region. The incised ARS margins are then sutured together with a slowly absorbable running suture 2/0. A further difference is the use of a biosynthetic absorbable mesh, which is fixed to the ARS at the four cardinal points with interrupted suture and along the lateral margins of the ARS with barbed running sutures. The use of a drain in the subcutaneous space is optional.

Full endoscopic suprapubic subcutaneous access

The full endoscopic suprapubic subcutaneous access (FESSA)[22] is a technique introduced by Bellido-Luque *et al.* for the repair of primary or incisional abdominal hernias <10 cm associated or not with a DRA >2 cm. This approach also involves an ARS incision for tension-free midline closure but is performed endoscopically only.

The patient lies on their back with the surgeon between his legs. A bottom-up approach is used with three suprapubic trocars (one 10-mm trocar for the camera and two 5-mm trocars for the instruments). Once the PAS has been obtained and any midline hernias have been identified and reduced, the ARS is incised in a longitudinal manner from the xiphoid process to 3-5 cm below the umbilicus, at 2-5 cm from the medial border of the rectus abdominis muscles. The two medial edges of the opened ARS are sutured with a Slowly absorbable continuous barbed sutures 2/0 to reconstruct the midline. A polypropylene mesh is placed in an onlay position and sutured with a continuous barbed suture to the lateral edge of ARS. In the final stage a suction drain is placed in the subcutaneous space.

Reparacion endoscopica pre-aponeurotica

Pre-aponeurotic endoscopic repair is the English name for REPA (reparacion endoscopica pre-aponeurotica [REPA]) devised by Juárez Muas *et al.*[23] for DRA between 2-4 cm in association with midline defects between 1 and 4 cm. This technique does not entail the incision of ARS, but rather the external oblique muscles release (EOR) when the DRA exceeds 7 cm. in order to decrease the tension on the midline when the two edges of the rectus muscles are sutured together. This is a fully endoscopic surgical technique and involved the utilization of three trocars creating a subcutaneous space in suprapubic space. The ARS is plicated from the xiphoid appendix to 5 cm below the navel with a barbed suture. The subsequent step is the placement of a polypropylene mesh within the PAS, which is then secured to the ARS with the use of trackers, straps, or absorbable sutures. A drain is then positioned in subcutaneous space.[24]

Minimally invasive bilayer suturing technique

This hybrid technique, developed by Ngo *et al.*,[25] is intended for the repair of ventral or incisional abdominal wall hernias measuring between 1 and 3 cm in conjunction with DRA between 3 and 12 cm. The patient is positioned supine with the legs apart, and the surgeon's position varies according to the stage of the procedure. Indeed, in the initial open step, the surgeon assumes a position on the patient's side, making a periumbilical incision to gain access to the umbilical PAS. A 6 cm Alexis retractor is then placed, approximating the medial margins of the rectus muscles for a length of 5-6 cm cranially and caudally with a slowly resorbable 2/0 continuous suture. Any umbilical hernia is reduced, and the defect is incorporated into the suture.

In the second endoscopic step, the surgeon moves between the patient's legs and two 5 mm trocars are placed at the level of the right and left flank, and one 12 mm trocar is placed at the level of the Alexis. A further dissection of the PAS is then performed, extending cranio-caudally and up to the lateral border of both rectus muscles. At this stage, it is possible to repair epigastric hernias.

The ARS is then sutured in a continuous slowly absorbable barbed suture 0, both cranially up to the xiphoid process and below the umbilicus. No mesh or drains are placed in the PAS.[25]

Subcutaneous video surgery for abdominal wall defects/endoscopic pre-aponeurotic repair/subcutaneous onlay laparoscopic approach/total endoscopic assisted linea alba reconstruction

The technical principles underlying these procedures are similar, and the differences between them are minor. All of the procedures utilize full endoscopic assistance and do not involve the release incision of ARS or EOR. The subcutaneous video surgery for abdominal wall defects (SVAWD)[26] finds its indications for DRA>2 cm in association with abdominal hernias <10 cm. Endoscopic pre-aponeurotic repair (EPAR)[27] Technique instead for DRA between 2-4 cm in association with abdominal wall hernia between 1-4 cm. It should be noted that some authors did not provide data regarding the dimensions of DRA defects or midline hernias like in sub-cutaneous onlay laparoscopic approach (SCOLA)[28] or no indication at all, as in the total endoscopic assisted linea alba reconstruction (TESLAR).[23]

The patient is positioned supine with the legs apart, and the surgeon is situated between the patient's legs. Three trocars are positioned in the suprapubic region. A 10-12 mm trocar is positioned in a suprapubic location for the camera. Subsequently, the supra-aponeurotic space is dissected, and two further 5mm trocars are placed on the same line at a variable distance of 2-5 cm from each other. The subcutaneous tissue is dissected from the anterior rectus sheath (RS) from the pubis until reaches the subxiphoid region and costal margin, continuing laterally to the lateral border of the anterior rectus sheath. The extent of the dissection was found to be consistent regardless of the width of the defect and the distance between the plication and the costal margin.[23, 26-28]

This dissection can also be performed with the introduction of a 10 mm trocar with a balloon.[26]

The hernial sacs were identified and reduced. The DR plication is performed with a running suture on the ARS to approximate the right and left abdominal rectus muscle edges in the midline. This extends from the xiphoid to 2–3 cm below the umbilicus.[23, 26-28] Mesh is is typically synthetic[26-28] or biological in nature.[23] The mesh is positioned in an onlay position and secured with tacks, sutures, or glue.[23, 26-28] Subsequently, a drain is introduced into the PAS via the same incision used for the portal, which is 5 mm in length.[23, 26-28]

Totally endoscopic sublay anterior repair

Fiori *et al.* proposed the totally endoscopic sublay anterior repair (TESAR)[29] technique as a means of repairing ventral or incisional midline hernias measuring no larger than 7 cm. This approach was subsequently extended to encompass DRA repair, including cases exceeding 5 cm.[30]

This surgical technique involves an entirely endoscopic bottom-up approach, with the surgeon positioning between the patient's legs. A subcutaneous space is created at the level of the suprapubic region, where two 10 mm and one 5 mm trocars are placed. A subcutaneous dissection is performed until the subxiphoid region and the lateral margins of the rectus abdominis muscles are reached. In this phase, any umbilical or epigastric hernias are reduced. A full-length incision is made in the ARS in order to gain access to the retrorectus space (RS). The RS is then subjected to extensive dissection, after which a prosthesis is placed within the RS and fixed at the four cardinal points with non-absorbable polypropylene sutures. If reconstruction of the posterior rectus sheat (PRS) is required, it is performed using a running slowly absorbable suture 1, in conjunction with the ARS along the midline. Two drains are placed: one in the RS and one in the subcutaneous space. This approach combines the advantages of fully endoscopic anterior access with those of sublay repair. Indeed, this technique provides a substantial working chamber, facilitating unobstructed and secure identification of anatomical planes and the positioning of a sublay mesh, which enhances the efficacy of incisional hernia repairs.

These procedures are conducted entirely extraperitoneal, without necessitating alterations to the trocar configuration. Furthermore, the extensive subcutaneous dissection permits greater skin retraction, thereby achieving superior aesthetic outcomes.

Retromuscular techniques

Endoscopic mini/less open sublay technique

The endoscopic mini/less open sublay technique[31] (E-MILOS) represents a hybrid technique that may be regarded as an endoscopic evolution of mini/less open sublay technique[32] (MILOS). This technique is indicated for the repair of ventral/incisional midline hernias in combination with DRA.

The initial phase necessitates an incision of approximately 3-6 cm at the herniated defect, which is then isolated and reduced.

Subsequently, the endoscopic phase is initiated by incising the PRS on one side and gaining access to the RS by introducing an independently constructed indigenous balloon in a caudal direction towards the pubic symphysis. Once the incision of the contralateral PSR has been completed to the greatest extent possible, CO_2 is insufflated through a trocar in order to create the working space within the RS. Subsequently, a 12 mm trocar is placed at the hypogastric level, which will be utilized for optics, and two additional 5 mm working trocars are positioned on either side of the mid-clavicular line, approximately 3-5 cm above the umbilicus. The surgeon is positioned between the patient's legs. The incision of PRS is completed in an upward direction and the dissection of the RS is carried out towards the xiphoid process and in a lateral direction towards the neurovascular bundles. An additional 10-mm optical trocar is positioned at the level of the upper left quadrant of the abdomen to obtain a downward view and complete the PRS incision and dissection of the RS up to the Retzius space.[31] The PRS is then closed with a running suture up to the adipose triangle, which is left open.[33] A large polypropylene or PVDF mesh is positioned in the RS and oriented using 4-6 holding loops. Two drains are systematically placed over the mesh in RS. The skin is re-opened, the wound is lavaged with an antiseptic solution, and the hernia defect is closed with a non-absorbable running suture in small-bite technique.[31, 33]

Totally endoscopic sublay

The totally endoscopic sublay (TES) repair has been developed by Li *et al.*[34] for the repair of ventral and incisional hernias <5 cm in association with DRA. This is a purely laparoscopic technique, which involves a bottom-up approach with the placement of a 12-mm optic trocar at the level of the hypogastric region and two 5-mm trocars in the bilateral intersection areas of the linea semilunaris and arcuate line. The hypogastric preperitoneal space can be obtained in two ways. The first is a stepwise approach, utilizing a trocar placed at the infraumbilical midline to perform a dissection of the RS up to the pubic symphysis, followed by the subsequent placement of trocars. Alternatively, a 12 mm incision at the hypogastric level can be made, followed by the direct placement of trocars. The surgeon stands between the patient's legs.

The transition to the RS is then achieved by detaching the PRS bilaterally, dissecting the RS upwards to the xiphoid process and laterally to the semilunaris line, and incising the PRS bilaterally to approximately 0.5 cm from Linea alba. The PRS is then closed with a running 1-0 barbed suture. In the case of DRA, the ARS can be closed with a running 1-0 barbed suture. A large macroporous PVDF mesh is placed in sublay position and secured with chemical glue. A closed suction drain is placed on top of the mesh.[34]

Extraperitoneal Rives-Stoppa repair

Moga *et al.* employed this technique for the repair of ventral or incisional hernias measuring between 1 and 4 cm in conjunction with DRA measuring between 4 and 6 cm. He designated it the Extended-view of a totally extraperitoneal Rives-Stoppa repair (eRives)[35] technique. This technique bears similarity to Extended view Totally extraperitoneal (e-Tep), yet it does not necessitate posterior separation of the components and is additionally utilized for DRA repair.

A 10-mm trocar was inserted with the open technique on the umbilical line at the level of the lateral border of the left rectus abdominis muscle. Two additional 5-mm trocars are positioned on the same line, one superiorly and one inferiorly. A wide dissection of the RS is performed, extending from the xiphoid process superiorly to a point at least 5 cm below the defect inferiorly. The PRS is incised at a distance of 0.5 cm from the linea alba to facilitate the crossing to the contralateral RS. The herniated sac is then subjected to a process of dissection.

The second step involves the placement of a 10-mm trocar in a hypogastric position along the midline, in addition to a 5-mm trocar at the level of the right upper quadrant. This allows the surgeon to adopt a more ergonomic position, thereby facilitating the closure of peritoneal defects and the DRA with a suture of the ARS. This is performed with a 0 non-absorbable barbed wire running suture. Subsequently, a large polypropylene macroporous mesh is positioned within the RS, attached at its superior end with a single 2/0 non-absorbable stitch to the PRS. The placement of a drainage tube is only indicated in cases where the dissection has been particularly challenging.[35]

Robotic transabdominal retromuscular rectus diastasis

Robotic Transabdominal Retromuscular Rectus Diastasis (r-TARRD) repair[36] is a surgical technique described by Cuccurullo *et al.* that involves the use of the Da Vinci Xi robotic platform.

The patients selected for this technique exhibited median hernia defects between 2 and 10 cm and concomitant DRA greater than 3 cm. The r-TARRD provides intraperitoneal access by placing three 8-mm robotic trocars on the left side at the level of the anterior axillary line, in a subcostal position and on the same line as the left flank. A fourth trocar was placed in a subcostal position, 2 cm laterally from the anterior axillary line. Once the robot has been docked, the PRS is incised laterally, and the RS is obtained through a gentle and meticulous dissection process, extending from the xiphoid process superiorly to the arcuate line inferiorly. Subsequently, an incision is made in the ipsilateral PRS on the medial side of the rectus abdominis muscle in order to gain access to the contralateral RS. The ARS is plicated on the midline using either a non-absorbable or absorbable bi-directional barbed suture 0. The same approach is used for the hernia defect. A large polypropylene mesh is then inserted into the RS and secured with fibrin glue. Finally, the PRS is closed with 3-0 barbed sutures. No retro muscular drainage is placed.[36]

Minimally invasive stapled abdominal wall repair

Minimally invasive stapled abdominal wall repair (MISAR)[37, 38] technique was proposed by Manetti *et al.* for DRA>2 cm associated with midline ventral hernia. The surgical technique is similar to Costa's technique[39] The principal distinctions lie in the utilization of three trocars instead of four, the non-fixation of the mesh to minimize post-operative pain and the indication. Indeed, MISAR was developed specifically for DRA repair in association or not with midline hernia.[37, 38]

This technique involves open access to the peritoneal cavity and placement of a 12-mm trocar in the hypogastric position. An additional 12-mm trocar is positioned at the level of the left iliac fossa, and a third 5-mm trocar is placed in the right iliac fossa.

After adhesion lysis and reduction of any hernias, two incisions are made in the peritoneum and PRS approximately 4 cm below the navel, creating a bilateral RS. Blunt dissection is performed cranially to the xiphoid process and laterally to the lateral margins of the rectus muscles on both sides, passing laterally to the hernia defect. Subsequently, a linear stapler is inserted into the two retromuscular pockets and fired as many times as necessary to reach the xiphoid process, joining the PRS and creating a single retromuscular pocket.[37, 38]

At last, a polypropylene or dual mesh is placed within the RS without the utilization of fixation device. The posterior fascial flap is closed with a barbered absorbable suture.[37, 38]

The author suggests that this technique is unfeasible for DRA below the navel due to the suprapubic position of the trocars. The routine removal of preperitoneal fat is a key aspect of this surgical approach, as its presence may potentially compromise the strength of the suture line.[37, 38]

Trentino hernia team technique

The Trentino hernia team technique (THT), as developed by Carrara *et al.*,[40] represents a further variant that may be defined as a hybrid technique. It involves alternating steps from open to laparoscopic surgery and makes use of a Single-incision laparoscopic surgery (SILS) port access with the placement of a mesh in the RS.

The author puts forth the utilization of this technique for midline ventral and incisional hernias situated between the umbilicus and epigastrium, with a defect width less than 10 cm (M1-M3, W1-2 sec EHS classification[41]), in conjunction with DRA between 4 and 8 cm.

The procedure employs the retromuscular plane, yet during the initial stage, it is always kept under view through laparoscopic intraperitoneal access, which is utilized to perform a potential lysis of adhesions and reduction of the hernia sac. carefully monitor repetitive firing of the stapling device, avoiding damage to the intraperitoneal structures.[40]

The next step is performed with an open approach and involves a periumbilical incision with opening of the ARS of both rectus muscles and gaining space in the RS bilaterally to obtain the space necessary to insert the two branches of the linear stapler. The latter is fired twice to connect the two edges of the PRS. A SILS is then inserted into the umbilical opening. Under endoscopic visualization of the RS, the suture is performed cranio-caudally (5 cm below the umbilicus) to suture the entire length of the PRS, creating a single retromuscular pocket. A blunt dissection of the RS is then performed to allow placement of a PVDF mesh without fixation with an overlap of at least 5 cm. Drainage is not placed. The final step is to closure of the initial surgical accesses to the ARS. Unlike other techniques, THT allows the repair of abdominal hernias and DRAs located below the navel.[40]

Stapled ventral hernias totally extraperitoneal approach

Cossa and Ngo *et al.*, in order to address the issue of swollen abdomens encountered in a previous series of patients undergoing the V-TEP technique,[42] proposed an innovative technique to performing the "crossing" of the posterior fascia using a linear stapler, called the stapled ventral hernias totally extraperitoneal approach (s-VTEP)[43] technique. This technique has been proposed for patients presenting with ventral or incisional midline hernias with DRA.

This procedure is conducted with a descending or ascending approach, depending on the location of the hernial defect. The first stage is similar to the THT technique, whereby a 2 cm incision is made two fingers below the umbilicus or two fingers below the xiphoid process. The ARS is incised to gain access to the RS, where the branches of the linear stapler are inserted and fired, thus creating a single RS. Subsequently, an endoscopic step is conducted, entailing the introduction of an optic trocar through the incision in the skin and the positioning of two additional trocars laterally within the RS. Following the dissection of the RS and the reduction of the hernia sac, the PRS suture with linear stapler is continued along the midline, thus completing the crossing.

The hernia defect and the stapler suture line are then sutured with a continuous suture, which should ideally be tensionless. If this is not the case, two release incisions in the PRS of 1-2 cm can be made medial to the semilunar line on both sides to achieve tension-free midline closure. Finally, a polypropylene mesh is placed without fixation.[43]

Pre-peritoneal techniques

Preperitoneal extended totally extraperitoneal repair

The preperitoneal extended totally extraperitoneal repair (Pe-TEP) technique approach developed by Alpuche *et al.*,[44] was devised to circumvent the shortcomings of the conventional e-TEP approach. These include the potential for cosmetic and functional disorders, and the risk of developing intraparietal hernias in the event of dehiscence of the PRS suture when the tension is excessive. This technique is indicated for the treatment of ventral hernias <4 cm with concomitant DRA. The fundamental principle underlying this technique is the avoidance of any action that would lead to a violation of the RS.[44]

The surgical procedure utilizes three 5 mm suprapubic trocars, which are positioned directly within the pre-transversalis space. The surgeon assumes a position between the patient's legs. A caudo-cranial dissection is then conducted, involving the hypogastric region up to the xiphoid process (Zone 1 and Zone 2), and then extending laterally on both sides up to the semilunaris line (Zone 3). This is a challenging step due to the thinness of the peritoneum in this zone. It is essential that all peritoneal orifices be sealed in order to prevent exposure of the mesh to the peritoneal cavity. The hernia defect and DRA were closed with a 45-cm barbed suture using a reverse horizontal mattress technique. A polypropylene mesh was introduced into the preperitoneal space along the PRS, generally without fixation. The potential benefits of using fibrin sealant were considered, and no drainage was placed.[44]

Totally extraperitoneal approach

The totally extraperitoneal approach (TEA)[45] technique was designed by the same author of TES for the repair of primary midline ventral hernias <4 cm with or without concomitant DRA<3 cm and, unlike the latter, uses the pre-peritoneal space for working space and mesh placement without violating the PRS. The configuration and size of the trocars are the same as for the TES technique, and a bottom-up approach is also used, with the surgeon positioned between the patient's legs. Pre-peritoneal dissection starts from the hypogastric region, below the Arcuate line, and special care must be taken not to violate the PRS in cranial dissection, which is conducted up to the xiphoid process superiorly and the semilunaris line laterally. Once the dissection is complete, any fascial defects are sutured, while

TABLE I.—*List of mini-invasive approaches for* diastasis recti.[20-45]

Name/author	Dissection space	Access type	Suture	MESH: Positioning/ type/fixing	Release incision
ELAR, Kockerling *et al.*[20]	Pre-aponeurotic	LAP/END*	ARS: non-absorbable loop suture	Onlay/polypropylene/ continuous non-absorbable suture	ARS° incision
MILAR, Kohler *et al.*[21]	Pre-aponeurotic	MINI OR LESS OPEN	ARS: Slowly absorbable continuous barbed sutures 2/0	Onlay/biosynthetic absorbable/stitches in cardinal point + running barbed suture in lateral edge of ARS	ARS incision
FESSA, Luque *et al.*[22]	Pre-aponeurotic	LAP/END	ARS: Slowly absorbable continuous barbed sutures 2/0	Onlay/polypropylene/ continuous barbed suture to the lateral edge of ARS	ARS incision
REPA, Juarez Musas *et al.*[24]	Pre-aponeurotic	LAP/END	ARS: Absorbable continuous barbed suture	Onlay/polypropylene/ trackers, straps or absorbable sutures	External oblique muscle release
Bilayer technique, Ngo *et al.*[25]	Pre-aponeurotic	Mini or less open	ARS continuous slowly absorbable barbed sutures	No mesh positioning No drain positioning	No
SVAWD, Barchi *et al.*[26]	Pre-aponeurotic	LAP/END	ARS continuous barbed sutures	Onlay/polypropylene	No
EPAR, Gandhi *et al.*[27]	Pre-aponeurotic	LAP/END	ARS continuous non-absorbable barbed suture	Onlay/polypropylene	No
SCOLA, Claus *et al.*[28]	Pre-aponeurotic	LAP/END	ARS continuous barbed sutures	Onlay/polypropylene	No
TESLAR, Kler *et al.*[23]	Pre-aponeurotic	LAP/END	ARS continuous sutures	Onlay/composite, biological	No
TESAR, Fiori *et al.*[29]	Pre-aponeurotic	LAP/END	ARS running slowly absorbable suture 1 PRS running slowly absorbable suture 1	Sublay/polypropylene/ stitches in 4 cardinal points	ARS incision
E-MILOS, Schwarz *et al.*[31]	Retromuscular	Mini or less open	ARS: no suture PRS: running suture	Sublay/polypropylene, PVDF	PRS incision
TES, Li *et al.*[34]	Retromuscular	LAP/END	ARS running 1-0 barbed suture PRS running 1-0 barbed suture	Sublay/PVDF/fibrin glue	PRS^ incision
E-RIVES, Moga *et al.*[35]	Retromuscular	LAP/END	ARS non-absorbable running 0 barbed suture PRS: No suture	Sublay/polypropylene/ 1 stich in PSR	PRS incision
r-TARRD, Cuccurullo *et al.*[36]	Retromuscular	LAP/END robotic	ARS: bidirectional non-absorbable/ absorbable barbed suture 0 PRS: non-absorbable barbed suture 3.0	Sublay/polypropylene/fibrin glue	PRS incision
MISAR, Manetti *et al.*[37]	Retromuscular	LAP/END	PRS: linear stapler	Sublay/polypropylene	No
THT, Carrara *et al.*[40]	Retromuscular	SILS#	PRS: linear stapler	Sublay/PVDF	No
s-VTEP, Cossa *et al.*[42]	Retromuscular	LAP/END	PRS: linear stapler	Sublay/no specification on mesh	Prs incision
pE-TEP, Alpuche *et al.*[44]	Preperitoneal	LAP/END	PRS: non absorbable barbed suture 1	Sublay-pre peritoneal/ polypropylene/fibrin glue	No
TEA, Li *et al.*[45]	Preperitoneal	LAP/END	ARS: no suture PRS: no suture	Sublay-pre peritoneal/PVDF/ fibrin glue	No

LAP/END: laparo-endoscopic; ARS: anterior rectus sheath; PRS: posterior rectus sheath; SILS: single incision laparoscopic surgery.

the Linea alba is not plicated in the presence of DRA. A large PVDF mesh is then placed in the pre-peritoneal space and secured with chemical glue. The placement of a drainage tube is only considered in cases where unsafe hemostasis is observed (Table I).[45]

Discussion

Over the last few decades, the treatment of DRA associated with ventral hernia has expanded and evolved alongside advancements in minimally invasive surgical techniques. These techniques now represent the first-line option for most patients due to their reported benefits in terms of abdominal core functionality and cosmetic outcomes. Open surgery is increasingly reserved for cases involving concomitant plastic surgery procedures, such as dermolipectomy.

The management of DRA, particularly in female patients following one or more pregnancies, has garnered significant interest within the scientific community and literature.[2, 6, 7] This condition is often further complicated by the presence of a midline hernia. The primary rationale for the surgical treatment of DRA lies in the restoration of abdominal core functionality in patients who no longer experience the increased intra-abdominal pressure associated with pregnancy. From this perspective, restoring core function and stability not only improves functionality but also enhances cosmetic outcomes.

As highlighted in this review article, a wide variety of minimally invasive approaches for DRA repair have been proposed and described, sometimes leading to confusion regarding techniques, acronyms, and expected outcomes. Nonetheless, most techniques can be categorized based on their anatomical working space into three main groups: pre-aponeurotic, retromuscular, and preperitoneal approaches.

Intraperitoneal approaches were excluded from the present review, as there are currently no techniques specifically indicated for DRA repair; instead, they are primarily designed for the repair of abdominal hernias.[46-48] While some technical variants of the intraperitoneal onlay mesh (IPOM) technique have been described for DRA closure such as single- or double-layer suture techniques, triangular "mattress" sutures,[49, 50] or the Venetian blind technique[51] these methods are associated with complications that have led many surgeons to prefer alternative mesh placement locations.

In particular, placing a mesh within the abdominal cavity carries risks such as adhesions and fistula formation.[52] Additionally, post-operative pain is often exacerbated by the fixation methods used for the mesh, increasing the likelihood of chronic pain.[53, 54]

For these reasons, we have focused on techniques employing an extraperitoneal approach, which we believe to be safer and more effective for DRA repair. These methods allow for more precise identification of anatomical structures, minimizing risks of visceral injury while optimizing surgical outcomes.

Pre-aponeurotic techniques Initially proposed in the mid-1990s[55, 56] have evolved over time and are now primarily indicated for women with postpartum insufficiency of the anterior abdominal wall, aiming to restore abdominal wall function.[57] Malcher *et al.* standardized these techniques under the acronym ENDOR (ENDoscopic Onlay Repair).[58]

These techniques share common principles: the development of a PAS, plication of the DRA via an anterior approach, and placement of a mesh, which is typically positioned in an onlay fashion.[58] Surgical intervention is generally indicated in cases of DRA with widths ranging from 2 to 6 cm (with reports extending up to 15 cm), often accompanied by umbilical, epigastric, or abdominal incisional hernias measuring 2 to 4 cm in width, though cases with widths up to 11 cm have also been described. Pre-aponeurotic techniques exhibit numerous similarities between them. Some of these techniques are hybrid, involving an initial open step followed by an endoscopic step, while others are purely endoscopic. They may also include a release incision of the ARS or EOR. The DRA is consistently repaired with ARS suturing using various materials, and a mesh is almost always placed in an onlay position.

The principal advantages of these procedures include their minimally invasive nature, which allows for simultaneous endoscopic repair of both the DRA and the hernia, excellent cosmetic outcomes, favorable surgical ergonomics, and ease of adaptability. Additionally, they are considered safer due to a low risk of visceral injury, the absence of the need to work against abdominal pressure, and the elimination of reverse-instrumentation requirements seen in posterior approaches. Complete removal of the hernia sac is also achievable, offering optimal morphological outcomes, particularly for thin patients. However, there are limitations to these techniques. Their application in obese patients is challenging. Many studies have excluded such cases due to difficulties in identifying and dissecting the PAS. Furthermore, detachment of subcutaneous tissue can lead to altered sensitivity of the abdominal wall skin.[55] In some cases, skin adhesions between the mesh and the overlying skin may form, resulting in skin folds.[59]

The most common complication reported in literature is seroma formation, with an incidence ranging from 4.7% to 81% across studies. There is also an increased risk of surgical site infections (SSI) and hernia recurrence compared to the sublay repair technique. The studies included in this review documented recurrence rates between 1.9% and 12.5%, although six studies reported no recurrences, albeit with limited follow-up periods (1-24 months). Retromuscular space positioning is often considered superior in the literature due to its lower risks of SSI and recurrence. To our knowledge, only a single case of abdominal wall pseudocyst formation has been reported in association with the subcutaneous approach.[60]

Retro-muscular approach involves the positioning of a mesh within the RS. This concept was initially proposed by Stoppa *et al.*[61] and is based on the principle that the mesh becomes firmly integrated between the RS and PRS. The biomechanical properties of this anatomical space facilitate the compression of the mesh by intra-abdominal pressure, effectively entrapping it within the retromuscular pocket and ensuring its optimal integration with the surrounding tissue.[61] Additionally, the predominance of mature type I collagen in this region enhances the tensile strength of the wound, contributing to greater repair durability.[62] The Stoppa's concept has been integrated with MIS, leading to the development of new techniques that combine the advantages of both approaches.

These characteristics allows for the possibility of mesh placement without fixation, thereby avoiding potential trauma caused by fixation methods and significantly reducing postoperative pain.

Moreover, the risk of seroma formation is minimal due to the absence of pre-aponeurotic detachment and does not typically necessitate the utilization of surgical drains. The retromuscular mesh placement also prevents direct contact with abdominal viscera, thereby reducing the likelihood of adhesions, perforations, recurrences, and infections compared to ENDOR procedures and the use of an extraperitoneal working space minimize the risk of iatrogenic visceral injuries.[63, 64] Retromuscular MIS also provides easier access to defects in the subxiphoid or suprapubic areas.

Conversely, the potential drawbacks include an extended learning curve due to the challenging accessibility of the RS and the suboptimal ergonomics of these techniques, particularly during midline suturing at the roof of the surgical field. Additionally, the lack of closure of the PRS after it is opened to access the contralateral may result in the risk of a swollen abdomen (linear bulging along the midline) and persistent seroma, caused by the presence of a residual hernia sac included within the repair suture.

Undoubtedly, the most well-known technique in this category is the enhanced view – totally extraperitoneal technique (e-Tep). Initially developed by Daes *et al.*[65, 66] for inguinal hernia repair, this approach was later extended by Belyansky *et al.*[67] to address ventral hernia repairs. As this technique was not specifically developed for DRA repair, it will not be described in detail here. However, it is important to note that many of the retromuscular techniques discussed in this review are based on the technical principles underlying the e-Tep approach.

The primary objective of retromuscular techniques is to gain RS and perform a blunt dissection in this virtually avascular space, creating sufficient space for a mesh of appropriate size to cover both the hernia defect and the DRA. It is crucial to preserve the neurovascular bundle and the epigastric vessels during this step to maintain the thickness and function of the rectus muscles, as damage to these structures can occur during the procedure.[61]

The present review describes seven techniques for repairing DRA using the retromuscular approach. These include one employing a minimally invasive or less open approach,[31] five utilizing a purely endoscopic approach[34, 35, 37, 40, 43] and one performed with the assistance of a robotic platform.[36] The DRA repair is achieved either through direct suturing[31, 34-36] or by using a linear stapler for PRS suturing.[37, 40, 43]

Compared to pre-aponeurotic techniques, the incidence of seroma was significantly lower, ranging from 0.9% to 3.8%. The most frequently observed adverse events were retromuscular bleeding. Suture line failure occurring in 8% of patients who underwent s-VTEP.[43] The mean follow-up period ranged from 6 to 14.4 months. Only r-TARRD[36] and MISAR[37, 38] demonstrated recurrence rates of 8.89% and 2.7%, respectively; however, these rates may be influenced by inadequate follow-up.

Operative times showed considerable variability, ranging from 82.4 to 285 minutes. Notably, operative times for stapling techniques were consistent and shorter, while suture-based techniques were observed to be more time-consuming and complex.

The utilization of robotic platforms has the potential to enhance operational efficiency, thereby increasing operational time.

There were no significant differences in postoperative hospital stays, which consistently ranged from 1 to 3.2 days. However, r-TARRD[36] had a longer average postoperative stay of 4.2 days compared to other techniques. The reported inter-rectus distance varied between 3 and 9 cm, though this parameter was not consistently documented across all studies.[31, 34, 43]

Direct suturing techniques allow for the approximation of the medial margins of the rectus muscles at the midline, achieved through continuous or interrupted plication using slowly absorbable or non-absorbable materials, typically in one or two layers.[31, 34-36, 68] In all retromuscular techniques, PRS is sutured, with the exception of those described by Moga *et al.*,[35] who advocate leaving it open. Conversely, in EMILOS, ARS is only not sutured.[31] The authors observed that the non-closure of the PRS resulted in the protrusion of the abdominal wall at the midline.[42] To address this issue, the PRS was closed, thus preventing the formation of an aesthetically displeasing defect.

Direct suture for DRA repairing is a technically demanding procedure requiring advanced expertise, but it is relatively cost-effective. However, it has been suggested that tension forces may converge at the point where the suture line penetrates the fascia, which can lead to uneven tension distribution and potentially increase the risk of post-operative discomfort.[69-71]

In recent years, novel techniques utilizing linear staplers have been developed for this purpose.[37, 40, 43] The idea of using a linear stapler to restore the midline by incorporating the hernia sac was first proposed by Costa *et al.*[39]

This approach allows for a more even distribution of tensile forces across the suture line, which effectively approximates the rectus muscles toward the midline. The PRS and hernia sac are directly sutured together, promoting the restoration of the midline and evenly distributing tension, which may reduce the risk of recurrence and post-operative pain.[38-40]

An experimental study conducted on an animal model and human cadavers for fascial closure in the abdominal wall showed that the pressure and tension thresholds of stapled sutures were comparable to those of conventional sutures.[72]

Stapling techniques offer numerous advantages, including simplicity, reduced operating time, and decreased post-operative pain compared to direct suturing. However, one potential disadvantage is the high cost.[37, 40, 43] Furthermore, excessive tension on the midline may be a concern when dealing with herniated defects that are too large. This can be addressed through a medial incision on the PRS to relieve the tension or with a transversus abdominis release.[40]

Despite the advantages of retromuscular techniques, they remain complex and require a comprehensive understanding of abdominal wall anatomy. Some techniques, particularly those with a narrow initial working space, require extended training. Furthermore, the appropriate selection of patients for the various surgical approaches remains controversial.[17, 73]

In all of the aforementioned techniques, a polypropylene[35-38]or PVDF[34, 40] mesh is positioned in the RS. The fixation methods include fibrin glue, single stitches or non-fixation of the mesh.

The type of mesh material used in the s-VTEP is not reported, nor is the means of fixation.

This review examines also two fully endoscopic preperitoneal techniques. The fundamental principle of preperitoneal approaches is to avoid disrupting the posterior RS (PRS), thereby preserving the RS. This approach enables the minimally invasive repair of single or multiple primary midline hernias, along with the plication of rectus muscle diastasis without creating a ridge, and the placement of an extraperitoneal mesh. By avoiding the division of the PRS, as seen in retromuscular techniques, this approach prevents complications that could lead to unsatisfactory aesthetic outcomes and the formation of intraparietal hernias due to the closure of the PRS under high tension. In this case, the mesh is also excluded from the intraperitoneal cavity. Given the advantages previously outlined, this technique utilizes a natural surgical plane without disrupting normal anatomical structures, thereby adhering to intrinsic anatomical principles and significantly reducing postoperative pain. A limitation of the preperitoneal eTEP technique is the difficulty arising from the thinness of the peritoneum, making it suitable only for small or moderate defects. Plication of the diastasis, when involving the lower abdomen, is not feasible with this approach, so anterior plication with onlay mesh placement is preferred. The fragility of the peritoneum, especially in lateral zone, may complicate the space creation and increase the risk of peritoneal tears. Additionally, care must be taken to avoid thermal injury to the intestine adjacent to the thin peritoneum. No intestinal adhesions have been observed thus far, but long-term follow-up is necessary.

In this category, only TEA demonstrated a 7.1% incidence of seroma, with no additional complications reported beyond wound-related issues, which were observed in 3.5% of TEA cases and 3.3% of the comparison group, respectively. No significant differences were identified in the length of postoperative hospital stays, which consistently ranged from one to two days. The mean follow-up period spanned 12 to 18 months, during which no recurrences were detected. Although the size of the herniated defect was noted, the dimensions of the DRA were not specified. Operative times were similar, ranging from 90 to 103.3 minutes. These findings suggest that the outcomes are comparable to those achieved with retromuscular techniques.

One of the primary challenges associated with minimally invasive techniques for DRA repair is the potential for residual excess skin following midline suturing. This issue arises from an incongruence between the unaltered dermal layer and the sutured musculoaponeurotic layer. In cases where the patient is overweight or obese, or when the DRA or associated abdominal hernias exceed 6 cm, an open approach is often preferred, as it enables the removal of redundant skin. It is noteworthy that a growing number of studies are no longer excluding patients with obesity from these procedures.[58, 74]

It is of the utmost importance to communicate effectively about the expected postoperative outcomes. The selection of the surgical technique should be based on a collaborative decision-making process between the patient and the surgeon, with the objective of ensuring alignment with the patient's goals and expectations.[58, 74]

Finally, robotic approaches should be mentioned. Recent studies have shown ergonomic benefits of using robotic platforms compared to traditional laparoscopy, although they come with longer operative times and increased costs.[75] The development of robotic techniques in minimally invasive abdominal wall surgery is rapidly progressing, overcoming many challenges of laparoscopic techniques. Robotic systems allow for greater precision in tissue dissection and overcome limitations in suturing, especially in hard-to-reach areas like the roof of the operating field.[76]

Skepticism about robotic techniques stems from the fact that the benefits associated with this type of surgery, such as lower complication rates and shorter hospital stays, are offset by long operating times, poor availability and a high learning curve for operating surgeons, assistants and nursing staff.[77, 78] Currently, there is a paucity of scientific literature with studies specifically documenting the results of robotic repair of DRA.[36, 79, 80] Nevertheless, some of the procedures described previously can be successfully reproduced with the aim of robotic platform,[81-84] while some could be ideally reproduced by repeating the same steps to repair the DRA

So, the present review should be an exhortation to perform prospective comparative evaluation (with adequate follow-up and outcomes evaluation), in the absence of any possible conflict of interest, in order to assess (at least) which procedure should be preferred on every single case, in the optic of an actual tailored surgery.

Conclusions

Surgery for DRA associated with ventral hernia has evolved and spread through recent years towards minimally invasive approach, as many different techniques have been proposed and described, mainly differentiating for the type of approach to the abdominal wall: pre-aponeuritoc, retromuscular and intraperitoneal. Despite the presence of a large choice, to date no comparative study exist on this specific matter, and giving a definitive statement becomes not possible. So, scientific community needs this kind of study to be performed.

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Conflicts of interest
The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions
Angelo Iossa and Giuseppe Cavallaro designed the study; Giulio Lelli and Alessia Fassari developed the research strategy, and retrieved the full text article; Giulio Lelli and Giorgio Soliani completed the review process and wrote the manuscript; Alessandra Micalizzi and Francesco De Angelis participated in proofs correction. All authors read and approved the final version of the manuscript.

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