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REVIEW

Closing the gap: evidence-based surgical treatment of rectus diastasis associated with abdominal wall hernias

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Abstract

Purpose Rectus diastasis (RD) associated with abdominal hernias present a surgical challenge associated with a paucity in treatment guidelines. The objective of this systematic review is to review surgical techniques and assess complication and recurrence rates of RD in patients with concurrent abdominal hernias.

Methods PubMed and EMBASE databases were systematically searched, and data extraction was performed on articles which met the inclusion criteria. Pooled analyses of complication and recurrence rates were performed to compare open vs. minimally invasive surgery. Student *t* tests were performed to compare differences in continuous outcomes.

Results Twenty-eight studies were included in this review. RD can be surgically repaired by both open and laparoscopic approaches using both non-absorbable and absorbable sutures. The majority of the techniques reported included mesh insertion either above the aponeurosis, retromuscular, preperitoneal, or intraperitoneal. Open techniques, compared to laparoscopic approaches, were associated with a significantly higher rate of skin dehiscence (6.79% vs. 2.86%; $p=0.003$) and hematoma formation (4.73% vs. 1.09%; $p<0.001$) and a significantly lower rate of post-operative seroma formation (2.47% vs. 8.29%; $p<0.001$). No significant difference in RD recurrence rates were observed between open and laparoscopic repair (0.22 vs. 0.63%, $p=0.17$).

Conclusion Both open and laparoscopic surgery are safe and effective methods that can be used to repair RD in patients with RD and concurrent abdominal hernias as evident by the low recurrence and complication rates and almost negligible major complications post repair.

Keywords Abdominal hernias · Rectus diastasis · Laparoscopic · Complication rates

Introduction

Rectus diastasis (RD) is defined as the widening of the linea alba and the separation of the rectus abdominis muscles by more than 2 cm at the midline [1]. The pathophysiology of RD is secondary to increased intra-abdominal pressure, which reduces the consistency of the intercrossed fibers of the linea alba [2]. Given that RD is generally perceived as a cosmetic condition, it is not covered by the vast majority of insurance coverage plans in the United States, despite its association with a multitude of functional sequalae that significantly worsen a patient's quality of life [3].

RD is associated with decreased intra-abdominal wall integrity which causes aesthetic dissatisfaction and musculoskeletal pain. These patients often complain of weakness and muscular instability, which can ultimately lead to pelvic and spinal injury [4, 5]. While RD is a distinct entity, it is frequently misclassified as a ventral hernia as it often shares the same clinical presentation of a protruded abdomen [6]. RD differs from a ventral hernia as it has an intact continuous linea alba with no midline defects and lacks a true hernia sac [6]. However, untreated RD can increase the risk of midline hernias, further adding to the misdiagnosis [7, 8].

Treatment options vary from conservative physiotherapy to surgical repair and reconstruction [4, 9]. As there is a paucity in the literature relating to guidelines on surgical

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indications and the advent of a wide array of novel surgical approaches, there is a need for an updated review of the literature to help develop an evidence-based approach to the surgical management of this condition.

To that end, the overarching goal of this study is to systematically review all the studies that reported on RD repair associated with abdominal wall hernias and to compare their complication and recurrence rates.

Methods

Search strategy

This review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [10]. The PubMed and EMBASE databases were systematically searched to retrieve any clinical study that describes and reports on surgical techniques and outcomes of RD repair in patients with abdominal hernia defects. The search strategy was performed using a combination of keywords and MeSH terms including the terms divarication, rectus diastasis, plication, abdominal hernias, ventral hernias, and hernias, joined by the BOOLEAN terms AND & OR.

Articles retrieved from the searches were combined into a library on Endnote X9 (Philadelphia, PA) which underwent deduplication. Two authors (H.E. and N.B.) independently reviewed the search entries using strict inclusion and exclusion criteria. Articles were first screened by title and abstract. The remaining articles then underwent full text screening and any discrepancies between reviewers were resolved through consensus. Eligible studies then underwent data extraction. Inclusion criteria comprised of any clinical study reporting on surgical technique and outcomes of RD repair in patients with concomitant abdominal hernias. Studies were only included if the majority of their participants underwent a concomitant hernia repair. Studies with less than 10 participants were excluded. No date restriction was applied. Studies published in languages other than English were excluded.

Data collection and quantitative synthesis

Data extracted from eligible studies included author, year, study title, study type, total number of participants, mean age, gender stratification, diastasis size, surgical incision location, mean follow-up, surgical technique, type of suture used, type of mesh used, surgical time, satisfaction, pain, hospital stay, return to activities to daily living, complications, recurrence and radiographic outcomes. Pooled analyses of complication and recurrence rates were performed to compare open vs. minimally invasive surgery. To avoid over/underestimating complication and recurrence rates, any study that did not explicitly report on these variables was excluded from the pooled analyses. Moreover, studies that did not differentiate their outcomes based on surgical technique (open vs. laparoscopic) were included in the study but excluded from the pooled analyses. Chi-square tests were used to assess significant differences between complication and recurrence rates regarding the variables of interest. Level of significance was set at <0.05. The statistical analyses were performed using IBM SPSS Version 25.0 (IBM Corp., Armonk, N.Y.).

Results

The initial search strategy yielded 1252 results of which 290 were duplicates. The remaining 962 non-duplicate papers underwent title and abstract screening. Of which, 54 were deemed relevant and underwent full-text assessment against the aforementioned inclusion and exclusion criteria. A total of 28 studies were finally included in this analysis [11–37] (Fig. 1).

Surgical techniques

Out of the 28 articles, 10 described open RD repair techniques [11–18, 38, 39], 20 described laparoscopic RD repair techniques [12, 15, 20, 21, 23–37, 40], with two of these studies describing both open and laparoscopic studies. [12, 15]. A summary of the techniques used in RD repair can be found in Tables 1, 2, 3, 4. For all the included studies, the abdominal wall hernia was repaired when present. Out of the 10 studies that described open techniques, a majority ($n=7$) included inserting a mesh. The incision site varied depending on the position of the hernia, with the vast majority of skin incisions employed being either horizontal suprapubic or vertical midline (Table 1). Similarly, out of the 20 studies that described laparoscopic techniques, the vast majority ($n=19$) included mesh placement. The skin incisions were usually comprised of 3 laparoscopic ports (5–10 mm) which constitutes the standard laparoscopic approach. For both open and laparoscopic approaches, the mesh was placed either above the aponeurosis as an onlay, retromuscular, preperitoneal, or intraperitoneal (Table 2).

Primary outcomes

The main outcome reported was recurrence rates which were reported in 25 studies amounting to a total of 453 and 630 patients who underwent open and laparoscopic RD repair, respectively. Open RD repair was associated with an average recurrence rate of 0.22%. On the other hand, laparoscopic RD repair was associated with an average recurrence rate of

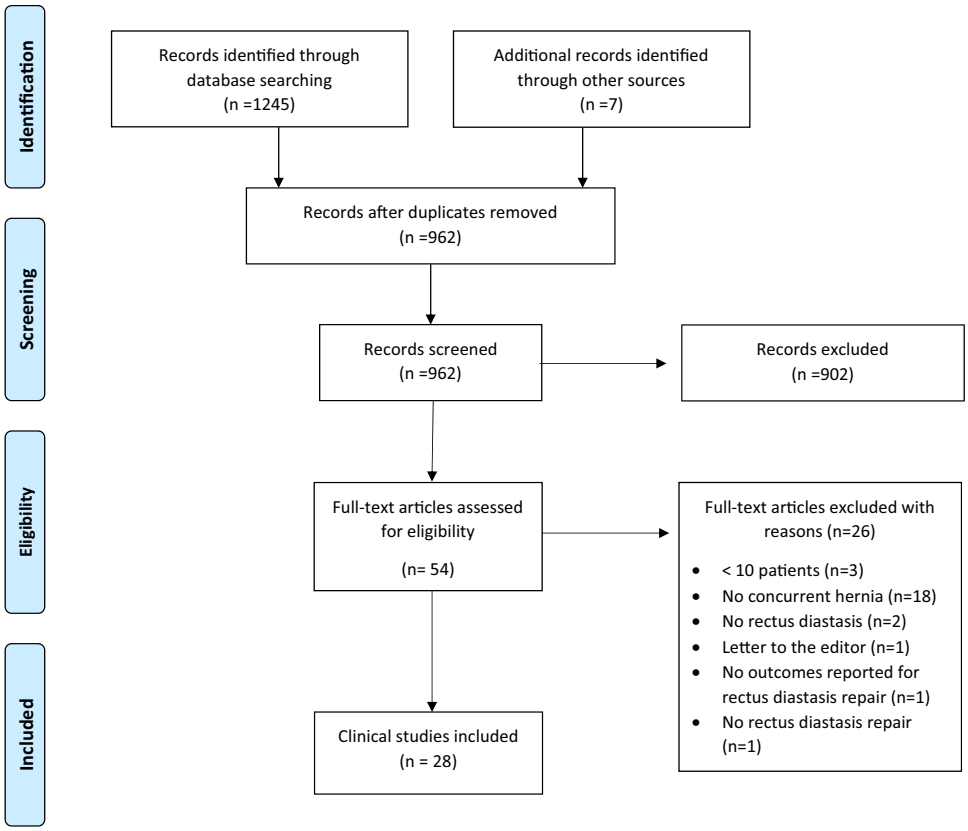

Fig. 1 PRISMA diagram for screening and study inclusion

0.63%. There was no significant difference in RD recurrence rates between open and laparoscopic repair ($p = 0.32$).

The other outcomes reported varied from one study to another. Out of the studies that evaluated open techniques, the average operative time was 132.8 ± 26.4 min ($n = 144$), while the average hospital stay was 4.4 ± 0.5 days ($n = 112$) (Table 1). With respect to studies specifically evaluating laparoscopic techniques, the average operative time was 120.4 ± 44.0 min ($n = 682$), while the average hospital stay was 3.3 ± 1.4 days ($n = 610$). Post-operative pain was reported using varying visual analogue scales or opioid consumption with all studies reporting significant pain reduction post-surgery and no opioid consumption after the 3rd post-operative day (Table 2).

Complication rates

A pooled analysis of the complication was performed. A total of 324 and 735 patients underwent open and laparoscopic RD repair from a total of 27 studies that reported on complications. Open RD repair was associated with a total complication rate of 14.6%. The three most reported complications were wound dehiscence (6.79%), hematomas/post-operative bleeding (4.73%) and seromas (2.47%) (Table 5). With regards to laparoscopic RD repair, there was a total complication rate of 15.9%. The three most common complications associated with laparoscopic repairs were seromas (8.29%), wound dehiscence (2.86%) and infection (1.36%) (Table 4). There was no significant difference in the total complication rates between open and laparoscopic RD repair (14.6 vs. 15.9, respectively; $p = 0.56$). With regards to specific complications, open techniques were associated with a significantly higher rate of wound dehiscence and hematoma/bleeding compared to laparoscopic techniques ($p < 0.001$ and $p = 0.003$, respectively). On the other hand, laparoscopic techniques were associated with a significantly higher rate of post-operative seroma compared to open techniques ($p < 0.001$). There were no other significant differences in the other complications reported (Table 5).

Discussion

This systematic review of surgical techniques and pooled analysis of complications and recurrences demonstrate the wide array of techniques of rectus diastasis repair in patients with concomitant hernia. Both open and laparoscopic techniques are quite effective in repairing RD as evident by the low recurrence rate and the positive outcomes at long-term follow-up.

Rectus diastasis repair was traditionally perceived as an aesthetic condition. However, we have recently learnt that

Table 1 Included study characteristics and outcomes of open rectus diastasis (RD) repair techniques

Study	Study type (Study groups)	Number of Patients	Mean age (% female)	Average Diastasis size (cm)	Incision	Average follow-up (months)	Type of suture used for RD repair	Type of mesh used for RD repair	Main outcomes
Bruner et al. (2009)	Retrospective case series	17	NR (NR)	NR	NR	42	NR	No Mesh	· None
Cheesborough and Dumanian, (2015)	Retrospective chart review	32	53 (91)	6.7	Midline vertical	15.5	Non-absorbable (0-polypropylene)	Midweight polypropylene uncoated mesh	· Surgical time: 151 min
Fiori et al. (2020)	Retrospective G1: open surgery G2: TESAR	T: 94 G1: 68 G2: 26	T: 41 (97.8) G1: 40 (100) G2: 43 (92.3)	T: 5.6* G1: 5.7* G2: 5.5*	G1: Suprapubic transverse incision G2: 1 Suprapubic laparoscopic port	T: 12	T: Slowly absorbable suture	T: Mesh	· Surgical time: 150 min · Hospital stay: 4 days · Pain: Compared to preoperatively, both G1 ($p < 0.01$) and G2 ($p < 0.01$) had significant and similar pain reduction by 6 months postoperatively · Satisfaction: Both G1 ($p < 0.01$) and G2 ($p < 0.01$) reported similar significant satisfaction with cosmetic outcome as of 7 days postoperatively compared to preoperatively · Return to ADLs: By 6 months postoperatively, restriction was significantly reduced compared to preoperatively and similar between G1($p < 0.01$) and G2 ($p < 0.01$)
Kulhanek and Mestak (2013)	Retrospective cohort	50	NR (100)	NR	Suprapubic horizontal	60	Absorbable (0-PDS)	No mesh	· Patient satisfaction: 98%
Matei et al. (2014)	Retrospective case review	44	60.2 (NR)	NR	Midline vertical and periumbilical dovetail	NR	Absorbable (2–0 vircryl)	Non-resorbable, light weight polypropylene mesh	· Surgical time: 93.3 min · Hospital stay: 5 days · Pain: Postoperative opioid treatment required for a median of 3.3 days

Table 1 (continued)

Study	Study type (Study groups)	Number of Patients	Mean age (% female)	Average Diastasis size (cm)	Incision	Average follow-up (months)	Type of suture used for RD repair	Type of mesh used for RD repair	Main outcomes
Neinstein et al. (2015)	Retrospective case series	11	39.4 (100)	NR	Side of the umbilicus	12	Non Absorbably (Nylon)	PTFE	· None
Nishihara et al. (2020)*	Retrospective observational	T:30 Laparoscopic: 13 Open: 17	63 (46.7)	NR	NR	8	Absorbable and non-absorbable	Prosthesis mesh	· Surgical time: 144.5 min
Perry et al. (2021)	Retrospective	82	NR (NR)	NR	Suprapubic horizontal	NR	Absorbable and nonabsorbable suture (0 polydioxanone and 0 prolene)	No mesh	· Radiologic outcomes: CT confirmed no recurrence of rectus diastasis or hernia · Other: Added cost is approximately 20 min of OR time, additional sutures and the dermatome blade use
Prado et al. (2004)	Retrospective case review	20	53 (100)	NR	NR	36	Non-absorbable (NS)	Polypropylene mesh	· Patient satisfaction: 9.2/10 · Radiographic outcomes: U/S showed no rectus muscle separated & adequate mesh effect in 10 cases during a mean of 24 month follow-up
Privett and Ghusn (2016)	Retrospective	173	NR (NR)	NR	1–2 cm supraumbilical	NR	Non-absorbable suture	Parietex progrip (self-fixating mesh)	· None

NR: Not reported, ADLs; activities of daily living

*Not included in the pooled analysis of outcomes as they did not separate outcomes for open vs. laparoscopic approaches

T: Total

Table 2 Included study characteristics and outcomes of laparoscopic rectus diastasis (RD) repair techniques

Study	Study type (Study groups)	Number of Patients	Mean age (% female)	Average Diastasis size (cm)	Incision	Average follow-up (months)	Type of suture used for RD repair	Type of mesh used for RD repair	Main outcomes
Barbato et al. (2020)	Retrospective	12	51 (83.3)	3.55	3 laparoscopic ports 10 mm (1) 5 mm (2)	14	Slowly absorbable barbed sutures	Parietex mesh	· Hospital stay: All patients discharged on POD2 · Pain: No chronic pain or back pain were detected before/after surgery
Barchi et al. (2019)	Prospective observational	21	47.5 (42.8)	3.2	3–4 laparoscopic ports 10 mm (1) 5 mm (2–3)	14	NR	Light weight polypropylene mesh	· Surgical time: 112.4 min Hospital stay: Median was 1 day
Bellido Luque et al. (2015)	Prospective cohort	21	37.6 (85.7)	3	1 cm suprapubic horizontal and laparoscopic ports	20	Non-absorbable barbed suture	Polypropylene mesh	· Surgical time: 99 min Hospital stay: 1.5 days · Pain: Significant improvement in back pain when diastasis recti is solved ($p < 0.001$) · Patient satisfaction: 8.7/10 · Radiographic outcomes: Using U/S, significant reduction in IRD at 3 midline locations ($p < 0.001$)
Carrara et al. (2019)	Prospective case series	14	42 (85.7)	5.3	4 cm periumbilical + 2–3 laparoscopic ports	6	None	PVDF mesh	· Surgical time: 80 min Hospital stay: 1 day · Pain: VAS, 6/10 on POD1, 2/10 on POD7. No pain at POD30 · Return to ADLs: All patients resumed their ADLs between the 7th and 12th postoperative day and resumed work within first postoperative month

Table 2 (continued)

Study	Study type (Study groups)	Number of Patients	Mean age (% female)	Average Diastasis size (cm)	Incision	Average follow-up (months)	Type of suture used for RD repair	Type of mesh used for RD repair	Main outcomes
Carrara et al. (2020)	Prospective observational	110	43.1 (93)	4.9	Lower periumbilical + 1 or more laparoscopic ports	14.4	None	Synthetic mesh or biosynthetic mesh	· Surgical time: 82.4 min · Hospital stay: 2.1 days · Pain: Postoperative VAS was 4.4, 38.2% received rescue analgesics, Significant improvement in ODI 1 month postoperatively vs. preoperatively ($p < 0.0001$) · Other: ISI score was significantly improved at 1 month postoperatively ($p < 0.0001$) and EuraHSQoL was significantly improved at 6–8 months postoperatively ($p < 0.0001$)
Claus et al. (2018)	Retrospective case review	48	44.3 (58.3)	4.1	2 cm Suprapubic horizontal	8	Barbed (NS)	Polypropylene mesh	· Surgical time: 93.5 min · Patient satisfaction: 93.7%
Dong et al. (2020)	Retrospective chart review	16	45.7 (87.5)	NR	3 cm suprapubic transverse + 3 laparoscopic ports 12 mm (1) 5 mm (2)	2.1	Barbed (NS)	Polypropylene or self-fixating mesh	· Surgical time: 146 min

Table 2 (continued)

Study	Study type (Study groups)	Number of Patients	Mean age (% female)	Average Diastasis size (cm)	Incision	Average follow-up (months)	Type of suture used for RD repair	Type of mesh used for RD repair	Main outcomes
Fiori et al. (2020)	Retrospective G1: open surgery G2: TESAR	T: 94 G1: 68 G2: 26	T: 41 (97.8) G1: 40 (100) G2: 43 (92.3)	T: 5.6 G1: 5.7 G2: 5.5	G1: Suprapubic transverse incision G2: 1 Suprapubic laparoscopic port	T: 12	T: Slowly absorbable suture	T: No mesh	· Surgical time: 190 min · Hospital stay: 3 days · Pain: Compared to preoperatively, both G1 ($p < 0.01$) and G2 ($p < 0.01$) had significant and similar pain reduction by 6 months postoperatively · Satisfaction: Both G1 ($p < 0.01$) and G2 ($p < 0.01$) reported similar significant satisfaction with cosmetic outcome as of 7 days postoperatively compared to preoperatively · Return to ADLs: By 6 months postoperatively, restriction was significantly reduced compared to preoperatively and similar between G1($p < 0.01$) and G2 ($p < 0.01$)
Gomez-Menchero et al. (2018)	Prospective observational	12	56.5 (41.7)	5.1	NR	15	Long-lasting absorbable (monofilament) or non-absorbable barbed (1-Vloc PBT)	PVDF mesh or Dynamesh or Ventralight ST mesh or c-PTFE mesh	· Surgical time: 54 min · Hospital stay: 1.5 days · Pain: VAS, 0 at 90 days and 1 year postoperatively · Radiologic outcomes: CT scan at 1 month showed significant decrease in IRD ($p < 0.003$) · Other: No apparent abdominal bulging in any patient

Table 2 (continued)

Study	Study type (Study groups)	Number of Patients	Mean age (% female)	Average Diastasis size (cm)	Incision	Average follow-up (months)	Type of suture used for RD repair	Type of mesh used for RD repair	Main outcomes
Kler and Wilson (2020)	Retrospective	21	53.1 (61.9)	NR	2 + laparoscopic ports 10 mm (1) 5 mm (NS)	NR	1–0 Ethilon suture	Synthetic mesh or Biological mesh	· Pain: 1 patient had chronic pain
Kockerling et al. (2017)	Retrospective**	140	54.7 (35.7)	5.9	2–3 cm periumbilical	NR	Non-absorbable (NS)	Polypropylene mesh	· Surgical time: 116 min · Hospital stay: 4.5 days · Pain: At 1 year follow-up, 2 patients reported occasional pain including pain at rest in one
Kohler et al. (2018)	Prospective pilot series	20	41 (85)	80%: < 2 20%: 2–4	2–3 cm periumbilical	5	Slowly absorbable barbed (2–0 stratafix PDS)	Phasix mesh	· Surgical time: 79 min · Hospital stay: 4.1 days · Pain: 1 patient had chronic pain (stress pain) · Other: No reoperation or readmission
Lari et al. (2019)	Retrospective case series	47	35 (NR)	3.24	Low horizontal incision then 3 laparoscopic ports	29	NR	Parietex mesh	· Surgical time: 200 min · Hospital stay: 2.5 days
Li et al. (2020)	Prospective	26	48.6 (73.1)	NR	3 laparoscopic ports 12 mm (1) 5 mm (2)	9.2	1–0 barbed suture and a 1–0 nonabsorbable suture	Dynamesh	· Surgical time: 106.6 min · Hospital stay: 2.8 days · Pain: POD3 VAS scores were 2.4 · Other: No readmission within 30 days
Masurkar et al. (2020)	Retrospective	89	41.2 (91)	NR	3 or 6 laparoscopic ports 10 mm (1) 5 mm (1–5)	58.7	Absorbable (No. 1 polydioxanone, PDS)	Polypropylene mesh	· Surgical time: 192 min Hospital stay: 5 days

Table 2 (continued)

Study	Study type (Study groups)	Number of Patients	Mean age (% female)	Average Diastasis size (cm)	Incision	Average follow-up (months)	Type of suture used for RD repair	Type of mesh used for RD repair	Main outcomes
Muas (2019)	Prospective study	50	38 (94)	55.5%: < 5 29.6%: 5.1–8 14.9%: > 8.1	3 laparoscopic ports 10 mm (1) 5 mm (2)	23	Absorbable bearded (PDS #0) or absorbable (PDS #2–0) or non-absorbable polypropylene	Lightweight or intermediate or heavy polypropylene mesh	· Surgical time: 83 min Hospital stay: 1.3 days · Pain: 3/10 · Patient satisfaction: 96% · Radiographic outcomes: Seromas observed by ultrasound · Return to ADLs: returned to ADLs at 16.4 days after surgery
Nishihara et al. (2020)*	Retrospective observational	30 Laparoscopic: 13 Anterior: 17	63* (46.7)	NR	NR	8	Absorbable and non-absorbable	Prosthesis mesh	· Surgical time: 144.5 min
Shipkov et al. (2017)	Retrospective series	10	35 (100)	NR	Suprapubic horizontal	28.8	Absorbable Polyglycolic acid 1 (Vycril)	Parietex mesh (self-fixating)	· Hospital stay: 2.8 days
Van Schalkwyk et al. (2018)	Prospective series	10	37.2 (100)	5.35	Suprapubic horizontal + 4 laparoscopic ports	12	Non-absorbable barbed (1-Vloc PBT)	Parietex mesh (self-fixating)	· None
Wiessner et al. (2017)	Retrospective**	42	63.5 (40.5)	NR	3 laparoscopic ports	10	Non-absorbable barbed (V-Lok PBT)	Synthetic mesh	· Surgical time: 92.4 min · Hospital stay: 4.6 days · Pain: 1 patient with chronic pain symptoms · Patient satisfaction: 100% · Other: No bulging

ODI: Oswestry disability index, ISI: Incontinence Severity Index, ADLs: Activities of Daily Living

*Not included in the pooled analysis of outcomes as they did not separate outcomes for open vs. laparoscopic approaches

**Prospectively maintained databases were included as retrospective studies

Table 3 Complications and recurrence following open rectus diastasis repair

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgia	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Bruner et al. (2009)	A laparotomy incision was made through the linea alba. Fascial defect identified and hernia reduced. RD was then plicated (technique not described)	17 (42)	17 (NR)	0	0	0	0	0	0	0	0
Cheesborough et al. (2014)	Ventral hernias were exposed and reduced using an open approach. RD repaired by fixing a polypropylene mesh in the retromuscular space. Anterior rectus sheath was closed with figure-of-8 suturing using non-absorbable sutures. The posterior sheath is closed using a running suture	32 (7.9)	NR (6.7)	2	0	0	0	0	0	0	0

Table 3 (continued)

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgia	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Fiori et al. (2020)	RD repaired by direct suture of anterior aponeurosis with slowly absorbable running suture in an open approach. When hernias were present they were repaired by direct suture and a sublay mesh	68 (NR)	50 (5.7)	1	13	15	0	0	0	0	1 (Pneumonia)
Kulhanek and Mestak (2013)	RD repaired by single-layer horizontal suturing using absorbable sutures. The hernia's fascial defect is fixed using the same running suture	50 (NR)	NR (NR)	5	8	0	0	0	0	0	1 (Granuloma)

Table 3 (continued)

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgia	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Matei et al. (2014)	Hernia defect is fixed under direct visualization after reducing the hernia. A non-absorbable mesh is fixed in the retromuscular space. RD repaired by double-layer running suturing of the rectus sheath using absorbable sutures	44 (NR)	44 (NR)	0	1	0	0	0	0	NR	0
Neinstein et al. (2015)	RD repaired by interrupted and running non absorbable sutures (nylon end nuluon). A mesh is inserted post hernia reduction in a sublay technique	11 (12)	11	0	0	0	0	0	0	0	0
Nishihara et al. (2020)*	Not specified (included both open and laparoscopic approaches)	30 (8)	25 (NR)	0	0	0	0	0	0	3	2 (NR)

Table 3 (continued)

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgia	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Perry et al. 2021	RD repaired by interrupted and running absorbable sutures (0 polydiaxanone and 0 prolene). Then, a dermal autograft is secured from external oblique insertion to the external oblique insertion at the linea semilunaris from costal margin to the level of ASIS	82 (NR)	27 (NR)	0	0	0	`0	0	0	0	0
Prado et al. (2004)	RD repaired by single-layer closure using non-absorbable sutures. Hernias were repaired by reduction and repair of the hernia defect. An anterior mesh reinforcement was used	20 (36)	9 (NR)	0	0	0	0	0	0	0	0

Table 3 (continued)

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgia	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Privett and Ghusn (2016)	A self-fixating mesh (Parietex) is inserted and positioned with the adhesive surface facing upwards. Then, the RD is closed in an interrupted or standard Mayo-type repair with a non-absorbable suture	173 (NR)	58 (NR)	NR	NR	NR	NR	NR	NR	1	NR

NR: not reported

*Not included in the pooled analysis of outcomes as they did not separate outcomes for open vs. laparoscopic approaches

Table 4 Complications and recurrence following laparoscopic rectus diastasis repair

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgias	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Barbato et al. (2020)	RD repaired by multiple barbed slowly absorbable running sutures. Patrietex mesh was applied in the intraperitoneal space from the xiphoid process to the mons pubis	12 (14)	12 (3.6)	0	0	0	0	0	0	0	0
Barchi et al. (2019)	RD repaired by sutures. Then, a light-weight polypropylene mesh is onlayed	21 (14)	8 (3.2)	1	0	0	2	0	0	0	5 (NR)
Bellido Luque et al. (2015)	Hernia sac was identified dissected and reduced. RD repaired by fixing a non-absorbable mesh in the preperitoneal space. The rectus sheath was closed by a single layer running suture using non-absorbable sutures	21 (20)	21 (3)	5	0	0	0	0	0	0	2 (Subcutaneous Emphysema)

Table 4 (continued)

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgias	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Carrara et al. (2019)	RD repaired by linear stapler applied from costal margin to 5 cm caudal of the umbilicus. A PVDF mesh is then placed in the retromuscular space	14 (6)	14 (5.3)	0	0	0	0	0	0	0	0
Carrara et al. (2020)	RD repaired by linear stapler applied from costal margin to 5 cm caudal to umbilicus. A synthetic mesh was placed in the retromuscular pace	110 (14.4)	110 (4.9)	1	0	5	4	0	0	0	1 (Internal hernia)
Claus et al. 2018	RD repaired by continuous suturing using barbed sutures from the xiphoid 3 cm below the umbilicus. A non-absorbable mesh was sometimes fixed in the preperitoneal space	48 (8)	48 (4.1)	13	0	0	1	0	0	1	1 (Subcutaneous tissue retraction)

Table 4 (continued)

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgias	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Dong et al. (2020)	RD repaired by running barbed sutures anteriorly. A polypropylene or self-fixating mesh was added in the subcutaneous space (onlay)	16 (2.1)	16 (NR)	3	0	0	1	0	0	NR	0
Fiori et al. (2020)	RD repaired by direct suture of anterior aponeurosis with slowly absorbable running suture in an endoscopic approach. A mesh was inserted sublay after fixing the hernia defect	26 (NR)	16 (5.5)	0	0	0	0	0	0	0	0

Table 4 (continued)

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgias	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Gomez-Menchero et al. (2018)	RD repaired by incising and dissecting posterior rectus sheath, and continuously suturing the remaining aponeuroses using non-absorbable barbed or long-lasting monofilament sutures. A non-absorbable mesh was fixed in the intraperitoneal space	12 (15)	10 (5.1)	6	0	0	0	0	0	0	0
Kler and Wilson, 2020	RD repaired using 1–0 Ethilon sutures anteriorly. If a mesh was used, an on-lay mesh was used to complete the repair and it was fixed to the anterior rectus sheath	21 (NR)	21 (NR)	17	0	0	1	1	0	1	0

Table 4 (continued)

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgias	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Kockerling et al. (2017)	RD repaired by releasing and incising the anterior rectus sheath, then continuously suturing the remaining aponeuroses using non-absorbable sutures. A non-absorbable mesh was fixed anteriorly (onlay)	140 (60)	140 (5.9)	6	9	2	0	0	0	0	0
Kohler et al. (2018)	RD repaired by releasing and incising the anterior rectus sheath, then continuously suturing the remaining aponeurosis using slowly absorbable barbed sutures. An absorbable mesh was fixed anteriorly (onlay)	20 (5)	20 (NR)	1	0	0	0	1	0	2	0

Table 4 (continued)

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgias	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Lari et al. (2019)	Low horizontal incision preformed. Abdominal flap elevated over the recuts abdominis aponeurosis. Diastasis repaired at this point. Then hernia repaired via 3 port technique	47	47 (3.2)	0	4	1	0	4	0	0	0
Li et al. (2020)	RD repaired using running 1–0 barbed sutures in the posterior rectus sheath. The anterior layer is closed by several interrupted 1–0 nonabsorbable barbed transmural sutures. Then, a Dynamesh is placed as a sublay in the retromuscular space	26 (9.2)	8 (NR)	2	0	0	0	0	0	0	0

Table 4 (continued)

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgias	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Masurkar et al. (2020)	RD repaired by absorbable running suture of No. 1 polydioxanone in the anterior sheath. A polypropylene mesh was placed from the xiphisternum to the pubic symphysis in the retromuscular space	89 (58.7)	NR (NR)	0	8	0	1	0	0	NR	1 (Suture line disruption)

Table 4 (continued)

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgias	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Muas (2019)	RD repaired using absorbable PDS bearded suture #0 or absorbable PDS #2–0 or non-absorbable polypropylene sutures from xiphoid appendix to 5 cm subumbilical anteriorly. A lightweight/intermediate or heavy weight polypropylene mesh is placed to cover area of external oblique release	50 (23)	50 (NR)	6	0	0	0	0	0	0	0
Nishihara et al. (2020)*	Not specified (included both open and laparoscopic approaches)	30 (8)	25 (NR)	0	0	0	0	0	0	3	2 (NR)

Table 4 (continued)

Study	Brief description of RD repair technique	Number of patients (avg. follow-up in months)	Number of patients with RD and hernia (avg. RD size in cm)	Number of seromas	Number of dehiscence/necrosis	Number of bleeding/hematomas	Number of infections	Number of chronic pain/neuralgias	Number of thromboembolic events (DVT/PE)	Number of recurrences	Other complications (type)
Shipkov et al. (2017)	RD repaired by single-layer closure with horizontal mattress suturing using absorbable sutures. An intraperitoneal non-absorbable mesh reinforcement was used	10 (28.8)	10 (NR)	0	0	0	0	0	0	0	0
Van Schalkwyk et al. (2018)	RD repaired by double-layer closure using non-absorbable barbed sutures. An intraperitoneal non-absorbable mesh reinforcement is used	10 (12)	10 (5.35)	0	0	0	0	0	0	0	0
Wiessner et al. (2017)	RD repaired by continuous suturing of rectus sheath using non-absorbable barbed sutures. A non-absorbable mesh was fixed in the intraperitoneal space	42 (10)	NR (NR)	0	0	0	0	1	0	0	0

NR: Not reported

*Not included in the pooled analysis of outcomes as they did not separate outcomes for open vs. laparoscopic approaches

Table 5 Pooled analysis of complication rates of open and laparoscopic rectus diastasis (RD) repair techniques

Main Surgical Approach	Rate of Seroma	Rate of Dehiscence/ Necrosis	Rate of Bleeding/ Hematoma	Rate of Infection	Rate of Chronic Pain/ Neuralgia	Rate of Thromboembolic Events (DVT/PE)	Rate of Other Complications*	Total Rate of complications
Open ($n=324$)	2.47%	6.79%	4.73%	0%	0%	0%	0.62%	14.6%
Laparoscopic ($n=735$)	8.29%	2.86%	1.09%	1.36%	0.95%	0%	1.36%	15.9%
I value	< 0.001	0.003	< 0.001	N/A	N/A	N/A	0.29	0.56
Chi-square	12.5	8.92	13.3	N/A	N/A	N/A	1.11	0.34

n = The total number of patients included in pooled analysis; DVT/PE: deep vein thrombosis/pulmonary embolism

*Other complications included: scar revision, pneumonia, granuloma, internal hernia, subcutaneous tissue retraction, subcutaneous emphysema and P-PRS suture line disruption

not only does RD cause cosmetic dissatisfaction to many patients, but it is also associated with significant functional impairments. A recent study demonstrated that RD is associated with increased pelvic organ prolapse, decreased abdominal muscle strength, increased lower back pain and overall decreased health related quality of life [41]. Although physiotherapy is considered the first line treatment for RD, severe cases associated with health outcomes are amendable to surgery, especially if a concomitant abdominal hernia is present. [42].

The copresence of abdominal hernias with RD adds complexity to its surgical management [42]. Hence, the current systematic review only included papers that reported on outcomes of RD repairs associated with abdominal hernias. Although open surgical approaches allows for optimal visualization of the linea alba and rectus muscles, they are generally associated with higher levels of post-operative pain and larger scars [43]. Minimally invasive approaches have recently surged as suitable and often preferred techniques for ventral hernia repairs mainly due to their minimal post-operative pain and shorter hospital stay [43]. Our review showed that RD can be effectively repaired using both open and minimally invasive techniques as evident by the very low recurrence rate (close to zero) at long-term follow-up. Moreover, our review is in line with previous papers that show that RD plication can be performed using both absorbable and non-absorbable sutures [9, 43]. Furthermore, while RD repair does not necessarily warrant a mesh insertion, this review demonstrates it is often used when there is a concomitant hernia. There is a paucity in clear guidelines on using mesh to reinforce RD repair. Al-Qattan demonstrated 100% recurrence of RD in patients with severe musculoaponeurotic laxity without using mesh [44]. More recently, studies have been reporting the use of mesh with RD greater than 5 cm [24]. Future studies should aim to study and characterize the indications for mesh in RD repair.

Since the surge of minimally invasive techniques for ventral hernia repairs, many variations and novel approaches have been introduced that allow for RD repair as well. In addition to the traditional laparoscopic approaches, our review also includes novel minimally invasive surgical techniques such as laparoscopic intracorporeal rectus aponeuroplasty (LIRA) which involves incising the posterior rectus aponeurosis lengthwise around the hernia defect, creating two flaps laparoscopically, followed by plication [30]. Gomez-Menchero et al. showed that this minimally invasive technique was effective at significantly decreasing RD from 5.5 to 2.2 cm at 1 year follow-up [30]. However, this technique was complicated by 50% seroma formation. Other endoscopic approaches such the endoscopic mini or less open sublay repair (EMILOS) have also been recently studied and show great potential in repair RD associated with ventral hernias [25, 45].

This study has several limitations. The first of which is that the included studies contained different levels of evidence. The primary goal of this study was to demonstrate all the surgical approaches to RD repair associated with ventral hernias, and therefore, we included different levels of evidence to be as comprehensive as possible. Moreover, due to the variation in the original studies' patient population, we were not able to control for their baseline characteristics such as RD size and patient comorbidities. Second, due to the wide heterogeneity in patient outcomes, a meta-analysis was not feasible. Moreover, some of the included studies included patients without abdominal hernias but did not separately report their outcomes which presents a limitation in our pooled analysis. Finally, there was a paucity in outcomes reported in open techniques, which limits our statistical analysis when comparing outcomes between open and laparoscopic techniques. Future prospective studies should compare the clinical outcomes and complications

associated with these different RD repairs to better ascertain comparative efficacy. Moreover, due to the important aesthetic component of RD repairs, future studies should develop a standardize patient reported outcome tool to measure patients' satisfaction with their RD repair and be able to better compare studies in the future.

Conclusion

Rectus diastasis repair in patients with RD with concomitant abdominal hernias is a quickly evolving domain associated with a wide array of surgical techniques. Both open and laparoscopic approaches for rectus diastasis are effective as evidenced by very low recurrence rates. Moreover, both approaches are safe as evident by the low complication rates and almost negligible major complications post repair.

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Availability of data and materials The data are available upon request.

Declarations

Conflicts of interest Dr. Janis receives royalties from both Thieme and Springer Publishing. None of the other authors have any potential conflicts of interest.

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