Meta-Analysis

Annals of Surgery Open

OPEN

Suture Techniques and Materials for Fascial Closure of Abdominal Wall Incisions

A Comprehensive Meta-Analysis

Rudolf van den Berg, BSc,* Lucas Visscher, BSc,* Anand G. Menon, MD, PhD,†
Eva B. Deerenberg, MD, PhD,‡ and Pieter J. Tanis, MD, PhD*

Background: The aim of this systematic review and meta-analysis was to evaluate the effectiveness of different suture materials and techniques for laparotomy closure.

Methods: A literature search was conducted in 3 databases in April 2024. All randomized controlled trials (RCTs) and prospective cohort studies on laparotomy closure were included. The quality of the studies was evaluated using critical appraisal checklists (ROB2 and ROBINS-I). The primary outcome was incisional hernia (IH) formation, and secondary outcomes were fascial dehiscence (FD), combined FD+IH, and surgical site infection (SSI). Meta-analyses were performed using random effects models.

Results: A total of 41 RCTs and 9 prospective cohort studies were included. Meta-analysis revealed no superiority of slowly absorbable sutures over fast-absorbable sutures (5 studies, 1177 patients). Furthermore, no differences between interrupted and continuous suturing were found (14 studies, 5939 patients). Small-bites technique with a slowly absorbable suture was associated with significantly less risk of IH (odds ratio [OR]: 0.44; 95% confidence interval [CI]: 0.30–0.65), combined FD+IH (OR: 0.40; 95% CI: 0.21–0.75), and SSI (OR: 0.70; 95% CI: 0.53–0.91) compared with a large-bites technique (8 studies, 2360 patients). Significant improvements were found for the continuous modified Smead-Jones suturing in the emergency setting (2 studies, 90 patients) and retention-line suturing (1 RCT, 124 patients). Layered closure (6 studies, 2660 patients) or Hughes closure (2 studies, 772 patients) revealed no superiority over mass closure.

Conclusions: Closure of laparotomies in the elective setting using a small-bites technique with slowly absorbable sutures is superior over a large-bites technique. More evidence is needed in the emergency setting, with promising alternatives such as the modified Smead-Jones technique and retention-line suturing.

Keywords: abdominal wound closure techniques, elective surgical procedures, emergencies, hernia, incisional hernia, laparotomy, meta-analysis, suture techniques, sutures, systematic review

INTRODUCTION

Incisional hernia (IH) is one of the most frequent long-term complications after abdominal surgery. The incidence of IH varies between 5% and 15%, while in high-risk patients, incidences of up to 69% have been reported.[1–3] IHs can lead to pain, impaired quality of life, and can even cause life-threatening events, such as incarceration or strangulation of the intestines.[4–6] Treatment of IHs might be challenging depending on several factors such as the size of the defect, and might subsequently result in recurrent IH.[7] This all leads to a high burden of disease for patients and significant healthcare costs from a community perspective.

Risk factors for the occurrence of an IH can be divided into patient- and surgeon-related risk factors. Most patient-related factors, for example, age, gender, history of an aortic aneurysm, or prior laparotomy, are not modifiable, whereas body mass index might be improved preoperatively depending on the urgency. Furthermore, patients who experience surgical site infection (SSI) are more likely to develop an IH.[8] Finally, the surgical closure technique and material can be optimized by the operating surgeon.[1] A wide variety of suturing techniques have been studied. A basic principle of these techniques is to spread the tension on the tissue, which can be accomplished by a high suture-to-wound ratio (small-bites technique), or by adding mattress-sutures (Smead-Jones) or extra loops (Hughes closure).[9,10]

The 2 most recent meta-analyses that were published on abdominal wall closure were published in 2017 and 2018.[11,12] Since then, multiple studies evaluating suture techniques and materials have been published. In the present systematic review and meta-analysis, our aim is to provide a comprehensive overview of closure strategies for abdominal wall incisions in adults, with IH rate as primary outcome measure, and fascial dehiscence (FD), combined FD+IH and SSI development as secondary outcomes. Furthermore, we aimed to perform sensitivity

From the *Department of Surgery, Erasmus University Medical Center, Rotterdam, The Netherlands; †Department of Surgery, IJsselland Hospital, Capelle aan den IJssel, The Netherlands; and ‡Department of General Surgery, Franciscus Gasthus and Vlietland, Rotterdam, The Netherlands.

Rudolf van den Berg and Lucas Visscher contributed equally to this work and should be regarded as shared first authors.

The authors declare that they have nothing to disclose.

All data supporting the findings are included in this article as references to published articles, or they are available from the corresponding authors upon reasonable request.

SDC Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.annalsofsurgery.com).

Reprints: Pieter J. Tanis, MD, PhD, Department of Surgery, Erasmus University Medical Centre, Dr. Molewaterplein 40, 3015 GD, Rotterdam, The Netherlands. Email: p.tanis@erasmusmc.nl.

Annals of Surgery Open (2025) 1:e548

Received: 10 August 2024; Accepted 31 December 2024

Published online 4 March 2025

DOI: 10.1097/AS9.0000000000000548

analyses based on surgical setting (elective and emergency surgeries) and incision types.

MATERIALS AND METHODS

A study protocol was registered on Prospero (CRD42022356908) before the initiation of the systematic review and meta-analysis. The data are reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[13]

Eligibility Criteria

Studies were potentially eligible for the present systematic review if the design comprised either a randomized controlled trial (RCT) or prospective cohort study, and if techniques and materials for fascial closure of a laparotomy were evaluated in human adults with at least IH as one of the studied endpoints. All abdominal incisions for laparotomy, both elective and emergency surgeries, and all surgical specialties were included. Studies involving underage children (age <18 years), animals, use of mesh, antimicrobial sutures, and/or historical suture materials, such as catgut and stainless-steel suture, were excluded.

Outcome Parameters

IH occurrence was the primary endpoint, and FD, combined FD+IH, and SSI were secondary endpoints. Incidences of IH and FD were calculated independently from diagnostic modality (physical examination, ultrasound, and computed tomography) or treatment (nonoperatively and reoperation). If studies reported on acute types of evisceration or burst abdomen, this was also considered as a FD. Data on SSI occurrence were extracted from the included studies, including both superficial and deep SSIs.

Search Strategy

A systematic search was formulated in partnership with a specialized medical librarian in the Erasmus MC for the following databases: Medline, EMBASE, and CENTRAL (Cochrane Register of Controlled Trials). The search term contained no restrictions on any language or year of publication. Conference abstracts, case reports, and reviews were excluded in the search term. The search was performed by 2 authors (R.B. and L.V.) on October 11, 2022, and was updated on November 12, 2023, and April 12, 2024. The detailed search term for each of the databases can be found in Supplemental File A, see http://links.lww.com/AOSO/A456. Reference lists of included studies and previous systematic reviews were checked for additional articles of interest.

Data Extraction

First, the records were independently screened based on title and abstract by 2 assessors (R.B. and L.V.). Second, the full text of selected articles was assessed for eligibility and all predefined variables of the included studies were extracted independently by 2 authors (R.B. and L.V.). Any disagreements during the selection- and extraction process were resolved by discussion and consensus.

Suturing Materials and Techniques

Suturing materials were categorized into levels of absorbability (slowly, fast- and nonabsorbable), type of suture (material and filament type). Suture techniques were divided into bite sizes and step sizes, continuous and interrupted suturing, suture configurations (eg, far-near, near-far), and mass- or layered suturing.

Small-Bites Suturing

In the studies analyzing bite and step sizes, the intervention groups were referred to as "small-bites" or "small stitches" and control groups as "large-bites" or "long stitches". For the purpose of this meta-analysis, we categorized these as small-bites or large-bites. The concept of the small-bites technique constitutes placement of at least twice as many stitches as the length of the incision, measured in centimeters. This results in a tissue bite of 0.5 cm and intersuture distance of 0.5 cm. Tissue bites of at least 1 cm and intersuture distance of 1 cm are used in the traditional large tissue bites or mass closure technique.

Retention-Line Sutures

Reinforced tension line (RTL) suture is a suturing technique, first described by Hollinsky et al,[14] where suture peak tensile forces are distributed from the suture base to the surrounding tissue through a horizontal suture, which aims to prevent the suture from cutting through the tissue (Fig. 1A). This might be of added value in the emergency setting, as this is often associated with more challenging conditions for the abdominal wall such as ileus, fecal contamination, impaired perfusion and edema. An increase in abdominal pressure from edema and bowel distension results in an increase in horizontal tensile forces on the site of the insertion of the suture. Therefore, it is hypothesized that the more even distribution of forces in RTL suturing might lead to fewer complications in these high-risk patients.

Hugh-Jones Abdominal Wall Closure

The abdominal wall closure technique eponymously titled "Hughes Repair", also known as the 'Cardiff Repair', combines standard mass closure using 2 loop 1-polydioxanone (PDS) sutures along with a series of horizontal and vertical mattress sutures within a single nylon-1 suture, distributing the tension along the length of the incision as well as across it (Fig. 1B).

Retention Modified Smead-Jones Closure

Smead et al were the first to describe a mass closure technique of the abdominal wall in 1900 (Fig. 1C). After Jones et al described the same technique in 1941, this technique was entitled the Smead-Jones technique. The Smead-Jones closure technique consists of far-near and near-far suturing in an interrupted fashion. In this technique, the far sutures are placed 1.5 cm from the edge of the fascia and the near points are 0.5 cm away from the fascial edge. More recently, a modified version of the Smead-Jones technique, also described as the continuous far-near-near-far technique has come into use for abdominal wall closures. This technique combines continuous suturing with the Smead-Jones technique, possibly creating an as strong, but also less time-consuming suturing technique in comparison with the original interrupted Smead-Jones technique.[15]

Quality Assessment

The quality of the included RCTs was assessed with the ROB2 tool,[16] and the quality of the prospective cohort studies was assessed with the ROBINS-I tool.[17] Two authors (R.B. and L.V.) independently assessed the quality of all included trials and compared them afterward. Any disagreements were resolved by consensus. Visualization of the quality of the included study was integrated into the forest plots, and summary bar plots were produced.

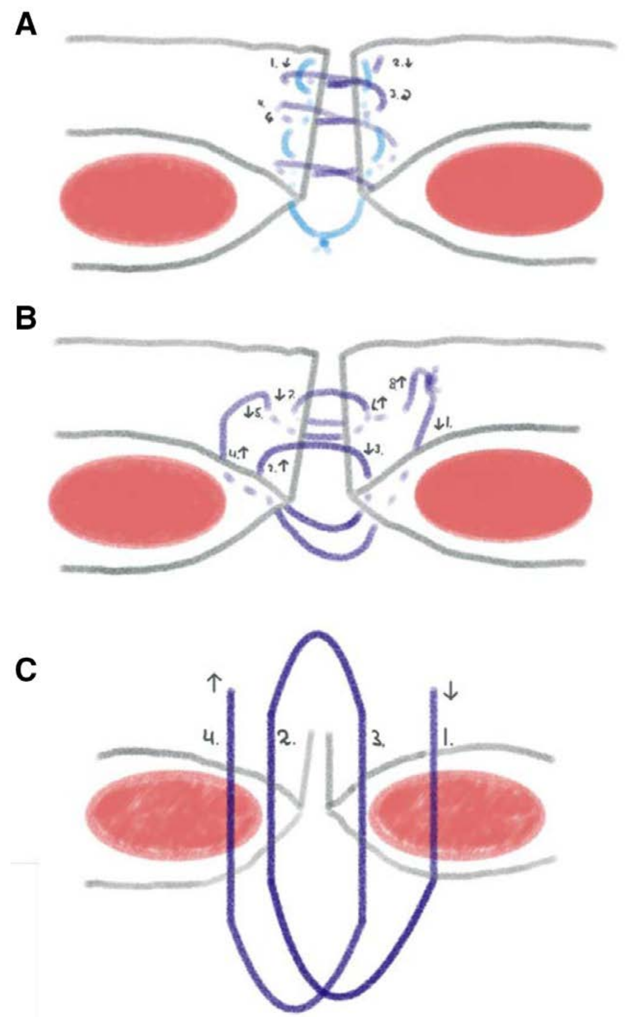

FIGURE 1. A, The reinforced tension line suture. B, The Hughes closure technique. C, The modified Smead-Jones technique.

Statistical Analysis

The primary meta-analysis focused on suture techniques and suture materials. All available comparisons of suture materials were grouped based on the 3 predefined categories (slowly, fast-, and nonabsorbable). Suturing techniques were grouped into continuous versus interrupted closure and small-bites versus large-bites. All different suturing configurations, specifically modified Smead-Jones, conventional Hughes, and retention-line suturing, were compared with conventional suturing. Data from trials were pooled if similar comparisons were made.

Emergency and elective surgeries were analyzed separately if the original article provided separate data for surgical setting. The different types of incisions (midline/transverse/oblique/paramedian) were planned to be analyzed separately where possible. We furthermore intended to perform sensitivity analyses for inclusion periods before and after the release of the World Health Organization (WHO) guidelines on SSI prevention, because of the association between SSI and IH.

The synchronized dichotomous outcomes were pooled in meta-analyses and reported as weighted odds ratios (ORs) and their 95% confidence intervals (CIs). Statistical heterogeneity was explored via forest plots and I^2/τ^2 statistics. Mantel-Haenszel random effects method was used in the meta-analysis due to anticipated high amounts of heterogeneity between studies. Funnel plots were used to assess the possibility of publication bias. Statistical analysis was performed with R studio using the "metabin" package (version 6.5-0).

RESULTS

Literature Search

The initial search produced 8461 unique results, and 3 publications were identified through other sources. After screening for eligibility by title and abstract, and subsequent assessment of the full text, 50 records were included in the final analysis (Fig. 2). These comprised 41 RCTs and 9 prospective cohort studies. The level of agreement between the 2 assessors was moderate for screening abstracts and high for assessing the eligibility of the full texts. All studies were published in peer-reviewed journals from 1976 to 2024. Two studies were written in Spanish and the remaining 50 studies in English. Study characteristics can be found in Table 1.

Risk of Bias

Risk of bias for the studies is reported in Supplemental File C, see http://links.lww.com/AOSO/A458. A serious risk of overall bias was found in all of the 9 cohort studies and in 9 of 41 RCTs, whereas 6 of the RCTs were graded with a low overall bias rating.

Assessment of Incisional Hernia

The majority of the studies (N = 42) diagnosed an IH with clinical examination defined as a protrusion of the laparotomy scar during Valsalva's maneuver. Eight studies used radiological examination (either by computed tomography or ultrasonography) in all patients for diagnosis of IH.

Suture Materials

A total of 32 studies[18–49] comparing distinct suture materials with different speeds of absorbability were identified, of which 4 were nonrandomized. Year of publication ranged from 1976 to 2023 with a maximum follow-up ranging from 3 months to 3 years. A total of 12,153 patients were included in the trials. No significant differences were observed when comparing nonabsorbable suture materials to either slowly absorbable or fast absorbable materials for IH, FD, total wound failure, and SSI (Supplemental Files D and E, see http://links.lww.com/AOSO/A459 and http://links.lww.com/AOSO/A460, respectively). For the overall comparison of slowly absorbable to fast absorbable suture material, 11 RCTs[18–23,32,34,43,46,48] could be included in the meta-analysis, which did not reveal significant differences in any of the outcomes (Figs. 3A–D).

Mass Closure Versus Layered Closure

Three RCT's[18,26,50] and 3 prospective cohort studies[29,49,51] analyzed mass- versus layered closure, with year of publication ranging from 1977 to 2021. A total of 2660 patients were treated after varying incision types. Maximum follow-up times ranged from 6 to 48 months. When pooled, they showed no significant differences between both techniques for any of the studied outcomes (Supplemental File F, see http://links.lww.com/AOSO/A461). Separate analyses for surgical setting could not be performed, as only Bucknall et al[29] reported their outcomes separately for elective and emergency procedures.

Reinforced Tension Line Suture

One RCT[52] was published on the use of RTL sutures in 2022. A total of 124 patients were treated after elective and emergency

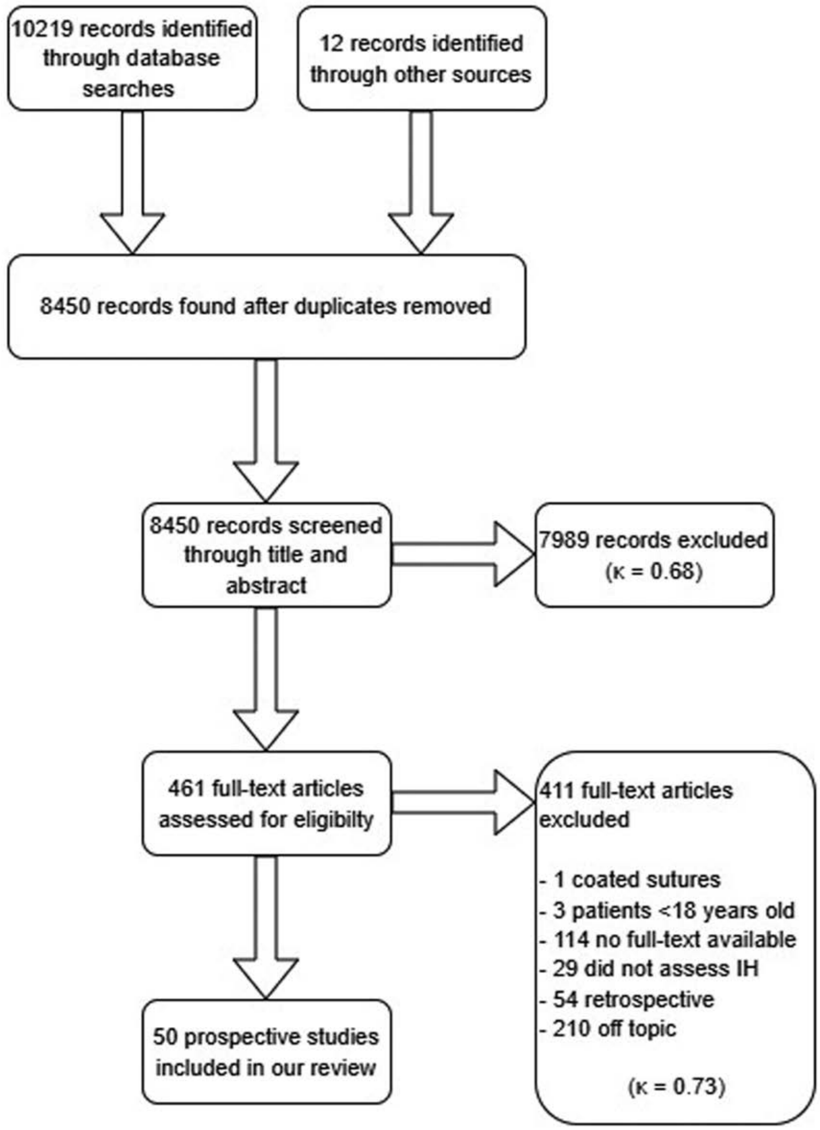

FIGURE 2. Flowchart of the included studies.

midline laparotomies. RTL sutures resulted in a significantly lower risk of IH (9.8% after RTL vs 20% after conventional continuous suturing, $P = 0.016$) and also a significant reduction in FD (4.5% vs 20%, $P = 0.03$) was reported.

Interrupted Versus Continuous Suturing

A total of 14 studies comprising 11 RCT's[18,21–23,26,28,32,45,46,53,54] and 3 prospective studies[49,51,55] were published on the comparison between continuous and interrupted suturing. The year of publication ranged from 1983 to 2016, and a total of 5939 patients were included in these studies. Maximum follow-up times ranged from 3 to 36 months. No significant differences were found between interrupted and continuous suturing for FD, IH, FD+IH, or SSI (Supplemental File G, see http://links.lww.com/AOSO/A463).

Bite Sizes

Eight studies addressed bite sizes in the closure of laparotomies, which consisted of 5 RCTs[56–61] and 3 prospective cohort studies[62–64] being published in the period 2009 to 2023. The short-, intermediate-, and long-term results from the ESTOIH trial[57,61,65] were published separately. A total of 2360 patients were included, of which 1198 were treated with the small-bites technique and 1162 patients with large-bites (Supplemental File H, see http://links.lww.com/AOSO/A462). Follow-up duration ranged from 6 to 36 months. Risk of bias in the RCTs was low, except for the randomization in the studies by Millbourn et al, Mustraqrasool et al, and Probst et al, which were graded with a high risk of bias. Furthermore, the prospective studies had a high risk of bias due to confounding. Relative risk reduction of IH by small-bites ranged from 36% to 75% across studies. In meta-analysis (Fig. 4), the small-bites technique compared with the large-bites techniques resulted in a significant reduction of IH (OR: 0.44; 95% CI: 0.28–0.67), combined IH+FD (OR: 0.38; 95% CI: 0.21–0.69) and SSI (OR: 0.70; 95% CI: 0.53–0.91), but not FD (OR: 0.53; 95% CI: 0.23–1.24).

Effect of Bite Sizes in Elective and Emergency Surgeries

Millbourn et al,[58] Mustaqrasool et al,[59] and Valverde et al[63] included both elective and emergency surgeries, while the other studies included solely patients undergoing elective surgery.

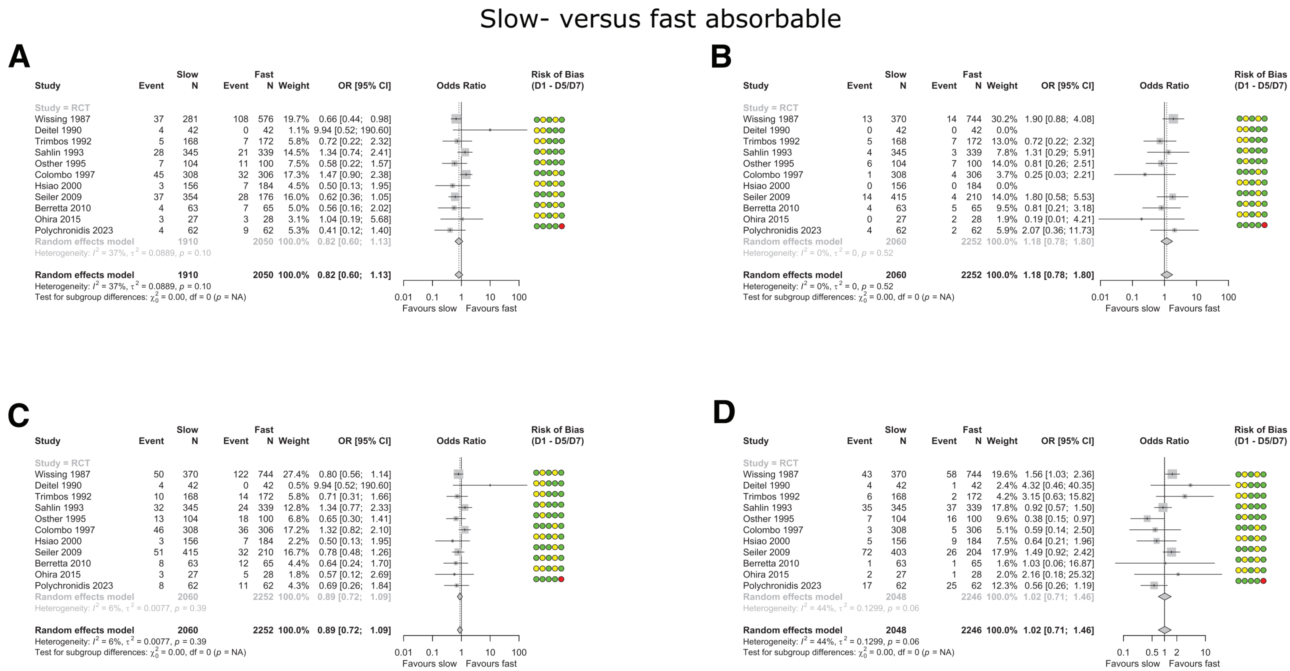

FIGURE 3. Forest plots for slow- versus fast absorbable sutures on (A) incisional hernia, (B) fascial dehiscence, (C) combined incisional hernia and fascial dehiscence, and (D) surgical site infection.

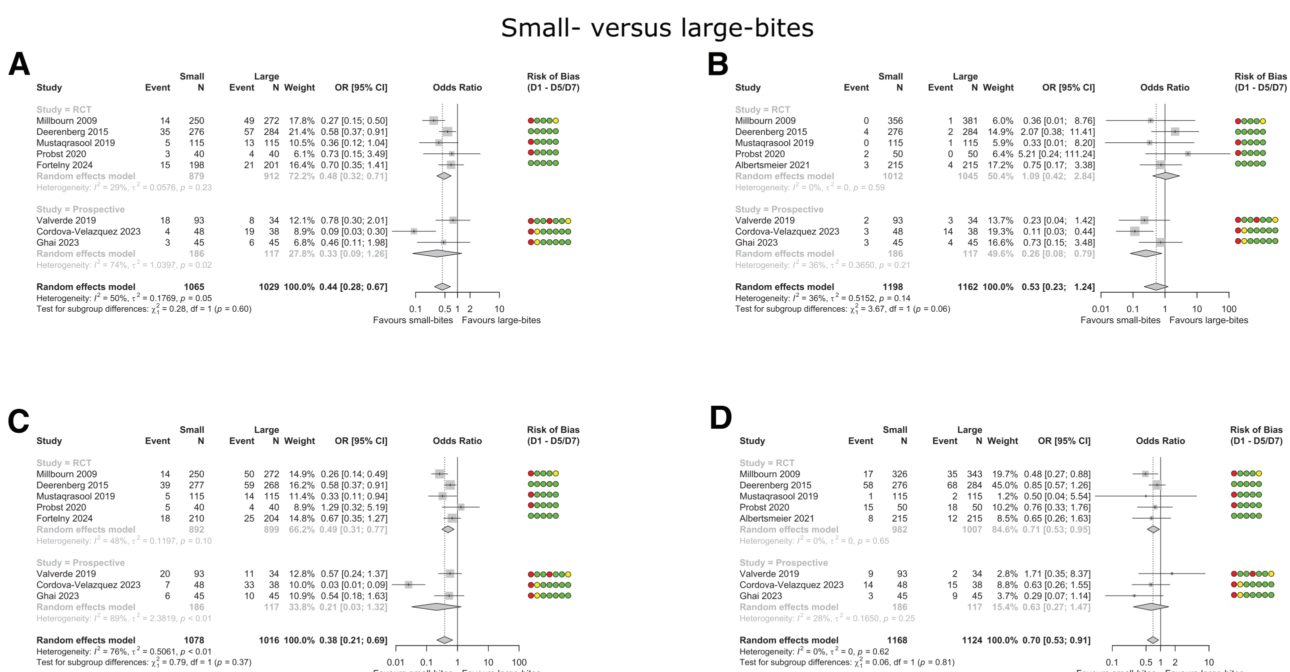

FIGURE 4. Forest plots for small-bites versus large-bites on (A) incisional hernia, (B) fascial dehiscence, (C) combined incisional hernia and fascial dehiscence, and (D) surgical site infection.

Valverde et al[63] documented IH rates after emergency (n = 49) and elective surgeries (n = 78) separately, (23% vs 19%) but not stratified for small- and large-bites.

Hughes Abdominal Wall Closure

Two separate trials[9,66] compared the incidence of IH between the Hughes repair and a conventional suture technique. The year of publication ranged from 2017 to 2022, and a total of 772 patients were included in these studies.

The HART trial[9] compared Hughes abdominal wall closure with mass closure and found that 50 of 339 patients (14.8%) in the Hughes group and 57 of 333 (17.1%) in the standard closure group developed an IH (OR: 0.84, 95% CI: 0.55–1.27; *P* = 0.40). At 2 years, 78 patients (28.7%) in the Hughes repair group and 84 patients (31.8%) in the standard closure group

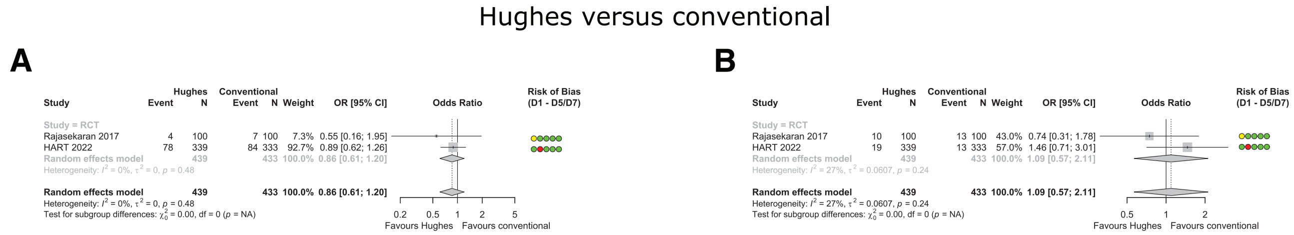

FIGURE 5. Forest plots for Hughes closure versus mass closure on (A) incisional hernia and (B) combined fascial dehiscence and SSI.

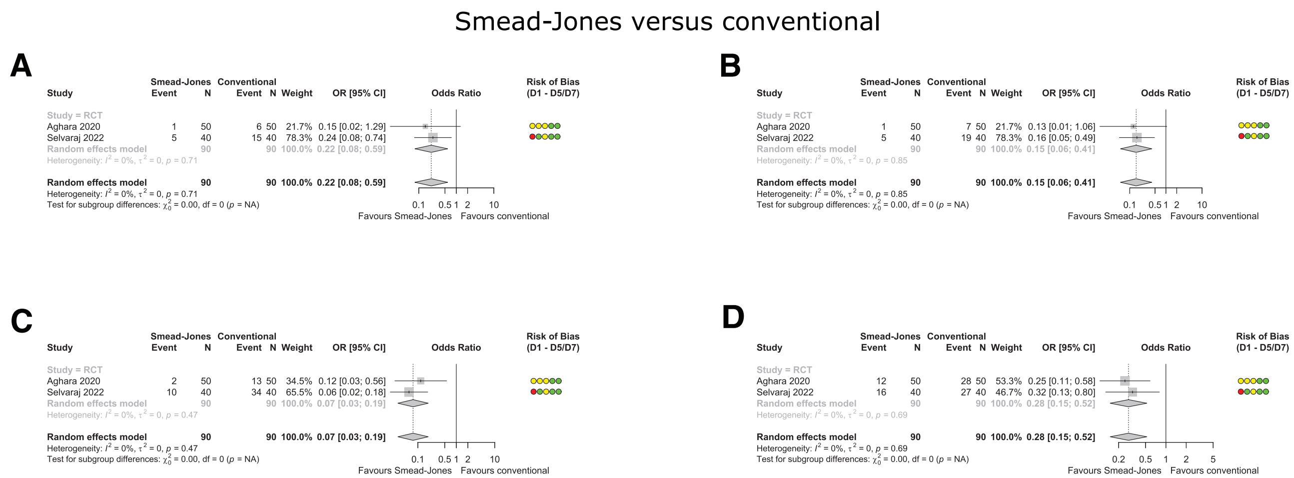

FIGURE 6. Forest plots for Smead-Jones versus conventional closure on (A) incisional hernia, (B) fascial dehiscence, (C) combined incisional hernia and fascial dehiscence, and (D) surgical site infection.

had developed an IH (OR: 0.86, 95% CI: 0.59–1.25; *P* = 0.43). Adverse events occurred similarly in the 2 groups, apart from the rate of SSI, which was higher in the Hughes closure group (13.2% vs 7.7%; OR: 1.82, 95% CI: 1.14–2.91; *P* = 0.01).

Rajasekaran et al[66] compared Hughes repair with conventional mass closure in an Indian study population. Both surgical procedures in the elective (n = 30 in both groups) and emergency (n = 20 in both groups) settings were included. They found no significant differences in the pooled number of SSIs and FDs (10/50 vs 13/50, *P* = 0.48) or IHs (4/50 vs 7/50, *P* = 0.34) between Hughes and mass closure.

Meta-analysis showed no significant difference between Hughes closure and conventional mass closure on IH formation or combined FD and SSI occurrence (Fig. 5). Risk of bias in the studies was low, except for the randomization in the studies by Rajasekaran et al and the deviations from intended intervention in the HART trial.

Modified Smead-Jones Closure

Two trials described the use of a continuous far-near-near-far technique. Both trials compared the modified/continuous Smead-Jones suturing technique to conventional closure for midline laparotomies in emergency surgery. The year of publication ranged from 2020 to 2022, and a total of 100 patients were included in the study by Aghara et al and 80 in the study by Selvaraj. Risk of bias in the RCTs was present as the trial by Aghara et al had some risk of bias in the domains randomization, deviations from the intended intervention and missing outcomes data, and Selvaraj et al had a high risk of bias in the randomization domain and some risk of bias in domain of missing outcome data.

Meta-analysis (Fig. 6) revealed that, in comparison with conventional continuous closure, the modified Smead-Jones technique resulted in a significant reduction of FD (OR: 0.15; 95% CI: 0.06–0.41), IH (OR: 0.22; 95% CI: 0.08–0.59), combined FD+IH (OR: 0.07; 95% CI: 0.03–0.19), and SSI (OR: 0.28; 95% CI: 0.15–0.52).

DISCUSSION

The present systematic review and meta-analysis provides a comprehensive and up-to-date overview about the evidence of fascial closure after laparotomy. This meta-analysis strengthens previous claims that the use of a small-bites technique with slowly absorbable suture is superior in the prevention of IH and SSI compared with large-bites, although this evidence is almost only based on elective surgery. It is important to emphasize that the small-bites technique used in the different trials also implicates small intersuture distance (small steps). There is uncertainty whether the results of small-bites suturing can be extrapolated to the emergency setting. Promising findings in the emergency setting were found for the modified Smead-Jones technique and retention-line suturing, but studies were small. For other comparisons, such as interrupted versus continuous suturing and Hughes or layered closure versus mass closure, no significant differences were found.

In the most recent recommendations of the European Hernia Society,[13] surgeons are advised to use a slowly absorbable suture in combination with a continuous suturing technique when closing the abdominal wall fascia. No separate recommendations about slowly absorbable sutures in comparison to fast absorbable sutures or interrupted sutures in comparison to continuous sutures were found. Considering the biology of wound healing, the use of a slowly absorbable suture for fascial closure seems most appropriate. Healing of the abdominal fascia mainly takes place during the first 3 weeks, but complete cellular-level remodeling can take up to a year.[67] Fast absorbable sutures like polyglactin and polyglycolic acid have a half-life tensile strength of about 2 to 3 weeks. This might not provide long enough support for the fascia to recover, since at 2 weeks fascial tissue only regains 15% of its initial strength and takes at least 6 weeks to regain half of its strength.[68,69] Slowly absorbable sutures such as PDS (Ethicon) have a half-life tensile strength of 6 weeks.[68] Furthermore, slowly absorbable sutures are theoretically preferable over nonabsorbable sutures due to suture sinus development, palpable knots, and wound pain, which have been described as issues with the use of nonabsorbable sutures.[15,26]

The current systematic review and meta-analysis found an OR of 0.44 in favor of the small-bites regarding the risk of developing IH, which is similar to what the investigators of the MATCH-review[11] found in 2018. However, we included 8 studies in our analysis, while the former review included only 2 studies. More recently, in 2023, another systematic review on this topic was published by Yii et al,[70] who also found a similar OR of 0.39 for IH, but they included only 3 studies. For SSI, the present meta-analysis revealed that the small-bites technique is significantly better for SSI prevention when compared with large-bites. Both previous meta-analyses found ORs for SSI comparable to our results, but not reaching statistical significance due to underpowered analyses. The difference in the number of included studies can be attributed to new studies being published after the inclusion period of the other systematic reviews. In a network meta-analysis, Lozada-Hernandez et al[71] found similar ORs for the prevention of IH but did not report on SSI.

The published RCTs comparing small-bites with a large-bites technique have used a different suture size and needle size in both study groups. In the small-bites group, a 2-0 suture was commonly used with a small-size needle. In the large-bites group, a 1 suture was most often used with a larger needle size. Whether these differences in suture size or needle size have an impact on the outcome of IH, FD or SSI remains unclear and are thereby possible confounding factors that should be looked into.

The use of the modified Smead-Jones technique has not been published in a systematic review as of yet. We show that this technique, which is only studied in an emergency setting, is effective in the reduction of complications after abdominal wall closure compared with conventional continuous closure using large-bites. The OR of developing an IH was found to be 0.22, and for FD this was 0.15. Two other studies on the modified Smead-Jones technique[72,73] could not be included in this systematic review, because of lacking IH as an endpoint. With respect to short-term complication rate, these studies further strengthen the potential added value of this technique in the emergency setting. However, it must be noted that the overall quality and patient numbers of the studies on this technique are low.

Emergency surgery is associated with higher levels of fecal or purulent contamination, which will probably result in higher SSI occurrence and thus higher risk of FD and IH occurrence.[74] Furthermore, postoperative ileus with increased intra-abdominal pressure is often encountered after emergency surgery. This might require a different closure method as compared with the elective setting. However, the selected studies in our review did not allow for comparative analyses based on surgical setting. Tolstrup et al[75] implemented continuous PDS 2-0 suture with a suture length to incision length ratio of at least 4:1. They compared these patients to a cohort of historic controls, which had unknown suture length to wound length ratios, and reported that the incidence of FD decreased from 6.6% to 3.8% (P = 0.03). Peponis et al[54] compared the interrupted versus continuous techniques for fascial closure in an emergency setting in a total of 136 patients and found that rates of IH, FD, and SSI did not differ significantly. The authors themselves devote the nonsignificant findings to a lack of power due to their relatively small sample size. The recent guidelines[76] on the closure of a laparotomy during emergency surgery suggest to use the small-bites technique in midline emergency laparotomy, but future trials on this topic are necessary to prove its effectiveness in the emergency setting and should also consider the use of RTL- and Smead-Jones suturing.

Unfortunately, minimizing the effects of the surgical-technical aspects of the closure of a midline laparotomy and expanding the use of minimally invasive surgery do not completely eliminate the occurrence of IH. Many patients with high-risk profiles, such as those undergoing emergency surgery, those who have had multiple previous laparotomies, or patients with significant abdominal surgical procedures, will still need open surgical procedures through midline incisions. Prevention of SSIs can also limit the risk of IH. In November 2016, the WHO published the first Global Guidelines on SSI prevention, which were updated in 2018.[77] Implementation of a bundle of preventive measures can indirectly influence the risk of IH. Other procedures, such as prophylactic mesh augmentation, which has been shown to be successful in preventing IHs during elective laparotomy, may be required in high-risk patients (eg, open aortic aneurysm surgery).[78]

The design of every meta-analysis is limited by the fact that the results depend on the included studies. For instance, the majority of RCTs only used clinical examination for the identification of IHs, which will have underestimated the hernia rate. However, one should question whether an IH that can only be diagnosed on ultrasonography without any reported signs by the patient is clinically relevant. This also depends on the duration of follow-up, while initial asymptomatic hernias might become symptomatic at a later stage. Besides definition of endpoints, also precise descriptions of interventions were sometimes lacking. For example, the size of the bites was not reported in many studies. Comparator arms in many trials differed by more than one component from the study arm, making it impossible to attribute differences between groups to one component. In addition, the patient populations included in many of the studies were very heterogeneous: trials included both emergency and elective cases, different types of disease pathology (eg, vascular surgery and hepatobiliary surgery), or different types of incisions (eg, midline and paramedian) and had varying follow-up lengths. It was not possible to perform pooled analyses for emergency and elective laparotomies as these data were often not separately reported in every trial. Similarly, analyses could not be stratified for the type of laparotomy (eg, midline, paramedian, and transverse).

Another limitation of this study is that one of the secondary objectives was not fulfilled. Due to a low number of recent studies conducted, sensitivity analysis could not be performed using studies that included patients after the implementation of the WHO guidelines for the reduction of SSIs. As SSI is one of the main risk factors for the development of an IH, patients operated on before the adoption of the new guidelines, could not be generalizable to the patient populations since then.[8] In upcoming years, an effort could be made to analyze these possible differences, but the available data fell short at this moment. It must be taken into account that not every surgeon adapts their practice immediately after implementation of new guidelines and as such, study results might lag behind for a couple of years.

CONCLUSIONS

In this meta-analysis, slowly absorbable suture materials were superior regarding IH rate over fast-absorbable sutures in the most recent studies. No discernable differences were found comparing a continuous- with an interrupted suture technique, or a mass- with a layered closure technique. The small-bites technique resulted in significantly lower IH, FD, and SSI rates as

TABLE 1.

Overview of the Included Studies

Category	Author	Year	Type of Study	Number of Patients (Per Group)	Type of Laparotomy	Elective/ Emergency	Intervention-I	Intervention-II	Intervention-III	Intervention-IV	Follow-Up (Months)	Outcome Measures	Outcome Diagnosis
Interrupted/ continuous	Askew	1983	RCT	104 (62/42)	m,t,p	Both	Nonabsorbable, Nylon-0, continuous, layered	Fast absorbable, Dexon-1, interrupted, mass			6	IH, FD, SSI	Clinical examination
	Richards	1983	RCT	571 (286/285)	m,t	Both	Nonabsorbable, Nylon-0, continuous, mass	Fast absorbable, Dexon-0, interrupted, mass			12	IH, FD, SSI	Not specified
	Wissing	1987	RCT	1539 (365/379/370/377)	m	Both	Fast absorbable, Vicryl-2, interrupted, mass	Fast absorbable, Vicryl-1, continuous, mass	Slowly absorbable, PDS-0, continuous, mass	Nonabsorbable, Nylon-1, continuous, mass	12	IH, FD, SSI	Clinical examination
	Lewis	1989	RCT	206 (93/103)	m, p	Both	Nonabsorbable, Prolene 1, continuous, mass	Fast absorbable, Dexon-1, interrupted, mass			60	IH, FD, SSI	Clinical examination
	Orr	1990	RCT	402 (201/201)	m,t	Not noted	Slowly absorbable, Maxon-1, interrupted, mass	Slowly absorbable, Maxon-1, continuous, mass			6	IH, FD, SSI	Clinical examination
	Trimbos	1992	RCT	340 (172/168)	m	Elective	Fast absorbable, PGA-1, interrupted	Slowly absorbable, Polyglyconate-0, continuous			12	IH, FD, SSI	Clinical examination
	Sahlin	1993	RCT	684 (345/339)	m,t,p,o	Both	Slowly absorbable, Maxon-1, continuous, mass	Fast absorbable, Vicryl-1, interrupted, mass			12	IH, FD, SSI	Clinical examination
	Brolin	1996	RCT	229 (120/109)	m	Both	Slowly absorbable, PDS-1, continuous	Nonabsorbable, Ethibond-1, interrupted figure-8			30	IH, FD, SSI	Determined by patient
	Colombo	1997	RCT	614 (306/308)	m	Elective	Fast absorbable, PGA-1, interrupted Smead-Jones mass closure	Slowly absorbable, Polyglyconate-1, continuous mass			33	IH, FD, SSI	Clinical examination
	Seiler	2009	RCT	625 (210/205/210)	m	Elective	Fast absorbable, Vicryl-2, interrupted	Slowly absorbable, PDS-1, continuous	Slowly absorbable, MonoPlus-1, continuous		12	IH, FD, SSI	Ultrasound confirmed
	Berretta	2010	RCT	192 (63/63/65)	m	Elective	Nonabsorbable, Premilene 1-0, continuous, mass	Slowly absorbable, PDS 1-0, continuous, mass	Nonabsorbable, Ethibond 2-0, interrupted, layered		36	IH, FD, SSI	Clinical examination with ultrasound as confirmation
	Peponis	2018	RCT	136 (69/67)	m	Emergency	Slowly absorbable, PDS-0, continuous	Slowly absorbable, PDS-0, interrupted			7	IH, FD, SSI	Clinical examination
	Polychronidis	2023	RCT	124 (62/62)	m	Emergency	Slowly absorbable, Monoplus-1, continuous, mass	Fast absorbable, Vicryl-2, interrupted, mass			12	IH, FD, SSI	Ultrasound
	Bucknall	1982	PCS	952 (684/104/164)	m, t, p	Both	Nonabsorbable, Nylon, mass	Fast absorbable, polyglycolic acid, mass	Nonabsorbable, nylon, layered		12	IH, FD, SSI	Clinical examination
	Chalya	2015	PCS	872 (804/68)	m	Elective	Various suture materials, continuous	Various suture materials, interrupted			24	IH, FD, SSI	Clinical examination
	Kumar	2016	PCS	50 (25/25)	m	Emergency	Slowly absorbable, PDS-1, continuous	Slowly absorbable, PDS-1, interrupted			3	IH, FD, SSI	Not specified
	Zhang	2016	PCS	258 (118/140)	t	Elective	Slowly absorbable, PDS, continuous, mass	Nonabsorbable, silk 7-0, interrupted, layered			16	IH, FD, SSI	Not specified

(*Continued*)

Table 1.
Continued

Category	Author	Year	Type of Study	Number of Patients (Per Group)	Type of Laparotomy	Elective/ Emergency	Intervention-I	Intervention-II	Intervention-III	Intervention-IV	Follow-Up (Months)	Outcome Measures	Outcome Diagnosis
Mass/ Layered	Askew	1983	RCT	104 (62/42)	m,t,p	Both	Nonabsorbable, Nylon-0, continuous, layered	Fast absorbable, Dexon-1, interrupted, mass			6	IH, FD, SSI	Clinical examination
	Ausobsky	1985	RCT	282 (135/147)	m, t, p	Both	Combination of PGA-0 and Nylon-1, continuous, layered	Nonabsorbable, Nylon-1, continuous, mass			48	IH, FD, SSI	Clinical examination
	Berretta	2010	RCT	192 (63/63/65)	m	Elective	Nonabsorbable, Premilene 1-0, continuous, mass	Slowly absorbable, PDS 1-0, continuous, mass	Nonabsorbable, Ethibond 2-0, interrupted, layered		36	IH, FD, SSI	Clinical examination with ultrasound as confirmation
	Chalya	2015	PCS	872 (842/30)	m	Elective	Various suture materials, mass	Various suture materials, layered			24	IH, FD, SSI	Clinical examination
	Zhang	2016	PCS	258 (118/140)	t	Elective	Slowly absorbable, PDS, continuous, mass	Nonabsorbable, silk 7-0, interrupted, layered			16	IH, FD, SSI	Not specified
Resorbability	Irvin	1976	RCT	161 (52/52/57)	m, p	Elective	Fast absorbable, Dexon, continuous (posterior rectus) and interrupted (anterior rectus sheath), layered	Fast absorbable, polyglactin, continuous (posterior rectus) and interrupted (anterior rectus sheath), layered	Nonabsorbable, Prolene, continuous, layered		6	IH, FD, SSI	Not specified
	Pollock	1979	RCT	198 (99/99)	m, t, p	Both	Nonabsorbable, Nylon-1, continuous, mass	Fast absorbable, Dexon-1, continuous mass			6	IH, FD, SSI	Clinical examination
	Cameron	1980	RCT	347 (167/180)	m, p	Both	Nonabsorbable, Prolene 1, interrupted, mass	Fast absorbable, Dexon-1, interrupted, mass			6	IH, FD, SSI	Not specified
	Corman	1981	RCT	161 (49/53/59)	m	Not noted	Nonabsorbable, Nylon, interrupted, mass	Nonabsorbable, Prolene, interrupted, mass	Fast absorbable, Vicryl, interrupted, mass		19	IH, FD, SSI	Not specified
	Askew	1983	RCT	104 (62/42)	m,t,p	Both	Nonabsorbable, Nylon-0, continuous, layered	Fast absorbable, Dexon-1, interrupted, mass			6	IH, FD, SSI	Clinical examination
	Richards	1983	RCT	571 (286/285)	m,t	Both	Nonabsorbable, Nylon-0, continuous, mass	Fast absorbable, Dexon-0, interrupted, mass			12	IH, FD, SSI	Not specified
	Leaper	1985	RCT	214 (97/107)	m, t	Not noted	Nonabsorbable, Nylon-1, continuous, mass	Slowly absorbable, PDS, continuous, mass			6	IH, FD, SSI	Clinical examination
	Cameron	1987	RCT	284 (141/143)	m, p	Both	Nonabsorbable, Prolene 1, interrupted, mass	Slowly absorbable, PDS-1, interrupted, mass			14,7	IH, FD, SSI	Clinical examination
	Krukowski	1987	RCT	757 (383/374)	m	Both	Nonabsorbable, polypropylene, continuous, mass	Slowly absorbable, polydioxanone, continuous, mass			12	IH, FD, SSI	Clinical examination
	Wissing	1987	RCT	1539 (365/379/370/377)	m	Both	Fast absorbable, Vicryl-2, interrupted, mass	Fast absorbable, Vicryl-1, continuous, mass	Slowly absorbable, PDS-0, continuous, mass	Nonabsorbable, Nylon-1, continuous, mass	12	IH, FD, SSI	Clinical examination
	Lewis	1989	RCT	206 (93/103)	m, p	Both	Nonabsorbable, Prolene 1, continuous, mass	Fast absorbable, Dexon-1, interrupted, mass			60	IH, FD, SSI	Clinical examination
	Deitel	1990	RCT	84 (42/42)	m	Elective	Slowly absorbable, polyglyconate-1, continuous	Fast absorbable, PGA-1, continuous			24	IH, FD, SSI	Clinical examination
	Trimbos	1992	RCT	340 (172/168)	m	Elective	Fast absorbable, PGA-1, interrupted	Slowly absorbable, Polyglyconate-0, continuous			12	IH, FD, SSI	Clinical examination
	Sahlin	1993	RCT	684 (345/339)	m,t,p,o	Both	Slowly absorbable, Maxon-1, continuous, mass	Fast absorbable, Vicryl-1, interrupted, mass			12	IH, FD, SSI	Clinical examination

(*Continued*)

Table 1.
Continued

Category	Author	Year	Type of Study	Number of Patients (Per Group)	Type of Laparotomy	Elective/ Emergency	Intervention-I	Intervention-II	Intervention-III	Intervention-IV	Follow-Up (Months)	Outcome Measures	Outcome Diagnosis
	Carlson	1995	RCT	225 (112/113)	m	Both	Nonabsorbable, Ethilon-0, continuous, mass	Slowly absorbable, Maxon-0, continuous, mass			24	IH, FD, SSI	Clinical examination
	Osther	1995	RCT	204 (104/100)	m, t, p, o	Both	Fast absorbable, Polyglyconate-0, interrupted	Slowly absorbable, Vicryl-0, interrupted			12	IH, FD, SSI	Clinical examination
	Brolin	1996	RCT	209 (109/120)	m	Elective	Nonabsorbable, Ethibond-1, interrupted	Slowly absorbable, PDS-1, continuous			29,4	IH, FD, SSI	Clinical examination
	Colombo	1997	RCT	614 (308/306)	m	Elective	Slowly absorbable, Maxon-1, continuous, mass	Fast absorbable, Dexon-1, continuous, mass			23	IH, FD, SSI	Clinical examination
	Hsiao	2000	RCT	340 (156/184)	m, t, p, o	Elective	Slowly absorbable, PDS II-0, continuous, mass	Fast absorbable, Vicryl-0, continuous, mass			24	IH, SSI	Clinical examination
	Orr Jr.	2003	RCT	201 (104/97)	m	Elective	Slowly absorbable, PLG-1, continuous	Nonabsorbable, Polypropolene-1, continuous			6	IH, FD, SSI	Not specified
	Dcobo-Durantez	2006	RCT	770 (451/319)	m, t	Both	Slowly absorbable, PDS, continuous	Nonabsorbable, Nylon, continuous			18	IH, FD, SSI	Clinical examination
	Seiler	2009	RCT	625 (210/205/210)	m	Elective	Fast absorbable, Vicryl-2, interrupted	Slowly absorbable, PDS-1, continuous	Slowly absorbable, MonoPlus-1, continuous		12	IH, FD, SSI	Ultrasound confirmed
	Gaikwad	2009	RCT	64 (34/30)	m	Elective	Nonabsorbable, Nylon-1, continuous mass	Slowly absorbable, PDS-1, continuous mass			6	IH, FD, SSI	Clinical examination
	Berretta	2010	RCT	192 (63/63/65)	m	Elective	Nonabsorbable, Premilene 1-0, continuous, mass	Slowly absorbable, PDS 1-0, continuous, mass	Nonabsorbable, Ethibond 2-0, interrupted, layered		36	IH, FD, SSI	Clinical examination with ultrasound as confirmation
	Bloemen	2011	RCT	523 (256/267)	m	Both	Nonabsorbable, Prolene 1-0, continuous single layer	Slowly absorbable, PDS 1-0, continuous single layer			35	IH, FD, SSI	Clinical examination with ultrasound when the IH was deemed possibly difficult to palpate
	Talpur	2011	RCT	274 (138/136)	m, o	Elective	Nonabsorbable, Prolene 1, continuous	Fast absorbable, Vicryl-1, continuous			6	IH, FD, SSI	Clinical examination
	Ohira	2015	RCT	55 (28/27)	m	Elective	Fast absorbable, Polysorb-1, interrupted,mass	Slowly absorbable, PDS, interrupted, mass			36	IH, FD, SSI	CT-scan
	Bucknall	1982	PCS	952 (684/104/164)	m, t, p	Both	Nonabsorbable, Nylon, mass	Fast absorbable, polyglycolic acid, mass	Nonabsorbable, nylon, layered		12	IH, FD, SSI	Clinical examination
	Zhang	2016	PCS	258 (118/140)	t	Elective	Slowly absorbable, PDS, continuous, mass	Nonabsorbable, silk 7-0, interrupted, layered			16	IH, FD, SSI	Not specified
	Aagja	2022	PCS	40 (20/20)	m	Emergency	Nonabsorbable, polypropylene, continuous, mass	Slowly absorbable, polydioxanone, continuous, mass			3	IH, FD, SSI	Not specified
RTL	Lozada-Hernandez	2022	RCT	124 (62/62)	m	Both	RTL suturing with PDS 1-0	Slowly absorbable, PDS 1-0, continuous in 4:1 SL/WL			36	IH, SSI	CT-scan if clinical examination was ambiguous
Bite sizes	Millbourn	2009	RCT	737 (381/356)	m	Both	Slowly absorbable, PDS 2-0 small-bites, continuous single layer	Slowly absorbable, PDS 1-0 large-bites, continuous single layer			12	IH, FD, SSI	Clinical examination

(*Continued*)

Table 1.
Continued

Category	Author	Year	Type of Study	Number of Patients (Per Group)	Type of Laparotomy	Elective/ Emergency	Intervention-I	Intervention-II	Intervention-III	Intervention-IV	Follow-Up (Months)	Outcome Measures	Outcome Diagnosis
	Deerenberg	2015	RCT	560 (284/276)	m	Elective	Slowly absorbable, PDS 2-0 small-bites, continuous mass	Slowly absorbable, PDS 1-0 large-bites, continuous mass			12	IH, FD, SSI	Ultrasound
	Mustaqrasool	2019	RCT	230 (115/115)	Not noted	Not noted	Slowly absorbable, Ethilon 1-0 small-bites, continuous single layer	Slowly absorbable, Ethilon 1-0 large-bites, continuous single layer			12	IH, FD, SSI	Clinical examination
	Probst	2020	RCT	100 (50/50)	m (relap)	Elective	Slowly absorbable, Monomax 2-0 small-bites, continuous single layer	Slowly absorbable, PDS-1 large-bites, continuous single layer			12	IH, FD, SSI	Clinical occurrence
	Fortelny	2024	RCT	425 (215/210)	m	Elective	Slowly absorbable, Monomax 2-0 small-bites, continuous single layer	Slowly absorbable, Monomax 1 large-bites, continuous single layer			36	IH, FD, SSI	Ultrasound
	Israelsson	1994	PCS	813 (408/405)	m	Both	Nonabsorbable, Nylon-1, continuous, mass	Slowly absorbable, PDS-2, continuous, mass			12	IH, FD, SSI	Clinical examination
	Valverde	2019	PCS	127 (34/93)	m	Both	Slowly absorbable, PDS 2-0 small-bites (SL:WL>4), continuous single layer	Slowly absorbable, PDS 2-0 large-bites (SL:WL <4), continuous single layer			6	IH, FD, SSI	CT
	Cordova-Velazquez	2023	PCS	86 (48/38)	m	Both	Various absorbable sutures, small-bites (SL:WL>4), continuous	Various absorbable sutures, large-bites (SL:WL4), continuous			6	IH, FD, SSI	CT
	Ghai	2023	PCS	90 (45/45)	m	Elective	Slowly absorbable, PDS 2-0 small-bites, continuous	Slowly absorbable, PDS 2-0 large-bites, continuous			6	IH, FD, SSI	Ultrasound
Modified Smead-Jones	Aghara	2020	RCT	100 (50/50)	m	Emergency	Modified Smead-Jones technique, polypropylene 1	Nonabsorbable, polypropylene 1, continuous			12	IH, FD, SSI	Not specified
	Selvaraj	2022	RCT	80 (40/40)	m	Emergency	Modified Smead-Jones technique, Prolene 1	Nonabsorbable, Prolene 1, continuous			6	IH, FD, SSI	Not specified
Hughes abdominal wall closure	Rajasekaran	2017	RCT	100 (50/50)	m	Both	Hughes technique	Nonabsorbable, continuous mass closure			12	IH, FD, and SSI combined	CT
	HART	2022	RCT	802 (401/401)	m	Elective	Hughes technique	Individual surgeons' preferred mass			24	IH, FD, adverse surgical events (including SSI)	Clinical examination and CT

CT indicates computed tomography; m, midline incision; o, oblique incision; p, paramedian incision; PCS, prospective cohort study; SL, suture length; t, transverse incision; WL, wound length.

compared with mass closure techniques in the elective setting. In the emergency setting, the modified Smead-Jones technique and the retention-line suture technique seem promising techniques, but the body of evidence is still limited.

ACKNOWLEDGEMENTS

The authors thank Dr. S.T.G. Meertens-Gunput at the ErasmusMC University Medical Centre Medical Library for assisting them with developing their search terms and managing their search.

REFERENCES

1. Bosanquet DC, Ansell J, Abdelrahman T, et al. Systematic review and meta-regression of factors affecting midline incisional hernia rates: analysis of 14 618 patients. *PLoS One*. 2015;10:e0138745.
2. Höer J, Lawong G, Klinge U, et al. [Factors influencing the development of incisional hernia. A retrospective study of 2,983 laparotomy patients over a period of 10 years] Einflussfaktoren der Narbenhernienentstehung. Retrospektive Untersuchung an 2.983 laparotomierten Patienten über einen Zeitraum von 10 Jahren. *Chirurg*. 2002;73:474–480.
3. Jairam AP, Timmermans L, Eker HH, et al. Prevention of incisional hernia with prophylactic onlay and sublay mesh reinforcement versus primary suture only in midline laparotomies (PRIMA): 2-year follow-up of a multicentre, double-blind, randomised controlled trial. *Lancet*. 2017;390:567–576.
4. van Ramshorst GH, Eker HH, Hop WCJ, et al. Impact of incisional hernia on health-related quality of life and body image: a prospective cohort study. *Am J Surg*. 2012;204:144–150.
5. Gillion JF, Sanders D, Miserez M, et al. The economic burden of incisional ventral hernia repair: a multicentric cost analysis. *Hernia*. 2016;20:819–830.
6. Kurzer M, Kark A, Selouk S, et al. Open mesh repair of incisional hernia using a sublay technique: long-term follow-up. *World J Surg*. 2008;32:31–6; discussion 37.
7. Dixit R, Prajapati OP, Krishna A, et al. Patient-reported outcomes of laparoscopic versus robotic primary ventral and incisional hernia repair: a systematic review and meta-analysis. *Hernia*. 2023;27:245–257.
8. Itatsu K, Yokoyama Y, Sugawara G, et al. Incidence of and risk factors for incisional hernia after abdominal surgery. *Br J Surg*. 2014;101:1439–1447.
9. Collaborative H. Incisional hernia following colorectal cancer surgery according to suture technique: Hughes Abdominal Repair Randomized Trial (HART). *Br J Surg*. 2022;109:943–950.
10. Niggebrugge AHP, Trimbos JB, Hermans J, et al. Influence of abdominal-wound closure technique on complications after surgery: a randomised study. *Lancet*. 1999;353:1563–1567.
11. Henriksen NA, Deerenberg EB, Venclauskas L, et al. Meta-analysis on materials and techniques for laparotomy closure: the MATCH review. *World J Surg*. 2018;42:1666–1678.
12. Patel SV, Paskar DD, Nelson RL, et al. Closure methods for laparotomy incisions for preventing incisional hernias and other wound complications. *Cochrane Database Syst Rev*. 2017;11:CD005661.
13. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71.
14. Hollinsky C, Sandberg S, Kocijan R. Preliminary results with the reinforced tension line: a new technique for patients with ventral abdominal wall hernias. *Am J Surg*. 2007;194:234–239.
15. Dhamnaskar S, Sawarkar P, Vijayakumaran P, et al. Comparative study of efficacy of modified continuous Smead-Jones versus interrupted method of midline laparotomy fascial closure for contaminated cases. *Int Surg J*. 2016;3:1751–1756.
16. Higgins JP, Altman DG, Gøtzsche PC, et al; Cochrane Bias Methods Group. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ*. 2011;343:d5928.
17. Sterne JAC, Hernán MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *BMJ*. 2016;355:i4919.
18. Berretta R, Rolla M, Patrelli TS, et al. Randomised prospective study of abdominal wall closure in patients with gynaecological cancer. *Aust N Z J Obstet Gynaecol*. 2010;50:391–396.
19. Hsiao WC, Young KC, Wang ST, et al. Incisional hernia after laparotomy: prospective randomized comparison between early-absorbable and late-absorbable suture materials. *World J Surg*. 2000;24:747–51; discussion 752.
20. Ohira G, Kawahira H, Miyauchi H, et al. Synthetic polyglycomer short-term absorbable sutures vs. polydioxanone long-term absorbable sutures for preventing incisional hernia and wound dehiscence after abdominal wall closure: a comparative randomized study of patients treated for gastric or colon cancer. *Surg Today*. 2015;45:841–845.
21. Polychronidis G, Rahbari NN, Bruckner T, et al. Continuous versus interrupted abdominal wall closure after emergency midline laparotomy: CONTINT: a randomized controlled trial. *World J Emerg Surg*. 2023;18:51.
22. Seiler CM, Bruckner T, Diener MK, et al. Interrupted or continuous slowly absorbable sutures for closure of primary elective midline abdominal incisions: a multicenter randomized trial (INSECT: ISRCTN24023541). *Ann Surg*. 2009;249:576–582.
23. Wissing J, Van Vroonhoven TJ, Schattenkerk ME. Fascia closure after midline laparotomy: results of a randomized trial. *Br J Surg*. 1987;74:738–741.
24. Cameron AEP, Parker CJ, Field ES, et al. A randomised comparison of polydioxanone (PDS®) and polypropylene (Prolene®) for abdominal wound closure. *Ann R Coll Surg Engl*. 1987;69:113–115.
25. Aagja J, Khare P, Sadhu D, et al. An observational study of outcome of the absorbable suture and non-absorbable suture in laparotomy wound closure in tertiary care hospital in South Gujrat. *Int J Toxicol Pharmacol Res*. 2022;12:25–30.
26. Askew AR. A comparison of upper abdominal wound closure with monofilament nylon and polyglycolic acid. *Aust N Z J Surg*. 1983;53:353–356.
27. Bloemen A, Van Dooren P, Huizinga BF, et al. Randomized clinical trial comparing polypropylene or polydioxanone for midline abdominal wall closure. *Br J Surg*. 2011;98:633–639.
28. Brolin RE. Prospective, randomized evaluation of midline fascial closure in gastric bariatric operations. *Am J Surg*. 1996;172:328–331.
29. Bucknall TE, Cox PJ, Ellis H. Burst abdomen and incisional hernia: a prospective study of 1129 major laparotomies. *Br Med J (Clin Res Ed)*. 1982;284:931–933.
30. Cameron AEP, Gray RCF, Talbot RW, et al. Abdominal wound closure: a trial of Prolene and Dexon. *Br J Surg*. 1980;67:487–488.
31. Carlson MA, Condon RE. Polyglyconate (Maxon®) versus nylon suture in midline abdominal incision closure: a prospective randomized trial. *Am Surg*. 1995;61:980–983.
32. Colombo M, Maggioni A, Parma G, et al. A randomized comparison of continuous versus interrupted mass closure of midline incisions in patients with gynecologic cancer. *Obstet Gynecol*. 1997;89(5 I):684–689.
33. Corman ML, Veidenheimer MC, Coller JA. Controlled clinical trial of three suture materials for abdominal wall closure after bowl operations. *Am J Surg*. 1981;141:510–513.
34. Deitel M, Alhindawi R, Yamen M, et al. Dexon plus versus Maxon fascial closure in morbid obesity: a prospective randomized comparison. *Can J Surg*. 1990;33:302–304.
35. Docobo-Durantez F, Sacristán-Pérez C, Flor-Civera B, et al. Randomized clinical study of polydioxanone and nylon sutures for laparotomy clousure in high-risk patients. *Cir Esp*. 2006;79:305–309.
36. Gaikwad V, Kapoor R, Thambudorai R. An ideal suture for midline abdominal closure? *Indian J Surg*. 2009;71:128–132.
37. Irvin TT, Koffman CG, Duthie HL. Layer closure of laparotomy wounds with absorbable and non absorbable suture materials. *Br J Surg*. 1976;63:793–796.
38. Israelsson LA, Jonsson T. Closure of midline laparotomy incisions with polydioxanone and nylon: The importance of suture technique. *Br J Surg*. 1994;81:1606–1608.
39. Krukowski ZH, Cusick EL, Engeset J, et al. Polydioxanone or polypropylene for closure of midline abdominal incisions: a prospective comparative clinical trial. *Br J Surg*. 1987;74:828–830.
40. Leaper DJ, Allan A, May RE, et al. Abdominal wound closure: A controlled trial of polyamide (Nylon) and polydioxanone suture (PDS). *Ann R Coll Surg Engl*. 1985;67:273–275.
41. Lewis RT, Wiegand FM. Natural history of vertical abdominal parietal closure: Prolene versus Dexon. *Can J Surg*. 1989;32:196–200.
42. OrrJWJr, Montz FJ, Barter J, et al. Continuous abdominal fascial closure: a randomized controlled trial of poly(L-lactide/glycolide). *Gynecol Oncol*. 2003;90:342–347.
43. Osther PJ, Gjøde P, Mortensen BB, et al. Randomized comparison of polyglycolic acid and polyglyconate sutures for abdominal fascial closure after laparotomy in patients with suspected impaired wound healing. *Br J Surg*. 1995;82:1080–1082.

44. Pollock AV, Greenall MJ, Evans M. Single-layer mass closure of major laparotomies by continuous suturing. *J R Soc Med*. 1979;72:889–893.
45. Richards PC, Balch CM, Aldrete JS. Abdominal wound closure. A randomized prospective study of 571 patients comparing continuous vs. interrupted suture techniques. *Ann Surg*. 1983;197:238–243.
46. Sahlin S, Ahlberg J, Granstrom L, et al. Monofilament versus multifilament absorbable sutures for abdominal closure. *Br J Surg*. 1993;80:322–324.
47. Talpur AA, Awan MS, Surhio AR. Closure of elective abdominal incisions with monofilament, non-absorbable suture material versus polyfilament absorbable suture material. *J Ayub Med Coll Abbottabad*. 2011;23:51–54.
48. Trimbos JB, Smit IB, Holm JP, et al. A randomized clinical trial comparing two methods of fascia closure following midline laparotomy. *Arch Surg*. 1992;127:1232–1234.
49. Zhang J, Zhang HK, Zhu HY, et al. Mass continuous suture versus layered interrupted suture in transverse abdominal incision closure after liver resection. *World J Surg*. 2016;40:2237–2244.
50. Ausobsky JR, Evans M, Pollock AV. Does mass closure of midline laparotomies stand the test of time? A random control clinical trial. *Ann R Coll Surg Engl*. 1985;67:159–161.
51. Chalya PL, Massinde AN, Kihunrwa A, et al. Abdominal fascia closure following elective midline laparotomy: a surgical experience at a tertiary care hospital in Tanzania. *BMC Res Notes*. 2015;8:281.
52. Lozada-Hernández EE, Mayagoitía-González JC, Smolinski-Kurek RL, et al. Prevention of incisional hernia with a reinforced tension line (RTL) versus primary suture only in midline laparotomies: 3-year follow-up in a randomized clinical trial. *Hernia*. 2022;26:447–456.
53. Orr JW, Jr, Orr PF, Barrett JM, et al. Continuous or interrupted fascial closure: a prospective evaluation of No. 1 Maxon suture in 402 gynecologic procedures. *Am J Obstet Gynecol*. 1990;163(5 Pt 1):1485–1489.
54. Peponis T, Bohnen JD, Muse S, et al. Interrupted versus continuous fascial closure in patients undergoing emergent laparotomy: a randomized controlled trial. *J Trauma Acute Care Surg*. 2018;85:459–465.
55. Karwasara RK, Dalal S, Bakshi V. Comparison of continuous versus interrupted abdominal fascia closure in patients of perforation peritonitis using polydioxanone (PDS) suture: a prospective study of 50 cases. *IJARESM*. 2016;4:9–13.
56. Deerenberg EB, Harlaar JJ, Steyerberg EW, et al. Small bites versus large bites for closure of abdominal midline incisions (STITCH): a double-blind, multicentre, randomised controlled trial. *Lancet*. 2015;386:1254–1260.
57. Fortelny RH, Andrade D, Schirren M, et al. Effects of the short stitch technique for midline abdominal closure on incisional hernia (ESTOIH): randomized clinical trial. *Br J Surg*. 2022;109:839–845.
58. Millbourn D, Cengiz Y, Israelsson LA. Effect of stitch length on wound complications after closure of midline incisions: a randomized controlled trial. *Arch Surg*. 2009;144:1056–1059.
59. Mustaqrasool TM, Dikshit B, Phalgune D. Comparison of efficacy of large tissue bites versus small tissue bites for midline abdominal wound closure. *Int Surg J*. 2020;7:455–458.
60. Probst P, Tran DTA, Hüttner FJ, et al. Randomised-controlled feasibility trial on abdominal wall closure techniques in patients undergoing relaparotomy (ReLap study; DRKS00013001). *Langenbecks Arch Surg*. 2020;405:427–434.
61. Fortelny RH, Hofmann A, Baumann P, et al. Three-year follow-up analysis of the short-stitch versus long-stitch technique for elective midline abdominal closure randomized-controlled (ESTOIH) trial. *Hernia*. 2024;28:1283–1291.
62. Cordova-Velazquez CA, Rodriguez-Espino EJ, Martin-Bufajer JM, et al. [Results of abdominal wall closure using the 4:1 suture/wound lenght technique]. *Rev Med Inst Mex Seguro Soc*. 2023;61:289–294.
63. Valverde S, Sanchez Garcia JL, Pereira JA, et al. Elective and emergent laparotomy closure: the importance of protocolizing the technique. *Cir Esp (Engl Ed)*. 2019;97:97–102.
64. Ghai GS, Harish H. A comparison of a small-stitch closure with a standard closure in midline laparotomy incisions: a prospective comparative study. *Cureus*. 2023;15:e50035.
65. Albertsmeier M, Hofmann A, Baumann P, et al. Effects of the short-stitch technique for midline abdominal closure: short-term results from the randomised-controlled ESTOIH trial. *Hernia*. 2022;26:87–95.
66. Rajasekaran C, Vijaykumar K, Arulkumaran M, et al. A randomized controlled study to compare the efficacy of Hughes abdominal repair with conventional abdominal closure-to reduce the incidence of incisional hernias in Indian population. *Int Surg J*. 2017;4:2291–2293.
67. Velnar T, Bailey T, Smrkolj V. The wound healing process: an overview of the cellular and molecular mechanisms. *J Int Med Res*. 2009;37:1528–1542.
68. Bourne RB, Bitar H, Andreae PR, et al. In-vivo comparison of four absorbable sutures: Vicryl, Dexon Plus, Maxon and PDS. *Can J Surg*. 1988;31:43–45.
69. Lau FH, Pomahac B. Wound healing in acutely injured fascia. *Wound Repair Regen*. 2014;22(Suppl 1):14–17.
70. Yii E, Onggo J, Yii MK. Small bite versus large bite stitching technique for midline laparotomy wound closure: a systematic review and meta-analysis. *Asian J Surg*. 2023;46:4719–4726.
71. Lozada Hernández EE, Hernández Bonilla JP, Hinojosa Ugarte D, et al. Abdominal wound dehiscence and incisional hernia prevention in midline laparotomy: a systematic review and network meta-analysis. *Langenbecks Arch Surg*. 2023;408:268.
72. Agrawal CS, Tiwari P, Mishra S, et al. Interrupted abdominal closure prevents burst: randomized controlled trial comparing interrupted-x and conventional continuous closures in surgical and gynecological patients. *Indian J Surg*. 2014;76:270–276.
73. Metawee AK, Abdelhamid HF, Aldarder AAK. Comparison between conventional and modified Smead Jones method for abdominal mass closure in emergency midline laparotomy. *Int J Health Sci (Egypt)*. 2023;1:96–104.
74. Papadopoulos A, Machairas N, Tsourouflis G, et al. Risk factors for surgical site infections in patients undergoing emergency surgery: a single-centre experience. *In Vivo*. 2021;35:3569–3574.
75. Tolstrup MB, Watt SK, Gögenur I. Reduced rate of dehiscence after implementation of a standardized fascial closure technique in patients undergoing emergency laparotomy. *Ann Surg*. 2017;265:821–826.
76. Frassini S, Cobianchi L, Fugazzola P, et al. ECLAPTE: effective closure of LAParoTomy in emergency – 2023 World Society of Emergency Surgery guidelines for the closure of laparotomy in emergency settings. *World J Emerg Surg*. 2023;18:42.
77. World Health Organization. *Global guidelines for the prevention of surgical site infection. 2nd ed*. Geneva: World Health Organization; 2018: 2018.
78. Van den Dop LM, Sneiders D, Yurtkap Y, et al. Prevention of incisional hernia with prophylactic onlay and sublay mesh reinforcement vs. primary suture only in midline laparotomies (PRIMA): long-term outcomes of a multicentre, double-blind, randomised controlled trial. *Lancet Reg Health Eur*. 2023;36:100787.