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REVIEW ARTICLE

Minimally invasive component separation technique for large ventral hernia: which is the best choice? A systematic literature review

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Abstract

Background Aim of the present systematic review is to compare the postoperative outcomes after minimally invasive anterior and posterior component separation technique (CST), in terms of postoperative morbidity and recurrence rates.

Methods Nine-hundred and fifty-nine articles were identified through Pubmed database. Of these, 444 were eliminated because were duplicates between the searches. Of the remaining 515 articles, 414 were excluded after screening title and abstract. One hundred and one articles were fully analysed, and 73 articles were further excluded, finally including 28 articles. Based on the surgical technique, three groups were created: Group A, endoscopic anterior CST and closure of the abdominal midline by laparotomy; Group B, endoscopic anterior CST and closure of the abdominal midline laparoscopically or robotically; Group C, laparoscopic or robotic posterior CST with transversus abdominal muscle release (TAR).

Results In group A, B and C, 196, 120 and 236 patients were included, respectively. Surgical and medical complication rates for the three groups were 31.2% and 13.7% in group A, 15.8% and 4.1% in group B, and 17.8% and 25.4% in group C, while recurrence rate was 10.7%, 6.6% and 0.4%, respectively. Statistically significant differences were observed in terms of surgical postoperative complication rate between group A versus B ($p=0.0022$) and between group A versus C ($p=0.0015$) and of recurrence rate between group A versus C ($p=<0.0001$) and B versus C ($p=0.0009$).

Conclusions Anterior CST with midline closure by laparotomy showed the worst results in terms of postoperative surgical complications and recurrence in comparison to the pure minimally anterior and posterior CST. Posterior CST-TAR showed lowest hospital stay and recurrence rate, although the follow-up is short. However, due to the poor quality of most of the studies, further prospective studies and randomized control trials, with wider sample size and longer follow-up are required to demonstrate which is the best surgical option.

Keywords Ventral hernia · Anterior component separation technique (ACST) · Posterior component separation technique (PCST) · Transversus abdominal muscle release (TAR) · Minimally invasive · Systematic review

Large abdominal wall defect reconstruction is a challenge for surgeons [1]. To solve this problem successfully by surgery, anatomical and tension-free restoration of the abdominal wall before its closure are mandatory [1, 2].

For this purpose, Ramirez et al. in 1990, first described the so-called component separation technique (CST) which provides the division of the posterior rectus sheath and the release of the external oblique aponeurosis opening the space between the external and the internal oblique muscles, by an anterior approach [3]. However, due to the division of abdominal wall perforators, several wound complications as seromas, flap necrosis and subcutaneous abscesses have been reported with the use of the open CST (OCST) [4–6]. For this reason, with the aim to improve the vascularization of the skin flap and consequently reduce these postoperative complications, Lowe et al. [7], in 2000 proposed the endoscopic CST (ECST), showing better postoperative results if compared to the open approach [1, 7].

On the other hand, in 2012, Novitsky et al. first described the posterior CST with transversus abdominal

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muscle release (TAR) [8]. The goal of this technique is to achieve the retromuscular space, after opening the posterior rectus sheath, dissecting the transversus abdominal muscle that is divided at its medial border, to reach the space between the muscle and the trasversalis fascia and preserve the neurovascular bundles close to the linea semilunaris [2, 8]. Such as the anterior CST, it was proposed to combine the advantages of a CST with the minimally invasive approach to reduce the postoperative morbidity and increase the TAR length [9].

This systematic review was carried out with the intention of reporting which is the best minimally invasive CST, in terms of postoperative complication and recurrence rates, comparing the postoperative outcomes after anterior CST and posterior CST with TAR.

Materials and methods

Institutional review board approval and informed consent from participants are no need for this systematic review.

Inclusion criteria

Inclusion criteria were: (1) articles from any country written in English, Spanish or Italian; (2) articles about minimally invasive anterior or posterior CST, including endoscopic, laparoscopic and robotic approach, for the treatment of the abdominal wall defects; and (3) articles reporting postoperative complications and/or recurrence after anterior or posterior minimally invasive CST.

Exclusion criteria

Exclusion criteria were: (1) articles reporting open anterior or posterior CST; (2) articles reporting both minimally invasive and open CST in which was not possible to extract only data regarding the minimally invasive approach; (3) articles reporting hybrid TAR; (4) articles obtained from the same sample of patients, from which one article has already been included; (5) articles reporting posterior CST without TAR; (6) reviews, systematic reviews, meta-analysis, studies with data retrieved from registries, comments, case reports, correspondence and letters to authors or editors, editorials, technical surgical notes, and imaging studies; and (7) articles involving animals.

Search strategy

A systematic review of published papers was conducted according to the preferred reporting items for systematic review and meta-analysis (PRISMA) statement [10]. The search was carried out in the PubMed database, using the keywords reported in Table 1.

The search revealed 959 articles published between December 1982 and February 2019. Of these, 444 were eliminated because there were duplicates between the searches. Of the remaining 515 articles, 414 were excluded after screening the title and abstract because they did not meet the inclusion criteria.

Assessment of the included article quality

The assessment of the quality of the included articles was made by two authors (A.B. and I.A.) using a modified Newcastle–Ottawa Scale (NOS) for cohort studies [11]. The evaluation considered three factors: patient's selection, comparability and the completeness of the reported results (postoperative outcomes). According to the NOS, when 3 or 4 points are attributed to patient's selection and 1 or 2 points are attributed to comparability and 2 or 3 points are

Table 1 Keywords used for research in the PubMed database

Anterior component separation
Anterior components separation
Posterior component separation
Posterior components separation
Endoscopic component separation
Endoscopic components separation
Laparoscopic anterior component separation
Laparoscopic anterior components separation
Robotic anterior component separation
Robotic anterior components separation
Laparoscopic posterior component separation
Laparoscopic posterior components separation
Robotic posterior component separation
Robotic posterior components separation
Minimally invasive component separation
Minimally invasive components separation
Laparoscopic component separation
Laparoscopic components separation
Robotic component separation
Robotic components separation
Laparoscopic transversus abdominis release
Laparoscopic tar
Robotic transversus abdominis release
Robotic tar

attributed to outcomes, the article is considered of "Good" quality. When 2 points are attributed to patient's selection and 1 or 2 points are attributed to comparability and 2 or 3 points are attributed to outcomes, the article is considered of "Fair" quality. Finally, when 0 or 1 point is attributed to patient's selection or 0 points are attributed to comparability or 0 points are attributed to outcomes, the article is considered of "Poor" quality [11]. For each article, the maximum score is nine points [11].

Assessment of risk of bias of the included articles

The assessment of risk of bias of the included articles was made by two authors (A.B. and I.A.) using the risk of bias in nonrandomised studies—of interventions (ROBIN-I) tool [12]. The evaluation considered seven domains: the first two domains cover confounding and selection of participants into the study, the third domain addresses classification of the interventions and the other four domains address biases due to deviations from intended interventions, missing data, outcomes measurement, and selection of the reported result [12]. For each domain, a judgment is assigned: low risk of bias (the study is comparable to a randomised trial); moderate risk of bias (the study provides sound evidence for a nonrandomised study but cannot be considered comparable to a randomised trial); serious risk of bias (the study has important problems); critical risk of bias (the study is too problematic to provide any useful evidence); no information on which to base a judgement about risk of bias. Finally, the same judgments are assigned at the entire article [12].

Study design

Data extracted from each article were: number of patients, age, body mass index (BMI), comorbidities and therapy that can influence the postoperative results, hernia area, mesh placement and site, concomitant surgical procedures, conversion, intra and 30-day postoperative complications, operative time, postoperative hospital stay, 30-day mortality, follow-up and recurrence.

After screening the titles and abstracts, we identified articles that fulfilled the eligibility criteria and reviewed their full text. Data were extracted by two surgeons (A.B. and I.A.) and stored in the Microsoft Excel program (Microsoft Corporation, Redmond, Washington, USA).

Included articles were divided in three groups based on the surgical technique employed: Group A, articles which report minimally invasive anterior CST and closure of the abdominal midline by laparotomy; Group B, articles which report minimally invasive anterior CST and closure of the abdominal midline by laparoscopic or robotic approach; Group C, articles which report minimally invasive posterior CST with TAR, including both being performed by laparoscopy or robotic.

Statistical analysis

Frequencies and percentages were used to report the categorical variables and mean and standard deviation (SD) were used to report the continuous variables. In the articles in which the continuous variables were expressed as median and interquartile range, mean and SD were calculated according to Hozo et al. [13]. The differences between groups were estimated using one-way ANOVA with Bonferroni as post hoc test for continuous variables and the Fisher's exact test for categorical variables. Statistical analyses were carried out with SPSS software 22.0 (SPSS Inc., Chicago, Illinois, USA) and p value lower than 0.05 was considered statistically significant.

Results

One hundred and one articles were fully analysed, and 73 further articles were excluded (Fig. 1). Finally, 28 articles, published between February 2000 and February 2019, were included in the present systematic review [7, 14–40] as shown in the Preferred PRISMA flow diagram (Fig. 1) [10]. Tables 2 and 3 show the assessment of articles' quality based on the NOS and the of risk of bias of the included articles based on the ROBIN-I.

Data regarding group A are reported in Tables 4 and 7 [7, 14–24]. Concomitant procedures were: panniculectomy (19), enterocutaneous fistula repair (1), ileostomy reversal (1) and colonoscopy (1) (11.2%) [7, 14–24].

Data regarding group B are reported in Tables 5 and 7 [18, 25–32]. One intraoperative complication (0.8%) was observed (enterotomy during adhesiolysis) [30]. In 33 cases, closure of the midline was performed robotically (27.5%) [29].

Data regarding group C are reported in Tables 6 and 7 [34–40]. Five intraoperative complications (2.1%) were observed (4 enterotomies, 1 subcutaneous emphysema) and concomitant procedures were: 9 inguinal hernia repair and 11 unspecified procedures (8.4%) [32–40]. In 223 cases, CST was performed robotically (94.5%) [34–40].

Table 7 shows the differences between groups. Regarding demographic data statistically significant differences were not observed in terms of age, BMI and hernia area. Overall comorbidity rate was 57.6%, 73.3% and more than 100%, in patients who underwent anterior CST and closure of the abdominal midline by laparotomy, anterior CST and closure of the abdominal midline by laparoscopy and posterior CST-TAR, respectively. Statistically significant differences were observed at each comparison between groups (Table 7).

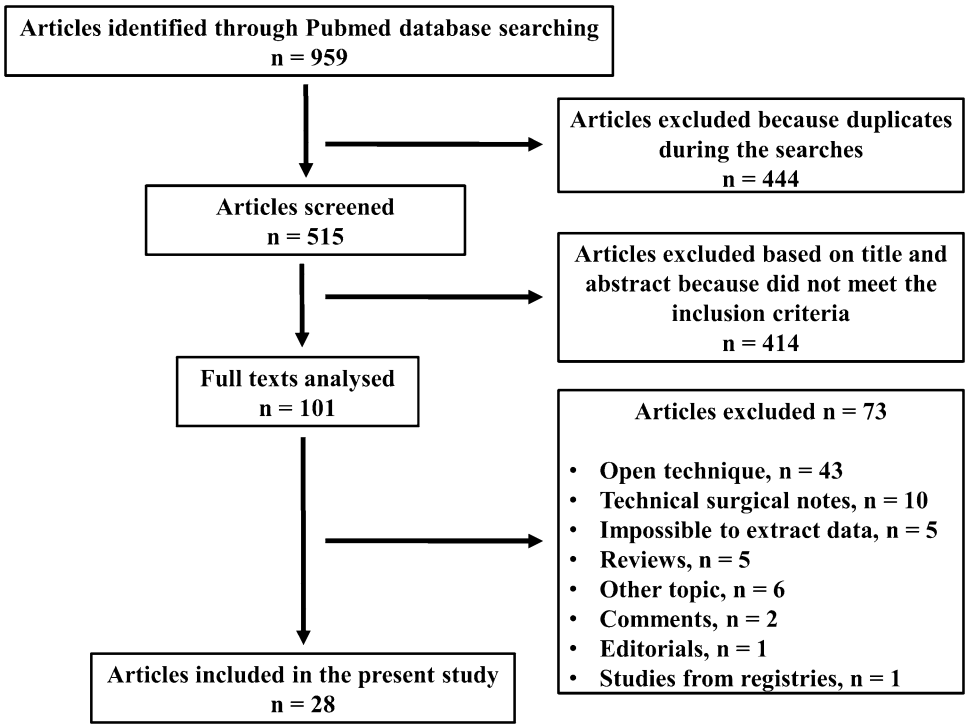

Fig. 1 Preferred reporting items for systematic review and meta-analysis (PRISMA) flow diagram

Regarding the intraoperative data, statistically significant differences were not observed in terms of intraoperative complications, conversion to open surgery and operative time. Twenty-two (11.2%) and 20 (8.4%) concomitant procedures were performed in patients who underwent anterior CST and closure of the abdominal midline by laparotomy and posterior CST-TAR, respectively, none in patients who underwent anterior CST and closure of the abdominal midline by laparoscopy (Table 7).

Regarding the postoperative outcomes, patients who underwent anterior CST and closure of the abdominal midline by laparotomy experienced the highest surgical complications rate (31.2%), length of hospital stay (8.1 ± 3.7 days) and recurrence rate (10.7%) in comparison with patients who underwent anterior CST and closure of the abdominal midline by laparoscopy (15.8%, 7.2 ± 2.1 days and 6.6%, respectively) and patients who underwent posterior CST-TAR (17.8%, 2.4 ± 1.4 days and 0.4%, respectively). Statistical analysis shows statistically significant differences comparing the group of patients who underwent anterior CST and closure of the abdominal midline by laparotomy with the other two groups (Table 7).

Discussion

This systematic review was conducted with the aim to compare the outcomes after minimally invasive anterior and posterior CST to provide which is the best surgical treatment for the treatment of large abdominal ventral hernia. Most of the included articles had small sample of patients and missing or very heterogeneous data, as reported by the study quality assessment and the assessment of the risk of bias of the included articles (Tables 2 and 3). Moreover, due to the lack of randomized control trials, it was not possible to perform a meta-analysis. Anyway, in terms of postoperative morbidity, group A has the higher surgical complications rate, followed by group C and B, respectively, achieving the statistically significant differences with groups B and C. One limitation of these results could be considered the fact that in group A there is 11.2% of patients who underwent concomitant procedures, that could increase the risk of surgical complications (since wounds in some of these cases would be considered a grade III, following Centers for Disease Control and Prevention surgical wound classification [41], which are associated to higher surgical site occurrences, and panniculectomy itself could also be associated to more surgical site occurrences). Moreover, the concomitant procedures could be a limitation to perform a pure minimally invasive anterior CST or a posterior CST-TAR. In group C the type of concomitant procedures is not specified, and this is a limit for a good analysis of the results.

The recurrence rate is highest in group A, followed by group B and C, respectively, achieving the statistically significant differences with both groups B and C. Group C has the highest reported hernia area defect without, however, statistically significance difference and the lowest hospital stay and recurrence rate in comparison with other groups.

Table 2 Assessment of the articles quality based on Newcastle–Ottawa scale (NOS) [11]

Author, year, type of study	Selection				Comparability	Outcomes			Total score	Assessment
	1	2	3	4	5	6	7	8		
Group A										
Lowe, 2000, retrospective [7]	*	*	*	*	*	*	–	–	7	Poor
Rosen, 2007, retrospective [14]	–	–	*	*	*	*	–	*	6	Fair
Bachman, 2009, prospective [15]	–	*	–	–	*	*	–	*	5	Poor
Cox, 2010, retrospective [16]	–	–	*	–	*	*	–	*	5	Poor
Albright, 2011, retrospective [17]	*	*	*	–	*	*	–	–	6	Poor
Azoury, 2014, retrospective [18]	*	*	*	*	*	*	*	*	9	Good
Ng, 2015, retrospective [19]	*	*	*	–	*	*	*	*	8	Good
Mommers, 2016, retrospective [20]	*	–	*	*	*	*	–	–	6	Poor
Thomesn, 2016, prospective [21]	*	–	*	*	*	*	–	–	6	Poor
Dauser, 2017, retrospective [22]	–	–	*	–	*	*	–	–	4	Poor
Muse, 2018, retrospective [23]	*	*	*	*	*	*	–	*	8	Good
Köhler, 2018, retrospective [24]	*	–	*	*	*	*	–	*	7	Good
Group B										
Malik, 2009, retrospective [25]	–	–	*	*	*	*	–	*	6	Fair
Giurgius, 2012, retrospective [26]	*	*	*	*	*	*	–	*	8	Good
Moazzez, 2013, prospective [27]	–	*	*	–	*	*	–	*	6	Fair
Fox, 2013, retrospective [28]	*	*	*	*	*	*	*	*	9	Good
Azoury, 2014, retrospective [18]	*	*	*	*	*	*	*	*	9	Good
Oviedo, 2017, retrospective [29]	*	*	*	–	*	*	*	–	7	Good
Wiessner, 2017, retrospective [30]	*	*	*	–	*	*	–	–	6	Fair
Elstner, 2018, prospective [31]	–	–	*	*	*	*	–	–	5	Poor
Group C										
Belyansky, 2016, prospective [32]	–	–	*	–	*	*	–	*	5	Poor
Moore, 2016, prospective [33]	–	–	*	*	*	*	–	–	5	Poor
Amaral, 2017, prospective [34]	–	*	*	–	*	*	–	*	6	Fair
Bittner, 2018, retrospective [35]	*	*	*	*	*	*	–	*	8	Good
Martin-del-Campo, 2018, retrospective [36]	*	*	*	*	*	*	–	–	7	Poor
Halka, 2018, retrospective [37]	*	*	*	*	*	*	–	–	7	Poor
Belyansky, 2018, retrospective [38]	–	–	*	–	*	*	–	*	5	Poor
Halpern, 2019, retrospective [39]	*	*	*	*	*	*	*	*	9	Good
Gokcal, 2019, retrospective [40]	*	*	*	*	*	*	–	–	7	Poor

*: 1; –: 0

Group A: minimally invasive anterior component separation technique and closure of the abdominal midline by laparotomy. Group B: minimally invasive anterior component separation technique and closure of the abdominal midline by laparoscopy. Group C: minimally invasive posterior component separation technique with transversus abdominis release

To note that most of posterior CST-TAR procedures (94.5%) were performed robotically, that could be a factor that lengthens the operating time.

CST is an effective and safe technique, and it quickly gained popularity for the treatment of the large abdominal defects [1]. It provides functional restoration of the muscles of the abdominal wall, without tension, and affords dynamic support to counter fluctuations of the intra-abdominal pressures [42]. If on one hand the introduction of minimally invasive surgery resulted in similar outcomes in terms of abdominal wall restoration in comparison to open CST, on the other hand it improves the outcomes in terms of

Table 3 Assessment of risk of bias of the included articles based on Risk Of Bias In Nonrandomised Studies—of Interventions (ROBIN-I) [12]

Author, year, type of study	Bias due to confounding	Bias in selection participants	Bias in classification of interventions	Bias due to deviations from intended interventions	Bias due to missing data	Bias in measurement of outcomes	Bias in selection of reported result	Overall
Group A								
Lowe, 2000, retrospective [7]	Serious	Low	Low	Low	Low	Low	Serious	Moderate
Rosen, 2007, retrospective [14]	Serious	Low	Low	Low	Low	Low	Serious	Moderate
Bachman, 2009, prospective [15]	Serious	Low	Low	Low	Serious	Low	Serious	Serious
Cox, 2010, retrospective [16]	Serious	Low	Low	Low	Low	Low	Serious	Moderate
Albright, 2011, retrospective [17]	Serious	Low	Low	Low	Serious	Low	Serious	Serious
Azoury, 2014, retrospective [18]	Serious	Low	Low	Low	Low	Low	Serious	Moderate
Ng, 2015, retrospective [19]	Serious	Low	Low	Low	Moderate	Low	Serious	Serious
Mommers, 2016, retrospective [20]	Serious	Low	Low	Low	Low	Low	Serious	Moderate
Thomesn, 2016, prospective [21]	Serious	Low	Low	Low	Low	Low	Serious	Moderate
Dauser, 2017, retrospective [22]	Serious	Low	Low	Low	Serious	Low	Serious	Serious
Muse, 2018, retrospective [23]	Serious	Low	Low	Low	Low	Low	Serious	Moderate
Köhler, 2018, retrospective [24]	Serious	Low	Low	Low	Moderate	Low	Serious	Serious
Group B								
Malik, 2009, retrospective [25]	Serious	Low	Low	Low	Moderate	Low	Serious	Serious
Giurgius, 2012, retrospective [26]	Serious	Low	Low	Low	Low	Low	Serious	Moderate
Moazzez, 2013, prospective [27]	Serious	Low	Low	Low	Low	Low	Serious	Moderate

Table 3 (continued)

Author, year, type of study	Bias due to confounding	Bias in selection participants	Bias in classification of interventions	Bias due to deviations from intended interventions	Bias due to missing data	Bias in measurement of outcomes	Bias in selection of reported result	Overall
Fox, 2013, retrospective [28]	Serious	Low	Low	Low	Moderate	Low	Serious	Serious
Azoury, 2014, retrospective [18]	Serious	Low	Low	Low	Low	Low	Serious	Moderate
Oviedo, 2017, retrospective [29]	Serious	Low	Low	Low	Moderate	Low	Serious	Serious
Wiessner, 2017, retrospective [30]	Serious	Low	Low	Low	Low	Low	Serious	Moderate
Elstner, 2018, prospective [31]	Serious	Low	Low	Low	Moderate	Low	Serious	Serious
Group C								
Belyansky, 2016, prospective [32]	Serious	Low	Low	Low	Serious	Low	Serious	Serious
Moore, 2016, prospective [33]	Serious	Low	Low	Low	Serious	Low	Serious	Serious
Amaral, 2017, prospective [34]	Serious	Low	Low	Low	Serious	Low	Serious	Serious
Bittner, 2018, retrospective [35]	Serious	Low	Low	Low	Serious	Low	Serious	Serious
Martin-del-Campo, 2018, retrospective [36]	Serious	Low	Low	Low	Serious	Low	Serious	Serious
Halka, 2018, retrospective [37]	Serious	Low	Low	Low	Serious	Low	Serious	Serious
Belyansky, 2018, retrospective [38]	Serious	Low	Low	Low	Low	Low	Serious	Moderate
Halpern, 2019, retrospective [39]	Serious	Low	Low	Low	Low	Low	Serious	Moderate
Gokcal, 2019, retrospective [40]	Serious	Low	Low	Low	Serious	Low	Serious	Serious

Group A: minimally invasive anterior component separation technique and closure of the abdominal midline by laparotomy. Group B: minimally invasive anterior component separation technique and closure of the abdominal midline by laparoscopy. Group C: minimally invasive posterior component separation technique with transversus abdominis release. Low: low risk of bias (the study is comparable to a randomised trial). Moderate: moderate risk of bias (the study provides sound evidence for a nonrandomised study but cannot be considered comparable to a randomised trial). Serious: serious risk of bias (the study has important problems)

Table 4 Studies included on minimally invasive anterior component separation technique and closure of the midline by laparotomy

Author	N. of patients	Mean age ± SD or range (years)	Mean BMI ± SD or range (kg/m^2)	Comorbidities and therapy	Mean hernia area ± SD or range (cm^2)	Mesh placement	Mean operative time ± SD or range (minutes)	30 day-postoperative complications	Mean hospital stay ± SD or range (days)	Mean follow-up ± SD or range (months)	Recurrence, n (%)
Lowe [7]	7	52 ± 11.6	35.5 ± 11.6	Diabetes: 1 Steroid use: 1 Smoker: 3	288 (170–375)	Onlay	294 (250–420)	Urinary tract infection: 1 Ileus: 1 Pulmonary complication: 1	7.1 (5–11)	n.r.	1 (14.2)
Rosen [14]	7	54 (34–84)	37 (30–45)	Hypertension: 5 Diabetes: 3 Smoker: 1	338 (187–450)	Underlay	185 (155–220)	Respiratory failure: 1 Hematoma: 1 SSS infection: 1	5.4 (4-6)	4.5 (2–6)	0
Bachman [15]	5	50.8 ± 21.1	30.9 ± 6.2	Pulmonary disease: 2 Diabetes: 1 Smoker: 2	n.r.	Underlay	227 ± 49	Anemia: 2 Hematoma: 1 Wound infection: 1	9.2 ± 3.6	Median 6 (0.25–9)	1 (20)
Cox [16]	6	49 ± 24.5	24 ± 4.5	n.r.	269.8 ± 74.5	Retrorectus	317.1 ± 79.7	Recurrent enterocutaneous fistula: 1 Wound infection: 1	10 ± 2	8.5 ± 3.8	0
Albright [17]	11	45.82	37.45	n.r.	n.r.	Retrorectus/ Intraperitoneal	245	Acute renal failure: 1 Skin dehiscence: 1 Small bowel obstruction: 1	5.8	n.r.	0
Azoury [18]	17	59 ± 11	34 ± 9	Diabetes: 3 Smoker: 3 COPD: 2 Anticoagulation: 1 Steroids: 1	195 ± 253	Underlay	378 ± 66	Seroma: 2 Hematoma: 1 Abscess: 1 Cellulitis: 1 Hernia in another site: 1	5 ± 1.5	11 (0.5–34.5)	0
Ng [19]	10	Median 48.7	Median 37.5	n.r.	Median 102.7	Underlay	n.r.	Wound infection: 2	6	Median 15 (4–26)	2 (20)

Table 4 (continued)

Author	N. of patients	Mean age ± SD or range (years)	Mean BMI ± SD or range (kg/m^2)	Comorbidities and therapy	Mean hernia area ± SD or range (cm^2)	Mesh placement	Mean operative time ± SD or range (minutes)	30 day-postoperative complications	Mean hospital stay ± SD or range (days)	Mean follow-up ± SD or range (months)	Recurrence, n (%)
Mommers [20]	27	Median 60 (35–77)	27 ± 2	Diabetes: 2 Smoker: 2	Median 116 (28–198)	Intrabdominal/Sublay	Median 110 (69–239)	Ileus: 2 Urinary tract infection: 2 Pneumonia: 1 Deep venous thrombosis:1 Hematoma: 1 Wound dehiscence: 1 Abscess: 3	Median 5 (3–15)	Median 13 (12–34)	7 (25.9)
Thomesn [21]	19	Median 61 (28–80)	Median 30.9 (18.8–48.6)	n.r.	170 (63–452)	Onlay Retrorectus	Median 204 (30–340)	Hematoma: 1 Skin dehiscence: 3 Cutaneous sinus: 2 Mesh displacement: 1 Ileus: 1 Pneumonia: 8 Urinary tract infection: 8 Gastroenteritis: 3	Median 6 (2–60)	Median 16 (8–29)	2 (10.5)
Dauser [22]	15	66 (40–76)	30.8 (21.6–42.5)	n.r.	n.r.	Sublay Onlay	n.r.	Hematoma: 2 SSS infection: 1 Bowel obstruction: 1	7 (2–22)	n.r.	n.r.
Muse [23]	53	Median 54.4	Median 35.3	Hypertension: 33 COPD: 14 Diabetes: 16 Smoker: 17	n.r.	Retrorectus	224 (114–439)	Unspecified wound complications: 18	Median 5	Median 12.6	8 (15)
Köhler [24]	19	61 (32–83)	30.8 (21.8–34.2)	n.r.	n.r.	Sublay	n.r.	Hematoma: 3 SSS infection: 2	7 (6–18)	12	0

SD standard deviation, *BMI* body mass index, *COPD* chronic obstructive pulmonary disease, *SSS* superficial surgical site, *n.r.* not reported

Table 5 Studies included on minimally invasive anterior component separation technique and closure of the midline

Author	N. of patients	Mean age ± SD or range (years)	Mean BMI ± SD or range (kg/m^2)	Comorbidities and therapy	Mean hernia area ± SD or range (cm^2)	Mesh placement	Mean operative time ± SD or range (minutes)	30 day-postoperative complications	Mean hospital stay ± SD or range (days)	Mean follow-up ± SD or range (months)	Recurrence, n (%)
Malik [25]	4	63.5 (54–75)	36.6 (24–37)	Diabetes: 1 Hypertension: 3 Asthma: 1	306 (140–468)	Onlay	n.r.	Seroma: 2	(2–12)	(1–3)	0
Giurgius [26]	21	51 ± 13	36 ± 7	Hypertension: 12 Diabetes: 9 Pulmonary disease: 4 Smoker: 10	255 ± 170	Retrorectus	229 ± 57	Abscess: 2 Cellulitis: 1 Skin dehiscence: 1 Pneumonia: 1 Acute tubular necrosis: 1	6.3 ± 3.6	(1–21)	1 (4.7)
Moazzez [27]	5	48.6 ± 7.9	29.7 ± 3.4	Hypertension: 3 Diabetes: 1 Smoker: 1 Dislipidemia: 2	175 ± 56.2	Onlay	372 ± 104	Pneumonia and respiratory failure: 2 Small bowel obstruction: 2 Hernia at trocar site: 1 Renal failure: 1	9.2 ± 5.4	12.3 ± 6.8	3 (60)
Fox [28]	18	57	34	Smoker: 9	n.r.	Underlay	n.r.	Wound infection: 1	7	Median 13.2	3 (16.6)
Azoury [18]	25	57 ± 11	35.4 ± 8	Diabetes: 5 Smoker: 5 COPD: 2 Anticoagulation: 2	162 ± 45	Underlay	278 ± 73	Seroma: 1 Hematoma: 1 Abscess: 2 Cellulitis: 1 Hernia in another site: 2	4 ± 2	7 (0.5–19)	1 (4)
Oviedo [29]	33	58.8 ± 14.1	36.2 ± 4.7	n.r.	n.r.	Onlay	154 ± 44.1	Cellulitis: 1 Skin dehiscence at trocar site: 1	10	19.9 ± 7	0

Table 5 (continued)

Author	N. of patients	Mean age ± SD or range (years)	Mean BMI ± SD or range (kg/m^2)	Comorbidities and therapy	Mean hernia area ± SD or range (cm^2)	Mesh placement	Mean operative time ± SD or range (minutes)	30 day-postoperative complications	Mean hospital stay ± SD or range (days)	Mean follow-up ± SD or range (months)	Recurrence, n (%)
Wiessner [30]	5	60.4 (52–73)	33.3 (26–42)	Hypertension: 3 Diabetes: 3 COPD: 1 Smoker: 3 Cardiomyopathy: 1 Chronic pancreatitis: 1 OSA: 2	140 (56–253)	Onlay	183 (138–255)	0	7 (4–10)	10 (1–24)	0
Elstner [31]	9	63 (47–81	(25–46)	Diabetes: 4	n.r.	Onlay	n.r.	0	n.r.	30	0

SD standard deviation, *BMI* body mass index, *COPD* chronic obstructive pulmonary disease, *SSS* superficial surgical site, *n.r.* not reported, *OSA* obstructive sleep apnea syndrome

morbidity rate and reduces the hospital stay in most of the previously reported articles [1, 2, 4, 5, 35]. In this sense, it has already been reported that a higher surgical postoperative complication rate, together with higher recurrence rate, are more common after open surgery in comparison to minimally invasive approach, so the use of this last one should be preferred to obtain less both early and late postoperative complications [43].

Even if CST provides a tension free reconstruction, the mesh placement during CST seems to provide better results if compared to primary closure [44–47]. Denney et al. reported a 13% of recurrence rate in patients who underwent CST and mesh placement [44]. Rezavi et al. showed recurrence rates of 14.8% and 34.6% in case of mesh placement or not after CST, respectively, confirming this data [45]. In the present review, all included articles reported the use of mesh, showing low recurrence rate [7, 14–40]. However, in the literature it is still debated which is the best prosthetic material to use in each case and the most proper anatomical plane to place the mesh [44–47], being evident in the present study a lack of a standardization of the procedures.

Despite previous published papers in the literature well documented the advantages of minimally invasive approach over the open one for the CST [1, 2, 4, 5, 9], a comparison which includes only patients treated with different minimally invasive CST is still missing. Thus, to the best of our knowledge, this is the first systematic review reported in the literature concerning the outcomes after different minimally invasive CST. The major limitations of the present study are the small sample of patients for each group, the heterogeneity of data reported in each article, which makes a comparison difficult, and the poor quality of the included papers. Moreover, the indications for surgery are not standardized in the included articles, being this another bias that can influence the results. Finally, it is difficult to achieve reliable data regarding recurrence due to the short follow-up reported in each group, especially in case of posterior CST-TAR. The mentioned above limitations affect the statistical analysis, being impossible a meta-analysis, and make difficult to draw firm conclusions.

In conclusion, based on the present study, anterior CST with closure of the abdominal midline by open approach showed the worst results in comparison with the other techniques, and therefore, it should be considered a hybrid technique, because patients do not benefit from the advantages of a pure minimally invasive approach. Minimally invasive posterior CST showed lower hospital stay and recurrence rate in comparison with the anterior CST, even if with the shorter follow-up period. Further prospective studies and randomized control trials, with wider sample size and longer follow-up are required to demonstrate which is the best surgical option in case of large ventral hernia.

Table 6 Studies included on minimally invasive posterior component separation technique with transversus abdominis release

Author	N. of patients	Mean age ± SD or range (years)	Mean BMI ± SD or range (kg/m^2)	Comorbidities and therapy	Mean hernia area ± SD or range (cm^2)	Mesh placement	Mean operative time ± SD or range (min)	30 day-postoperative complications	Mean hospital stay ± SD or range (days)	Mean follow-up ± SD or range (months)	Recurrence, n (%)
Belyansky [32]	3	70	30.1	n.r.	n.r.	Retromuscular	329	Ileus: 1	4.7	0.3	0
Moore [33]	10	56.4 (34–74)	28.6 (23.2–33.6)	n.r.	64	Retromuscular	126 (85–160)	Seroma: 1	1	n.r.	n.r.
Amaral [34]	6	n.r.	n.r.	n.r.	110	Retromuscular	340 (240–420)	Mesh extrusion: 1	3 (2–5)	n.r.	1 (16.6)
Bittner [35]	26	52.4 ± 12.9	33.4 ± 9	Coronary artery disease: 1 COPD: 6 Hypertension: 17 Immune: 1 Smoker: 6	235 ± 107	Retromuscular/preperitoneal	365 ± 78	Urinary retention: 2 ARDS: 1 Ileus: 1 Hematoma: 1	3 (2–10)	3	0
Martin-del-Campo [36]	38	58.9 ± 12.7	33.1 ± 8.8	Diabetes: 7 COPD: 4 Smoker: 6	n.r.	Retromuscular	299 ± 95	Seroma: 1	1.3 ± 1.3	n.r.	n.r.
Halka [37]	57	58.05 ± 13.9	33.6 ± 7.08	COPD: 2 Hypertension: 24 Diabetes: 13 Smoker: 10 ESRD/hemodialysis: 1	148.6 ± 22.4	Sublay	316.65	SSO: 4 Superficial wound infection: 1 Deep wound infection: 3 Respiratory insufficiency: 5 Bleeding: 2	2.8 ± 1.8	n.r.	n.r.
Belyansky [38]	8	n.r.	n.r.	n.r.	n.r.	Retromuscular	213 ± 57.8 430 (1 patient)	Seroma: 2	2.1 ± 1.3	1.7 ± 1	0
Halpern [39]	34	62.9 ± 13 (33–87)	34.8 ± 6.8 (23–50)	More than 1: 33 Smoker: 13	n.r.	Retromuscular	294	Seroma: 5 SSO: 4	1.8 (0–10)	7 (0.2–22.5)	0

Table 6 (continued)

Author	N. of patients	Mean age ± SD or range (years)	Mean BMI ± SD or range (kg/m^2)	Comorbidities and therapy	Mean hernia area ± SD or range (cm^2)	Mesh placement	Mean operative time ± SD or range (min)	30 day-postoperative complications	Mean hospital stay ± SD or range (days)	Mean follow-up ± SD or range (months)	Recurrence, n (%)
Gokcal [40]	54	59.1 ± 12.2	32.5 ± 6.7	Cardiovascular: 43 Pulmonary: 23 Endocrine: 20 Neuropsychiatric: 8 Medication that might cause bleeding: 18	Median 35.3	Retromuscular	219 (137.5–326.2)	Pain/discomfort: 23 Nausea/vomiting: 8 Respiratory: 11 Cardiac: 2 Small bowel obstruction/ileus: 5 Urinary retention: 1 Acute renal failure: 1 Edema: 3 Seroma: 4 Peritonitis: 1 Constipation: 4 Hepatic encephalopathy: 1 Cellulitis: 1 Urinary: 1 Trocar site bleeding: 1	Median 1 (IQR 0–2)	n.r.	n.r.

SD standard deviation, *BMI* body mass index, *COPD* chronic obstructive pulmonary disease, *SSS* superficial surgical site, *SSO* surgical site occurrences, *n.r.* not reported, *OSA* obstructive sleep apnea syndrome, *ESRD* end stage renal disease, *IQR* interquartile range

Table 7 Comparison between groups

	Group A (196 patients)	Group B (120 patients)	Group C (236 patients)	*p* value
Mean age ± SD (years)	55.1 ± 5.1	57.5 ± 5.5	59.6 ± 5.5	A vs B: 1.0000, A vs C: 0.298, B vs C: 1.0000
Mean BMI ± SD (kg/m^2)	33.4 ± 3.5	34 ± 2.2	32.2 ± 2.2	A vs B: 1.0000, A vs C: 1.0000, B vs C: 0.779
Comorbidities and therapy	113 (57.6)	88 (73.3)	258 (> 100)	A vs B: **< 0.0001**, A vs C: **< 0.0001**, B vs C: **< 0.0001**
Mean hernia area ± SD (cm^2)	223.1 ± 84.5	217.3 ± 75.4	236.3 ± 116	A vs B: 1.0000, A vs C: 1.0000, B vs C: 1.0000
Intraoperative complications, *n* (%)	–	1 (0.8)	5 (2.1)	A vs B: 0.3797, A vs C: 0.0064, B vs C: 0.6681
Concomitant procedures, *n* (%)	22 (11.2)	–	20 (8.4)	A vs B: **< 0.0001**, A vs C: 0.4151, B vs C: **0.0003**
Conversion to open surgery, *n* (%)	1 (0.5)	–	–	A vs B: 1.0000, A vs C: 0.4537, B vs C: 1.0000
Mean operative time ± SD (minutes)	255.1 ± 84.5	244.5 ± 84.8	292.4 ± 86.9	A vs B: 1.0000, A vs C: 1.0000, B vs C: 0.956
Postoperative complications, *n* (%)	**88 (44.9)**	**24 (20)**	**102 (43.2)** **42 (17.8)**	A vs B: **0.0001**, A vs C: 0.7705, B vs C: **< 0.0001**
Surgical complications	**61 (31.2)**	**19 (15.8)**	–	A vs B: **0.0022**, A vs C: **0.0015**, B vs C: 0.7662
Unspecified wound complications	18 (29.5)	–	4 (9.5)	A vs B: **0.0046**, A vs C: **< 0.0001**, B vs C: 1.0000
Hematoma/bleeding	10 (16.3)	1 (5.2)	7 (16.6)	A vs B: 0.4446, A vs C: 0.572, B vs C: 0.6666
Small bowel obstruction/ileus	6 (9.8)	2 (10.5)	–	A vs B: 1.0000, A vs C: 1.0000, B vs C: 0.7235
Abscess	4 (6.5)	4 (21)	–	A vs B: 0.0860, A vs C: **0.0417**, B vs C: **0.0125**
SSS infection	4 (6.5)	–	8 (19)	A vs B: 0.5676, A vs C: **0.0417**, B vs C: 1.0000
SSO	–	–	1 (2.3)	A vs B: 1.0000, A vs C: **0.0092**, B vs C: 0.0555
Wound infection	4 (6.5)	1 (5.2)	3 (7.1)	A vs B: 1.0000, A vs C: 0.1813, B vs C: 1.0000
Deep wound infection	–	–	–	A vs B: 1.0000, A vs C: 0.2547, B vs C: 0.5537
Skin dehiscence	4 (6.5)	2 (10.5)	15 (35.7)	A vs B: 0.6238, A vs C: **0.0417**, B vs C: 0.1130
Seroma	2 (3.2)	3 (15.7)	—	A vs B: 0.0841, A vs C: **0.0049**, B vs C: 0.1327
Anemia	2 (3.2)	–	—	A vs B: 1.0000, A vs C: 0.2053, B vs C: 1.0000
Cutaneous sinus	2 (3.2)	–	1 (2.3)	A vs B: 1.0000, A vs C: 0.2053, B vs C: 1.0000
Cellulitis	1 (1.6)	3 (15.7)	1 (2.3)	A vs B: **0.0398**, A vs C: 1.0000, B vs C: 0.1132
Hernia in other site	1 (1.6)	3 (15.7)	–	A vs B: **0.0398**, A vs C: 0.4537, B vs C: 0.0377
Wound dehiscence	1 (1.6)	–	–	A vs B: 1.0000, A vs C: 0.4537, B vs C: 1.0000
Mesh displacement	1 (1.6)	–	1 (2.3)	A vs B: 1.0000, A vs C: 0.4537, B vs C: 1.0000
Edema	–	–	1 (2.3)	A vs B: 1.0000, A vs C: 1.0000, B vs C: 1.0000

Table 7 (continued)

	Group A (196 patients)	Group B (120 patients)	Group C (236 patients)	*p* value
Peritonitis	–	–	1 (2.3)	A vs B: 1.0000, A vs C: 1.0000, B vs C: 1.0000
Recurrent enterocutaneous fistula	1 (1.6)	–	–	A vs B: 1.0000, A vs C: 0.4537, B vs C: 1.0000
Medical complications	**27 (13.7)**	**5 (4.1)**	**60 (25.4)**	A vs B: **0.0065**, A vs C: **0.0026**, B vs C: **< 0.0001**
Mean hospital stay ± SD (days)	8.1 ± 3.7	7.2 ± 2.1	2.4 ± 1.4	A vs B: 1.0000, A vs C: **0.0004**, B vs C: **0.012**
Mortality, *n* (%)	1 (0.5)	–	–	A vs B: 1.0000, A vs C: 0.4537, B vs C: 1.0000
Mean follow-up ± SD (months)	11.5 ± 4.8	15.3 ± 8.2	4.3 ± 3.7	A vs B: 0.819, A vs C: 0.482, B vs C: 0.147
Recurrence, *n* (%)	21 (10.7)	8 (6.6)	1 (0.4)	A vs B: 0.3154, A vs C: **< 0.0001**, B vs C: **0.0009**

Group A: minimally invasive anterior component separation technique and closure of the abdominal midline by laparotomy. Group B: minimally invasive anterior component separation technique and closure of the abdominal midline by laparoscopy. Group C: minimally invasive posterior component separation technique with transversus abdominis release

SD standard deviation, *BMI* body mass index, *SSS* superficial surgical site, *SSO* surgical site occurrences

Compliance with ethical standards

Disclosures Dr. Andrea Balla, Dr. Isaias Alarcón and Prof. Salvador Morales-Conde declare that they have no conflict of interest or financial ties to disclose.

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