SURGERY

VACUUM-ASSISTED LAPAROSTOMY IN SEVERE ABDOMINAL TRAUMA AND URGENT ABDOMINAL PATHOLOGY WITH COMPARTMENT SYNDROME, PERITONITIS AND SEPSIS: COMPARISON WITH OTHER OPTIONS FOR MULTISTAGE SURGICAL TREATMENT (SYSTEMATIC REVIEW AND META-ANALYSIS)

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ABSTRACT

Background. *The concept of multistage surgical treatment of patients has been established in surgery rather recently and therefore the discussions on the expediency of using a particular surgical technique in a specific situation still continue. Vacuum-assisted laparostomy is being widely implemented into clinical practice for the treatment of abdominal compartment syndrome, severe peritonitis and abdominal trauma, but the indications and advantages of this method are not clearly defined yet.*

The aim. *To conduct a systematic review and meta-analysis on the comparison of the effectiveness of vacuum-assisted laparostomy with various variants of relaparotomy and laparostomy without negative pressure therapy in the treatment of patients with urgent abdominal pathology and abdominal trauma complicated by widespread peritonitis, sepsis or compartment syndrome.*

Material and methods. *A systematic literature search was conducted in accordance with the recommendations of Preferred Reporting Items for Systematic Reviews and Meta-Analyses. We carried out the analysis of non-randomized (since January 2007 until August 6, 2022) and randomized (without time limits for the start of the study and until August 6, 2022) studies from the electronic databases eLibrary, PubMed, Cochrane Library, Science Direct, Google Scholar Search, Mendeley.*

Results. *Vacuum-assisted laparostomy causes statistically significant shortening of the time of treatment of patients in the ICU and in hospital and a decrease in postoperative mortality compared to other variants of laparostomy without vacuum assistance.*

Conclusion. *To obtain data of a higher level of evidence and higher grade of recommendations, it is necessary to further conduct systematic reviews and meta-analyses based on randomized clinical studies.*

Key words: *vacuum-assisted laparostomy, laparostomy, vacuum therapy, negative pressure therapy, open abdomen, on-demand relaparotomy, planned relaparotomy, abdominal compartment syndrome*

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ВАКУУМ-АССИСТИРОВАННАЯ ЛАПАРОСТОМИЯ ПРИ ТЯЖЁЛОЙ ТРАВМЕ ЖИВОТА И УРГЕНТНОЙ АБДОМИНАЛЬНОЙ ПАТОЛОГИИ С КОМПАРТМЕНТ-СИНДРОМОМ, ПЕРИТОНИТОМ И СЕПСИСОМ: СРАВНИТЕЛЬНЫЕ АСПЕКТЫ С ДРУГИМИ ВАРИАНТАМИ МНОГОЭТАПНОГО ХИРУРГИЧЕСКОГО ЛЕЧЕНИЯ (СИСТЕМАТИЧЕСКИЙ ОБЗОР И МЕТААНАЛИЗ)

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РЕЗЮМЕ

Обоснование. *Концепция многоэтапного хирургического лечения больных утвердилась в хирургии относительно недавно, поэтому продолжаются дискуссии о целесообразности использования той или иной методики в конкретной ситуации. В клиническую практику лечения абдоминального компартмент-синдрома, тяжёлого перитонита и травмы живота всё шире внедряется вакуум-ассистированная лапаростомия, но пока недостаточно чётко определены показания и преимущества данного метода.*

Цель исследования. *Проведение систематического обзора и метаанализа по сравнительной оценке эффективности вакуум-ассистированной лапаростомии с различными вариантами релапаротомий и лапаростомий без терапии отрицательным давлением при лечении пациентов с ургентной абдоминальной патологией и повреждениями живота, осложнёнными распространённым перитонитом, сепсисом или компартмент-синдромом.*

Материал и методы. *Систематический поиск литературы проведён в соответствии с рекомендациями Preferred Reporting Items for Systematic Reviews and Meta-Analyses. Произведён анализ нерандомизированных (с января 2007 г. по 6 августа 2022 г.) и рандомизированных (без временных ограничений начала исследования по 6 августа 2022 г.) исследований из электронных баз eLibrary, PubMed, Cochrane Library, Science Direct, Google Scholar Search, Mendeley.*

Результаты. *Вакуум-ассистированная лапаростомия приводит к статистически значимому сокращению сроков нахождения пациентов в отделении реанимации и интенсивной терапии и в стационаре, снижению послеоперационной летальности в сравнении с другими вариантами лапаростомий без вакуума.*

Заключение. *Для получения данных более высокого уровня достоверности доказательств и убедительности рекомендаций необходимо дальнейшее проведение систематических обзоров и метаанализов на основе рандомизированных клинических исследований.*

Ключевые слова: *вакуум-ассистированная лапаростомия, лапаростомия, вакуумная терапия, терапия отрицательным давлением, «открытый живот», релапаротомия «по требованию», программированная релапаротомия, синдром интраабдоминальной гипертензии, абдоминальный компартмент-синдром*

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INTRODUCTION

"When does a surgeon who is not a novice worry?
Not at the time of surgeries...
The worries of the surgeon begin after surgery,
when for some reason a high fever persists
or the abdomen does not subside, and now, on the tail of the missed time,
one must mentally cut open, see and understand
how to correct the mistake without using a knife.
It's useless to blame a postoperative complication
on a random side cause."
A.I. Solzhenitsyn, 1967

One of the most difficult problems of surgery remains the treatment of abdominal pyoinflammatory diseases and complications. In the structure of surgical morbidity, peritonitis and its destructive lesions of the abdominal cavity are among the most important [1]. The number of patients with infected forms of pancreatic necrosis, gastrointestinal perforation, traumatic injuries of the abdominal cavity and retroperitoneum, widespread peritonitis of various etiologies increase [1]. At the same time the mortality rate does not have any tendency to decrease and ranges from 19 to 70 **%** with the development of septic shock [1–6].

Saving the patient's life in these cases depends on timely diagnosis and effective surgical intervention. In extremely severe and hemodynamically unstable patients with widespread peritonitis, abdominal trauma in the presence of compartment syndrome, peritonitis, sepsis, there are currently three methods of multistage surgical treatment after primary laparotomy within the framework of *source control* and *damage control* strategies [1, 7–13]:

- on-demand relaparotomy (emergency);
- programmed relaparotomies (planned);
- various variants of laparostomy ("open abdomen" technique).

Current knowledge confirms the concept according to which on-demand relaparotomy performed with clinical deterioration of the patient's condition or lack of improvement is an effective measure to eliminate permanent or repeated infection of the abdominal cavity [1, 12, 14]. When comparing the results of treatment of patients with "open abdomen" and on-demand relaparotomy in a randomized clinical trial by F.A. Robledo et al. (2007) [15], the mortality was significantly higher in the group of patients with open abdominal management – 55 **%** versus 30 **%**, respectively, but no statistical significance of differences was obtained (cit. according to [12]). In a randomized study of O. van Ruler et al. (2007) [16], advantages of on-demand relaparotomy over planned lavages were shown in terms of reducing the cost of patient treatment, the duration of hospital stay, and the duration of the recovery period, but also no statistically significant difference in mortality was obtained (cit. according to [7, 12, 17]). Difficulties of timely diagnosis of postoperative intraabdominal complications and the resulting delays in repeated intervention determine still high frequency of poor treatment results when choosing a closed abdominal management method [1, 2, 4, 7, 12]. Most of the currently existing integral scales (scores) for assessing the severity of peritonitis and abdominal sepsis are not effective for determining indications for emergency relaparotomy [4].

Programmed relaparotomy is used when it is impossible to eliminate or reliably delimit the source of widespread fibrinous-purulent or fecal peritonitis and complete lavage of the abdominal cavity in a patient with septic shock, in the presence of intra-abdominal hypertension syndromes (IAHS; syn. abdominal compartment syndrome) and intestinal, doubts about the viability of the intestine and the need to perform a delayed intra-abdominal anastomosis [1, 2, 4, 7, 10, 12, 18]. The most obvious disadvantage of such a patient management tactic is multiple mechanical traumatization of abdominal organs during reoperations, in some cases leading to serious complications: suppuration of postoperative wounds, complete eventration, and the formation of intestinal fistulas; among patients with tertiary peritonitis, it can contribute to the progression of Multiple Organ Dysfunction Syndrome (MODS) [4, 7, 13].

The occurrance of laparostomy (*laparo* (Lat.) – abdominal wall; *stomia* (Lat.) – the operation of applying an artificial external fistula, stoma) is associated with Johann Mikulich-Radetsky, who in 1884 proposed tamponing the abdominal cavity with iodoform gauze with an untreated laparotomy wound in order to remove exudate from the abdominal cavity and delimit the purulent process [19]. This method is possible in two conditional variants – open and closed technology; using the latter, the wound of the abdominal wall is closed with temporary devices [18]. Laparostomy formation in the classic "open" option is of limited use in situations when visceral edema prevents effective closure of the abdominal cavity with its own tissues. Abdomen temporary closure is possible with the help of adhesive membranes, synthetic and biological meshes [20], vacuum (VAC, vacuum-assisted closure) therapy with negative pressure in the abdominal cavity and the laparostomy formation using negative pressure wound therapy (NPWT) [1, 7, 9, 18, 21]. VAC-laparostomy implies the mandatory presence of a protective (more often – perforated polypropylene) film, a polyurethane sponge, a sealing film, and a device for constant vacuum aspiration. Air is evacuated from the abdominal cavity through a system of tubes with a special vacuum generator, resulting in negative pressure, which accelerates the formation of granulation tissue, improves blood supply, reduces contamination of the abdominal cavity, localizes and reduces the exposure time of pathological peritoneal exudate [2, 4, 8, 12, 22–24].

Initially, VAC-laparostomy was used differently, in particular in the USA and Latin America, as well as in South-East Asia, it was indicated mainly in severe abdominal trauma, while in the UK, Germany and our country – mainly in widespread fibrinous-purulent/fecal peritonitis and sepsis [19, 25]. The advantage of this method is the elimination of IAHS, which contributes to the normalization of the respiratory, cardiovascular and nervous systems [1, 2, 7, 25, 26]. But even here discussions arise. On the one hand,

the use of NPWT solves the problem of increased intra-abdominal pressure and the development of IAHS, reduces the risk of severe abdominal sepsis in fibrinous-purulent/fecal peritonitis, leads to a decrease in mortality, the duration of hospital stay and the cost of treatment [7, 12, 23–25, 27]. Most researchers note a statistically significant improvement in the results of primary muscle-aponeurotic closure in comparison with other methods of laparostomy management [7, 12, 25]. At the same time, exposure to negative pressure can lead to ischemia of intestinal areas, development of petechial and erosive bleeding and increases the risk of intestinal fistulas [1, 4, 5, 7, 10, 12] from 5 to 20 % of observations [25, 27].

In 2015, the World Society of Emergency Surgery and the Panamerican Trauma Society initiated the creation of the International Register of Open Abdomen (IROA), and in 2017 the first results of an international study were published, according to which the VAC technique, compared with other types of laparostomy, has the lowest mortality and complications rates [9], but the risk of fistula formation is among the leaders along with the Wittmann patch (13.5 and 17.6 %, respectively), yielding the latter "leadership" [7, 28, 29].

There is a large number of studies in the modern press comparing various variants of laparostomy with vacuum therapy with each other (more recent publications), on-demand relaparotomy with programmed relaparotomy (older publications), but there are few studies comparing vacuum laparostomy with different variants of relaparotomy and laparostomy without negative pressure therapy, while these very methods remain relevant and sometimes the only possible ones in the treatment of patients with complicated widespread peritonitis, sepsis or compartment syndrome of urgent abdominal pathology and abdominal injuries.

The aim of our study was to conduct a systematic review and meta-analysis to compare the effectiveness of vacuum-assisted laparostomy with various variants of relaparotomy and laparostomy without negative pressure therapy in the treatment of patients with complicated by widespread peritonitis, sepsis or compartment syndrome of urgent abdominal pathology and abdominal injuries.

MATERIAL AND METHODS

Design and proper testing environment. A systematic literature search was conducted in accordance with the recommendations of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [30]. We carried out the analysis of non-randomized (since January 2007 until August 6, 2022) and randomized (without time limits for the start of the study and until August 6, 2022) studies from the electronic databases eLibrary, PubMed, Cochrane Library, Science Direct, Google Scholar Search, Mendeley in accordance with the recommendations of the Federal State Budgetary Institution Center for Healthcare Quality Assessment and Control of the Ministry of Health of the Russian Federation [31].

Criteria for inclusion and exclusion of original research in meta-analysis. Primary search strategy (without language restrictions): vacuum-assisted laparostomy, laparostomy, vacuum therapy, negative pressure therapy, "open abdomen", on-demand relaparotomy, programmed (planned) relaparotomy, intra-abdominal hypertension syndrome, abdominal compartment syndrome, – with subsequent exclusion from the query for experimental studies, literature reviews, clinical recommendations, case reports, non-cohort studies, incomplete articles/theses, manuscripts devoted to endoscopic (endoluminal) vacuum therapy, vacuum therapy of other localization, outside the abdominal cavity or comparing different varieties of vacuum-assisted laparostomy with each other. Additionally, we searched for articles from the references of the selected studies for sources not found during the initial search; the tables of contents of specialized journals were analyzed. Data extraction was performed independently by three researchers. Any disagreement regarding study selection was resolved by consensus.

The methodological quality of non-randomized studies was assessed on the Newcastle – Ottawa Scale (NOS) [31, 32]. The results of the systematic bias risk assessment were interpreted as follows:

- studies with 5 points or less (out of 9 possible) have a high risk of systematic errors [32];
- studies with 6 and 7 points – the average risk of systematic errors [32];
- studies with 8 and 9 points – low risk of systematic errors [32].

The methodological quality of randomized clinical trials was assessed according to the criteria of the current Guidelines of the Cochrane Community [33] and according to the methodology proposed by V.V. Omelyanovsky et al. (2019) [31].

Statistical data analysis was carried out using Microsoft Excel 2019 (Microsoft Corp., USA); PythonMeta software (China) was used to synthesize quantitative data.

The null hypothesis is based on the assumption that there are no differences in the treatment outcomes after vacuum-assisted laparostomy and various options of relaparotomy and laparostomy without negative pressure therapy among patients with urgent abdominal pathology and abdominal injuries complicated by widespread peritonitis, sepsis or compartment syndrome.

Statistical heterogeneity was assessed using the heterogeneity index I^2. If no significant heterogeneity was detected ($I^2 \leq 40$ %), then a fixed effect model (Mantel – Hansel method) was used to generalize the results [33]. Otherwise, a random effects model was used. The statistical significance of the findings was confirmed by the determination of a 95% confidence interval (95% CI) (if the level of statistical significance is $p < 0.05$, then the differences are statistically significant) [33].

To quantify the influence of various dichotomous parameters on the outcome of the event under study, the odds ratio (OR) was determined in retrospective studies, the relative risk (RR) was determined in randomized clinical trials (RCTs), prospective and combined stud-

ies [33]. Differences in treatment outcomes of different groups of patients were taken into account only for odds and relative risk ratio values other than 1. If the confidence interval for OR/RR included 1, then there was no statistically significant difference in the studied groups [33]. The values of OR/RR > 1 show that the reviewed surgical intervention among patients of the main group increased the probability of occurrence of the reviewed event compared with the control. If the calculated value of OR/RR is < 1, the reviewed intervention reduces the probability of occurrence of the reviewed event in comparison with the control [33].

In the meta-analysis of rates (the number of repeated surgical interventions), information about the rates of the phenomenon under study was summarized by determining rate ratios, which are determined by dividing the rate in the main intervention group by the rate in the control group [33].

The analysis of continuous data (the average duration of inpatient treatment, the average duration of surgical treatment, etc.) was performed using information about the mean values, their standard deviation in each of the comparison groups and the total number of patients in the corresponding comparison groups [33]. Summary statistics for continuous data were evaluated by the standard mean difference (SMD) using Hedges'g [33]. The value of SMD ≤ 0.40 corresponds to a small, SMD from 0.40 to 0.70 – moderate, SMD > 0.70 – a large effect value [33].

A qualitative assessment of the ***systematic publication error*** was carried out using a funnel plot. The asymmetry of the plot indicated a systematic publication error [33].

Study outcomes. Analysis in subgroups. Results

The stages of the evidence base search are presented in the PRISMA flowchart (Fig. 1). As a result, 33 studies were included in the systematic review (including 1 RCT, 5 prospective studies, 1 combined (pro- and retrospective) study, 5 prospective cohort studies, 2 combined cohort studies, 9 retrospective studies, 4 retrospective cohort studies, 1 case-series study, 5 descriptions of clinical cases). All cohort studies (12), including 1 RCT, are included in the meta-analysis.

SYSTEMATIC REVIEW

D. Perez et al. (2007) [34] prospectively analyzed the treatment outcomes of 37 patients with vacuum-assisted laparostomy performed with widespread perito-

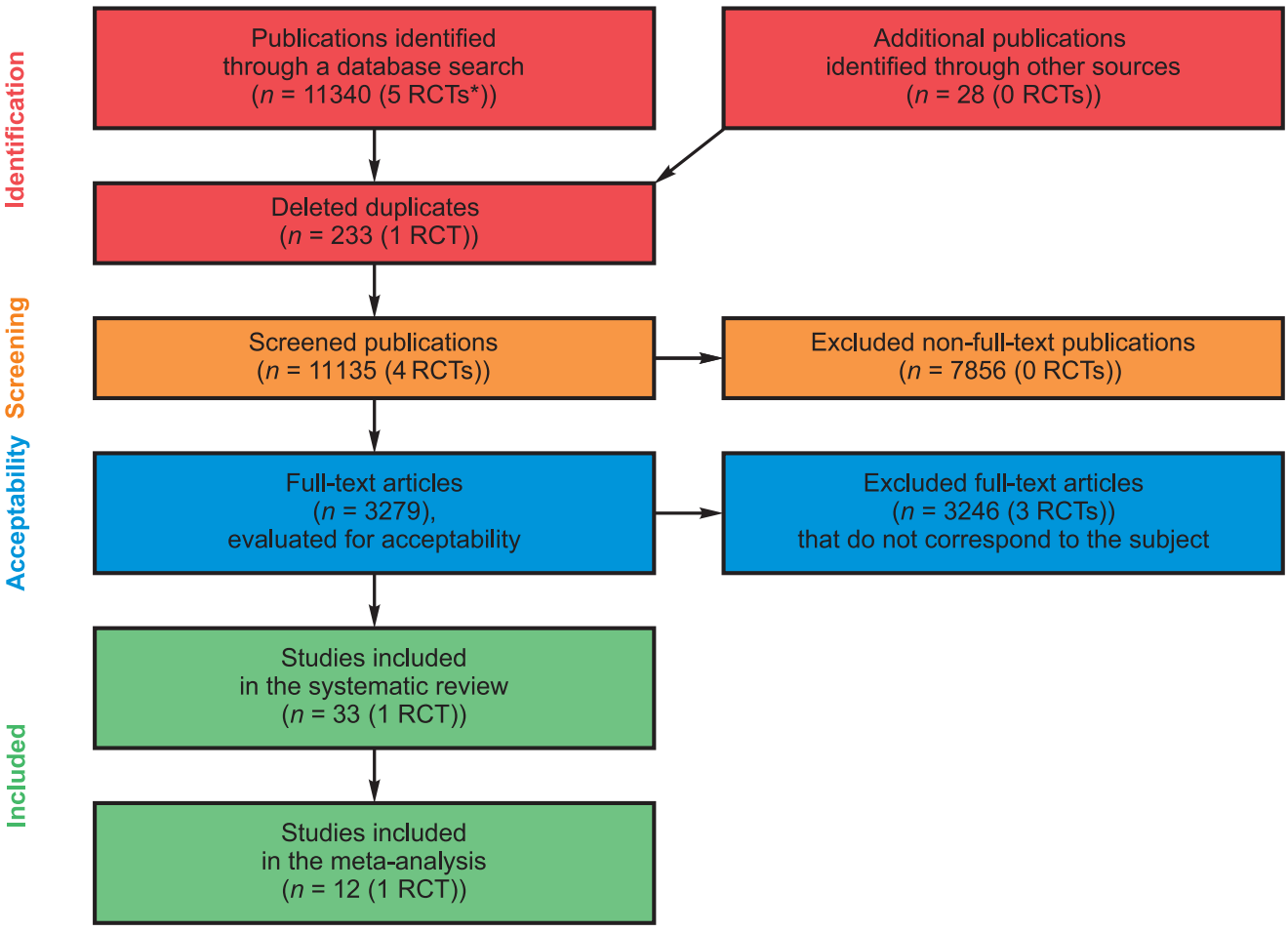

FIG. 1.
Stages of selection of the evidence base

nitis with severe abdominal sepsis (Mannheim peritonitis Index (MPI) > 29–21 (57 %) patient and/or IAHS – 16 (43 %) patients). These were critical patients (the SOFA (sequential organ failure assessment) score was 8.7 (7.2 to 11.5)); mortality was 65 % (24 patients: 14 died during the use of VAC-laparostomy, the rest – within 3 months after abdominal cavity closure). The average time spent in the intensive care unit (ICU) was 20.4 (12.3–35.2) days, while the duration of artificial lung ventilation (ALV) was 18.9 (12.6–29.9) days. The average duration of laparostomy was 22.7 (3–122) days with 3.8 intra-abdominal component replacements per patient (1–22 replacements). Complete closure of the fascia was achieved in 26 (70 %) patients [34].

M. Rao et al. (2007) [35] evaluated results of VAC-laparostomy in 29 patients; 10 (34.5 %) died; the average duration of vacuum therapy was 26 days (2–68 days range); the average stay in the ICU was 10.5 days (3–36 days range), 6 (20.7 %) patients developed intestinal fistulas with an average duration of 20 (2–50) days from the beginning of negative pressure therapy.

D.E. Barker et al. (2007) [36] retrospectively on 258 patients with vacuum-assisted laparostomy (116 patients with abdominal trauma, 120 patients with abdominal surgical pathology, 22 patients with vascular abdominal pathology) showed the following results. The length of hospital stay varied from 1 to 290 days (an average of 32 days); mortality was 26 % (67 patients); the average number of vacuum systems used per patient was 2.77 (planned relaparotomies were performed in 85 (59.9 %) patients with abdominal surgical and vascular pathology and in 27 (23.3 %) patients with abdominal trauma ($p < 0.05$; Pearson's χ^2)). Abdominal closure was successful among 226 (87.6 %) patients (without statistically significant differences in the three patient groups; primary muscular-aponeurotic closure was more frequently performed among patients who did not require intra-abdominal component replacement (89.4 % vs. 53.9 %; $p < 0.05$; Pearson's χ^2). The following complications were obtained in the groups of patients with abdominal trauma, abdominal surgical pathology and vascular abdominal pathology, respectively: enterocutaneous fistulas – 4 (3,4 %), 8 (6,7 %) and 1 (4.5 %), respectively; intra-abdominal abscesses – 5 (4,3 %), 4 (3,3 %) and 0 (0 %), respectively; intestinal obstruction – 1 (0,86 %), 1 (0,83 %) and 1 (4.5 %), respectively; IAHS – 1 (0,86 %), 1 (0,83 %) and 1 (4.5 %), respectively; evisceration – 1 (0,86 %), 0 (0 %) and 0 (0 %), respectively.

D. Wondberg et al. (2008) [37] conducted a prospective analysis of the treatment of 30 patients with abdominal sepsis who underwent vacuum-assisted laparostomy from 2004 to 2007. The mortality rate was 30 % (9/30); in 53 % of cases (16/30) it was impossible to perform muscular-aponeurotic closure, and 5 patients died before the conditions for laparostomy closure appeared; in 2 cases intestinal fistulas developed (6.66 %) [37]. The average number of intra-abdominal component replacements was 3 (1–10); the average duration of stay in the ICU was 7 (1–40), in hospital – 50 (18–101) [37]. The authors conclude that the use of this technique allows to achieve good results in this cohort of patients [37].

A.I. Amin et al. (2009) [17] with the help of 20 patients with VAC-laparostomy and the APACHE II Score of 16.7 ± 1.0 points (suspected hospital mortality – 37.2 ± 5.25 %) prospectively showed that primary closure was achieved in 15 (75 %) patients for 4.53 ± 1.64 days, mortality was 0 %, duration of stay in ICU – 19.8 ± 4.48 days, intestinal fistulas developed in 2 (10 %) patients.

J. Horwood et al. (2009) [38] studied 27 patients with VAC-laparostomy (the average ASA (American Society of Anesthesiologists) score – 3.75) and prospectively showed that the mortality rate was 37 % (10/27), and this is statistically significantly less than the suspected mortality as per the P-POSSUM scale, widely used in the UK; the average number of relaparotomies and intra-abdominal component replacements – 4, 2 (out of 17 survivors; 11.7 %) patients developed enterocutaneous fistulas, and for 5 (29.4 %) patients a delayed abdominal closure was performed. The authors state that vacuum-assisted laparostomy is associated with fewer complications and lower mortality among patients with IAHS and peritonitis [10, 38].

L. López-Quintero et al. (2010) [39] conducted a retrospective study of 19 patients with abdominal sepsis who underwent VAC-laparostomy: the average stay of patients in the ICU was 5.2 days (2–9 days range, ± 2), in hospital – 24.7 days (10–45 days range, ± 9.6), mortality was 26.3 % (5 patients), the average duration of vacuum therapy – 12.7 days (5–33 days range, ± 8.2), the average number of intra-abdominal component replacements – 3.9 (2–6 replacements range, ± 1.1). Among the survivors, the final closure of the abdominal cavity was achieved in 100 % of cases with half of them within 23 days; the incidence of enterocutaneous fistulas was 26.3 % (5 patients), acute intestinal obstruction (AIO) – 21 % (4 patients), postoperative hernias – 50 % (7 patients).

M. Schmelzle et al. (2010) [5] when retrospectively analyzing treatment results of 49 patients with secondary peritonitis (with an average value of MPI of 28 (10–44)) in Germany, who underwent "open abdomen" vacuum drainage for more than 7 days with negative pressure of 75–125 mm Hg, the following results were obtained: the average duration of stay in the ICU was 40 (0-197) days in hospital – 84 (14–197) days; 20 patients died (mortality – 40.8 %, and non-fecal peritonitis at the first relaparotomy was an independent prognostic factor for greater survival; $p = 0.031$), with VAC-laparostomy over 7 days, the possibility of delayed muscular-aponeurotic closure was 22.4 % (11 patients) [5]. The average number of relaparotomies was 4.9 (2–14), and 0.9 (0–5) after vacuum application [5]. The incidence of enterocutaneous fistula formation was 22.4 % (11 patients; 4 of them had multiple fistulas); performing relaparotomy after vacuuming statistically significantly increased the risk of this complication ($p < 0.001$) and reduced the possibility of successful muscular-aponeurotic closure of the abdominal cavity ($p = 0.033$) [5]. The authors emphasize that it is necessary to strive for earlier closure of the abdominal cavity, if possible, to re-

duce the likelihood of complications; at the same time, the risk of fistulas is associated not so much with the duration of vacuum therapy as with the number of repeated interventions [5].

R. Kafka-Ritsch et al. (2012) [40] conducted a retrospective study of 160 patients, most of whom (78 %) had signs of abdominal sepsis (median MPI – 25 (5–43)). The mortality rate was 20.6 % (33 patients). Factors increasing mortality were MPI > 25 (17 vs. 9 %; $p = 0.05$), extended volume of surgical intervention and male gender [40]. Delayed abdominal closure was achieved in 76 % of cases (121 patients); a single-factor analysis showed that the frequency of delayed closure was higher among women (86 vs. 69 %; $p = 0.04$) and among patients with limited primary surgery (e. g., resection of a section of the intestine without reconstruction) (93 vs. 62 %; $p = 0.00$) and lower among patients with relaparotomies (65 vs. 83 %; $p = 0.01$), when vacuum treatment lasted more than 5 days (67 vs. 81 %; $p = 0.04$), among patients with "open abdomen" according to M. Bjork classification type 3 or 4 (39 vs. 80 %; $p = 0.002$), among patients with pre-existing or formed fistulas during laparostomy (30 vs. 79 %; $p = 0.001$), as well as among patients with pancreatitis or pancreatic fistula (33 %; $p = 0.01$) [40]. Abscesses occurred among 13 (8 %) patients, 31 (19 %) – infections of the surgical site, enterocutaneous fistulas – 5 (3 %) patients [40].

L. Pérez Domínguez et al. (2012) [41] retrospectively analyzed the results of the use of VAC-laparostomy for 23 patients with secondary peritonitis; the number of abdominal set replacements averaged 3.1 (1–7 range), while the average duration of vacuum treatment was 14.8 (2–43) days before laparotomy wound closure; primary closure was achieved in 18 of 21 patients (85.7 %). The average duration of hospital stay was 110.1 (8–163) days, the mortality rate was 26 % (6 patients) [41]. Complications occurred in 7 (30.4 %) cases: in 3 (13 %) – intra-abdominal abscesses, in 4 (17.4 %) – enterocutaneous fistulas, in 1 (4.3 %) – evisceration [41]. The authors state that vacuum laparostomy is easy to use with an acceptable level of complications, and its wider use should be expected in the future [41].

V.N. Obolensky et al. (2013) [25] described a clinical case of successful treatment of a 35-year-old patient with duodenal ulcer bleeding, in whom, associated with the relapse and ineffectiveness of endohemostasis, the surgery revealed penetration of the ulcer into the head of the pancreas with bleeding from the gland vessels and with the formation of an inflammatory infiltrate involving the hepatic-duodenal ligament, common bile duct, and gallbladder. 2/3 gastric resection with gastroenteroanastomosis according to Hofmeister – Finsterer, cholecystectomy, lavage and drainage of the abdominal cavity were performed [25]. On the 5th day, due to negative dynamics, a relaparotomy was performed, pancreatic head necrosis and enzymatic peritonitis were revealed; duodenal stump and gastroenteroanastomosis were consistent; the abdominal cavity was lavaged and drained with skin suturing [25]. In 4 days, a programmed lavage relaparotomy was performed, and positive dynamics was noted; the abdominal cavity was lavaged and drained with skin suturing [25]. But in another 6 days, bile began to flow from the postoperative wound, and a relaparotomy was performed; ongoing peritonitis and bile leakage from the stump of the cystic duct were detected, where the Tachocomb sponge was fixed; a vacuum-assisted laparostomy was carried out, after which the patient's condition stabilized, and on the 4th day after the vacuum was placed, peritonitis was eliminated, and the wound was sutured completely [25].

H.T. Hougaard et al. (2014) [42] conducted a retrospective analysis of the use of the VAC Abdominal Dressing System with ABThera continuous dosed muscular-aponeurotic traction system in 115 patients, the average frequency of intra-abdominal component replacement was 4 (1–36), the average duration of vacuum use before laparostomy closure was 7 (1–75) days, delayed muscular-aponeurotic closure was achieved in 92 % of cases (106/115), mortality was 17 % (20/115), and the frequency of intestinal fistula was 3.5 % (4/115).

P.V. Polenok (2016) [22] presented an original technique of temporary abdominal cavity closure using a negative pressure system and applied it in 5 patients with secondary peritonitis and severity of condition as per the APACHE II Scale of 18–24 points; intra-abdominal pressure level in 4 out of 5 cases exceeded 15 mm wg at the end of the first laparotomy. The number of laparotomies among 3 patients was 4, among 2 patients – 5 [22]. By the time of laparostomy elimination, all patients had a satisfactory condition of the anterior abdominal wall tissues, no signs of suppuration and devitalization of tissues, which allowed to complete the last relaparotomy by layer-by-layer suturing of tissues without tension with complete reconstruction of the anterior abdominal wall [22].

D.S. Zemlyakov et al. (2016) [2] used NPWT system – Vivano Med-Abdominal Kit in 8 patients with widespread purulent peritonitis and noted a rapid decrease in intra-abdominal pressure, relief of peritonitis, and postoperative wound cleansing. The authors consider tertiary peritonitis with progressive abdominal sepsis as indications for this method [2].

O.V. Pervova et al. (2016) [43] presented a clinical case of successful 98-day treatment of a patient with total infected pancreatic necrosis, omental abscess, retroperitoneal phlegmon, widespread enzymatic peritonitis, abdominal sepsis, who underwent laparotomy, necrosequestrectomy, autopsy and drainage of retroperitoneal phlegmon, omentobursostomy, nasointestinal intubation, lavage, drainage of the abdominal cavity, laparostomy. The first programmed relaparotomy revealed progression of a purulent-destructive process in the pancreas, retroperitoneal tissue, necrosis of the transverse and ascending colon, transition of enzymatic peritonitis into fibrinous purulent one, which required performing right-sided hemicolectomy, ileostomy during the next planned relaparotomy [43]. Subsequently, due to vacuum flow-aspiration drainage of the omental bursa and retroperitoneum, the phenomena of abdominal sepsis and MSF were eliminated [43]. The authors note the important role of nega-

tive pressure technologies for adequate lavage of the infection focus [43].

I. Mintziras et al. (2016) [26] retrospectively, for 2005–2014, analyzed the results of using vacuum-assisted laparostomy in 43 patients with secondary peritonitis, the main causes of which were anastomotic dehiscence after resection (20 patients) or failure of sutured acute intestinal perforations (17 patients). The severity as per the APACHE II Score was 11 points, the average duration of VAC-laparostomy was 12 days (3–88 range). 20 (47 %) patients died from septic complications [26]. Enterocutaneous fistulas (ECFs) occurred among 16 (37.2 %) patients, and the authors found a direct relationship in their occurrence with the frequency of repeated interventions and the duration of vacuum therapy ($p < 0.001$) [26]. During the ROC analysis, it was found that the duration of VAC therapy over 13 days with negative pressure of 100 mmHg is a risk factor for the development of ECFs (81 % sensitivity, 74 % specificity) [26]. Besides, performing at least one relaparotomy after vacuuming statistically significantly increased the risk of this complication ($p < 0.001$), while gender, patient age, the cause of secondary peritonitis, the presence of cancer, the severity of peritonitis according to MPI had no statistically significant effect on fistula formation [26].

P. Sibaja et al. (2017) [21] retrospectively obtained the following results of 48 patients with abdominal sepsis and vacuum-instillation laparostomy: primary abdominal closure was achieved in 96 % of cases ($n = 46$) within an average of 6 days, no intestinal fistulas, a mortality was 8.33 % ($n = 4$); higher aponeurosis closure rates, lower mortality and reduced duration of hospital stay compared to the Bogota bag, the Wittmann patch and VAC-laparostomy without instillations were reported (cit. according to [6]).

K.A. Anisimova et al. (2018) [44] after a triplicate failure of the formed gastric tube after laparoscopic longitudinal resection of the abdomen and two sutures in a patient with overweight and metabolic syndrome (arterial hypertension, type 2 diabetes mellitus, dyslipidemia), the NPWT system was implanted, which helped to relief peritonitis and achieve wound cleansing for secondary suturing.

D.D. Sichinava et al. (2020) [45] presented a clinical case of treatment of a patient with widespread peritonitis complicated by an unformed biliodigestive fistula using a negative pressure system, which led to the formation of an external fistula, relief of widespread peritonitis and abdominal cavity closure.

V. Müller et al. (2020) [8] in their prospective study of 39 patients (2/3 with fecal peritonitis as a result of intestinal perforation or anastomosis failure), mortality was 10 % ($n = 4$); intra-abdominal bleeding occurred in 1 patient as a result of vacuum therapy; a primary muscular-aponeurotic closure was not achieved in 11 (28 %) patients. The authors note that patients with anastomosis failure required 2 or more relaparotomies (2–9) [8].

I.B. Uvarov et al. (2021) [46] presented a clinical case of anastomosis failure on the 6th day after laparoscopic low anterior rectal resection with total mesorectumectomy, ileostomy, colorectal anastomosis with a circumferential stapler. During relaparotomy, the abdominal cavity was lavaged without anastomosis separation with the installation of intra-abdominal and pelvic negative pressure therapy systems and transanal endoluminal vacuum drainage to the anastomosis site [46]. After two planned relaparotomies, the authors noted complete relief of peritonitis [46]. The experience of using combination therapy with negative pressure in the treatment of a patient with anastomosis failure complicated by secondary widespread purulent peritonitis has given encouraging results [46].

META-ANALYSIS

The results of the meta-analysis are presented in Table 1.

T.K. Bee et al. (2008) [47] conducted a randomized clinical trial comparing two types of laparostomies: vacuum-assisted ($n = 31$) and using a vicryl mesh (polyglactin 910) ($n = 20$) without vacuum (Table 1), most of these patients were with abdominal trauma, did not receive statistically significant differences in mortality and complications, and the percentage of successful abdominal closure.

S. Batacchi et al. (2009) [9] compared a vacuum variant of laparostomy ($n = 35$) with the Bogota bag in a prospective cohort study ($n = 31$). The primary diagnoses upon admission to the hospital were abdominal/vascular pathology (36.4 %), severe trauma (33.3 %) or abdominal sepsis (30.3 %) [9]. The authors obtained statistically significant differences in favor of vacuum therapy in terms of final abdominal closure, ALV duration, ICU stay and hospitalization in general, but did not receive statistically significant differences in hospital mortality [9]. After laparostomy in the interval from 8 to 24 hours, a statistically significantly faster decrease in intra-abdominal pressure ($p < 0.01$) and blood lactate ($p < 0.001$) was observed in the vacuum group [9]. A significant relative risk (RR) of mortality was observed at the age over 70 years (RR = 2.9), with intra-abdominal pressure values above 20 mmHg before decompression (RR = 3.4), the preoperative lactate level above 8 (RR = 2.8), and the postoperative lactate level above 6 (RR = 3.2); and vice versa, SAPS II and APACHE II Scales scores were not statistically significant in predicting mortality [9].

N.Y. Patel et al. (2011) [48] conducted a retrospective cohort study with 98 patients with abdominal/vascular pathology and abdominal trauma who were initially indicated for programmed re-intervention, who already had IAHS and could not fully close the anterior abdominal wall. At the same time, statistically significantly longer periods of abdominal cavity closure, ALV and hospital stay duration were obtained in the vacuum treatment group, but there is no data on the severity of patients in the study groups, early complications and mortality [48].

I. Pliakos et al. (2012) [49] conducted a retrospective cohort study of 58 patients, 27 of whom underwent VAC-laparostomy, the rest – other types of laparostomy without vacuum; at the same time, there was no statistical-

TABLE 1

THE MAIN CHARACTERISTICS OF THE PRIMARY STUDIES INCLUDED IN THE META-ANALYSIS

Author, publication year. Design and quality of research	Basic data and research results	Compared treatment methods in studies				
		1. VAC-laparostomy (main group)	Without vacuum therapy: 2. On-demand relaparotomy (1st control group)	Without vacuum therapy: 3. Planned relaparotomy (2nd control group)	Without vacuum therapy: 4. Other types of laparostomy (3rd control group)	OR, RR, 95% CI, p
1	2	3	4	5	6	7
Uvarov I.B. et al. (2022) [3] Prospective cohort study; 6 points as per the Newcastle – Ottawa Quality Assessment Scale	Number of patients	52	78	–	–	–
	Brief description of patients (MPI, severity of the condition according to ASA, APACHE Scales, etc.)	ASA 1 –10 (19.3 %)	ASA 1 – 31 (39.7 %)	–	–	**$p = 0.037$[a]** ASA 3_1 > ASA 3_2
		ASA 2 – 28 (53.8 %)	ASA 2 – 39 (50.0 %)			
		ASA 3 –14 (26.9 %)	ASA 3 – 8 (10.3 %)			
		MPI 1 (≤ 20 points) – 0 (0 %)	MPI 1 – 20 (25.6 %)			**$p < 0.001$[a]** MPI 3_1 > MPI 3_2
		MPI 2 (21–29 points) – 19 (36,5 %)	MPI 2 – 34 (43.6 %)			
		MPI 3 (≥ 30 points) – 33 (63.5 %)	MPI 3 – 24 (30.8 %)			
		APACHE II 1 (up to 10 points) – 13 (25.0 %)	APACHE II 1 – 30 (38.5 %)			$p = 0.236$[a] APACHE II_1 > APACHE II_2
		APACHE II 2 (11–15 points) – 33 (63.5 %)	APACHE II 2 – 37 (47.4 %)			
		APACHE II 3 (16–25 points) – 6 (11.5 %)	APACHE II 3 – 11 (14.1 %)			
	Complications as per the Clavien-Dindo classification, *n* (%)	2 – 52 (100 %)	2 – 78 (100 %)	–	–	$p = 1.000$[b]
		3a – 13 (25.0 %)	3a – 47 (60.3 %)			**$p < 0.01$[b]**
		3b – 0	3b – 19 (24.4 %)			**$p < 0.001$[b]**
		4a – 5 (9.62 %)	4a – 22 (28.2 %)			**$p < 0.001$[b]**
		4b (MSF) – 3 (5,8 %)	4b – 22 (28.2 %)			**$p < 0.001$[b]**
		d (the need to continue therapy after discharge from hospital) – 2 (3.9 %)	d – 37 (47.4 %)			**$p < 0.001$[b]**

TABLE 1 (*continued*)

1	2	3	4	5	6	7
	Switching from RLT/LS without VAC to VAC-LS, *n* (%)	–	11 (7 died (63.6 %))	–	–	–
	Number of reoperations on average per patient, *n*	3	1	–	–	–
	AC final closure period, days (M ± SD)	5.5	–	–	–	–
	Relieved sepsis by the end of surgical treatment, *n/N* (%)	9/11 (81.8 %)	5/24 (20.8 %)	–	–	–
	Average duration of treatment in ICU, days (M ± SD)	9.5 ± 1.5	10.2 ± 1.4	–	–	**$p = 0/011^{c}$**
	Average duration of inpatient treatment, days (M ± SD)	30.1 ± 10.3	32.7 ± 11.9	–	–	$p = 0.97^{c}$
	Mortality, *n* (%)	3 (5.8 %)	24 (30.8 %)	–	–	**$p < 0.001^{b}$**
Mutafchiyski V. M. et al. (2016) [20] Combined (retro- and prospective) cohort study; 5 points as per the Newcastle – Ottawa Quality Assessment Scale	Number of patients	49	–	–	59	–
	Brief description of patients (MPI, severity of the condition according to ASA, APACHE Scales, etc.)	$MPI_{av.}$ – 26.4 95% CI: 24.3–28.4 $APACHE\ II_{av.}$ – 19,3 95% CI: 17.9–20.6	–	–	"Closed" laparostomy with a mesh $MPI_{av.}$ – 27.3 95% CI: 25.1-29.4 $APACHE\ II_{av.}$ – 19,9 95% CI: 18.1-21.6	$p = 0.544^{d}$ MPI $p = 0.595^{d}$ APACHE II
	Complications, *n* (%)	Wound infections – 6 (12.2 %) ECF – 4 (8.1 %) Intra-abdominal abscesses – 5 (10.2 %) Necrotizing fasciitis – 1 (2 %)	–	–	Wound infections – 7 (11.8 %) ECF – 11 (18.6 %) Intra-abdominal abscesses – 19 (32.2 %) Necrotizing fasciitis – 9 (15.2 %)	$p = 0.952^{e}$ $p = 0.108^{e}$ $p = 0.142^{e}$ **$p = 0.012^{e}$**
	Number of reoperations on average per patient, *n*	3	–	–	3	$p = 0.409^{d}$
	AC final closure period, days (M ± SD)	8.8 ± 8.8	–	–	10 ± 13.7	$p = 0.209^{d}$
	Average duration of treatment in ICU, days (M ± SD)	6.1 ± 6.31	–	–	10.6 ± 8.43	**$p = 0.002^{d}$**
	Average duration of inpatient treatment, days (M ± SD)	15.1 ± 11.85	–	–	25.9 ± 20	**$p < 0.001^{r}$**
	Mortality, *n* (%)	14 (28.57 %)	–	–	31 (52.54 %)	**$p = 0.021^{e}$**

TABLE 1 (*continued*)

1	2	3	4	5	6	7
Bleszynski M.S. et al. (2016) [14] Retrospective cohort study; 6 points as per the Newcastle – Ottawa Quality Assessment Scale	Number of patients	136	75	–	–	–
	Brief description of patients (MPI, severity of the condition according to ASA, APACHE Scales, etc.)	APACHE IV – 86 ± 23	APACHE IV – 90 ± 25	–	–	$p > 0.05$
	Number of reoperations on average per patient, *n*	4	2	–	–	–
	Average duration of treatment in ICU, days (M ± SD)	15.3 ± 16	10.2 ± 11	–	–	**$p = 0{,}006$**[e]
	Average duration of inpatient treatment, days (M ± SD)	61.8 ± 57	40.8 ± 33	–	–	**$p = 0{,}008$**[e]
	Mortality, *n* (%)	31 (22.8 %)	29 (38.7 %)	–	–	OR = 0.41 95% CI: 0.21–0.81 **$p = 0.012$**[f]
Bee T.K. et al. (2008) [47] RCT, high overall risk of systematic errors (C); 3 points (out of 5) as per the Jadad Scale	Number of patients	31	–	–	20	–
	Brief description of patients (MPI, severity of the condition according to ASA, APACHE Scales, etc.)	SBP at admission – 112 ± 31.5 GCS – 13 ± 3.9 ISS – 30 ± 9.9	–	–	"Closed" laparostomy with a mesh SBP – 104 ± 36.3 GCS – 13.2 ± 3.6 ISS – 30 ± 9.9	–
	Complications, *n* (%)	ECF – 6 (19,35 %) Intra-abdominal abscesses – 12 (38.7 %) Evisceration – 2 (6.45 %)	–	–	ECF – 1 (5 %) External pancreatic fistula – 1 (5 %) Intra-abdominal abscesses – 9 (45 %)	$p_{ECF} = 0.14$ [b]
	Number of reoperations on average per patient, *n*	2	–	–	–	–
	Number of patients with AC final closure after LS, *n* (%)	9 (29 %)	–	–	5 (25 %)	$p = 0{,}14$[b]
	Mortality, *n* (%)	8 (26 %)	–	–	5 (25 %)	$p = 1{,}0$[b]

TABLE 1 (*continued*)

1	2	3	4	5	6	7
Batacchi S. et al. (2009) [9] Prospective cohort study; 6 points as per the Newcastle – Ottawa Quality Assessment Scale	Number of patients	35	–	–	31	–
	Brief description of patients (MPI, severity of the condition according to ASA, APACHE Scales, etc.)	APACHE II – 21.6 ± 6.5 SAPS II – 52.4 ± 17.8	–	–	"Closed" laparostomy with a Bogota bag APACHE II – 23.2 ± 7.1 SAPS II – 49.1 ± 17.5	p_{APACHE} = 0.298[d] p_{SAPS} = 0.274[d]
	AC final closure period, days (M ± SD)	4.4 ± 1.8	–	–	6.6 ± 3.7	p = **0.025**[d]
	Average duration of ALV, days (M ± SD)	7.1 ± 5.4	–	–	9.9 ± 6.5	p = **0.039**[d]
	Average duration of treatment in ICU, days (M ± SD)	13.3 ± 5.2	–	–	19.2 ± 9.6	p = **0.024**[d]
	Average duration of inpatient treatment, days (M ± SD)	28.5 ± 4.7	–	–	34.9 ± 8.8	p = **0.019**[d]
	Mortality, *n* (%)	8 (22.9 %)	–	–	11 (35.4 %)	**p** = 0.288[g]
Patel N.Y. et al. (2011) [48] Retrospective cohort study; 4 points as per the Newcastle – Ottawa Quality Assessment Scale	Number of patients	15	–	34	49	–
	Brief description of patients (MPI, severity of the condition according to ASA, APACHE Scales, etc.)	–	–	"Closed" laparostomy with skin suturing	"Closed" laparostomy with a Bogota bag	–
	Number of reoperations on average per patient, *n*	2 (1–17)	–	1 (1–4)	2 (1–9)	***p* = 0.003**[c]
	AC final closure period, days (Me (min-max))	5 (2–69)	–	2 (1–7)	4 (1–24)	***p* = 0.001**[c]
	Number of patients with AC final closure after LS, *n* (%)	12 (80 %)	–	33 (97 %)	45 (91.8 %)	–
	ALV average duration, days (Me (min-max))	14 (4–60)	–	4 (1–35)	11 (1–49)	***p* = 0.001**[c]
	Average duration of inpatient treatment, days (Me (min-max))	29 (5–109)	–	16 (5–85)	23 (5–81)	***p* = 0.012**[c]

TABLE 1 (*continued*)

1	2	3	4	5	6	7
Rodrigues Jr. A.C. et al. (2015) [50] Retrospective cohort study; 4 points as per the Newcastle – Ottawa Quality Assessment Scale	Number of patients	17	–	–	10	–
	Brief description of patients (MPI, severity of the condition according to ASA, APACHE Scales, etc.)	–	–	–	"Closed" laparostomy with a Bogota bag	–
	Number of reoperations on average per patient, *n*	2	–	–	2	***p*** = 0.3[b]
	AC final closure period, days (M ± SD)	7.52 ± 9.03	–	–	10.8 ± 14.46	***p*** = 0.23[e]
	Number of patients with AC final closure after LS, *n* (%)	16 (94.1 %)	–	–	8 (80 %)	***p*** = 0.98[b]
Cherdantsev D.V. et al. (2016) [13] Prospective cohort study; 6 points as per the Newcastle – Ottawa Quality Assessment Scale	Number of patients	26	–	–	30	–
	Brief description of patients (MPI, severity of the condition according to ASA, APACHE Scales, etc.)	Sepsis – 6 (23 %) Severe sepsis – 12 (46.2 %) Septic shock – 8 (30.8 %) MPI > 25	–	–	Sepsis – 14 (46.7 %) Severe sepsis – 10 (33.3 %) Septic shock – 6 (20 %) MPI > 25	–
	Number of reoperations on average per patient, *n*	4	–	–	6	–
	Mortality, *n* (%)	6 (23 %)	–	–	14 (46.7 %)	–

TABLE 1 (*continued*)

1	2	3	4	5	6	7
Coccolini *F.* et al. (2017) [29] Prospective cohort study; 6 points as per the Newcastle – Ottawa Quality Assessment Scale	Number of patients	1 – 163 2 – 47	–	–	3 – 117 4 – 42	–
	Brief description of patients (MPI, severity of the condition according to ASA, APACHE Scales, etc.)	1. Classical VAC-LS 2. Barker's vacuum-packing technique	–	–	3. "Closed" laparostomy with a Bogota bag + "zip" on the skin 4. Wittmann patch	–
	Complications, *n* (%)	Complications in general/ECF 1– 53/22 (32.5 %/13.5 %) 2 – 21/1 (43.9 %/2.4 %)	–	–	Complications in general/ECF 3 – 42/9 (35.8 %/7.4 %) 4 – 25/7 (58.8 %/17.6 %)	–
	Number of reoperations on average per patient, *n*	1 – 1 2 – 1	–	–	3 – 1 4 – 0	–
	AC final closure period, days (M ± SD)	1 – 5.0 ± 4.1 2 – 6.6 ± 7.2	–	–	3 – 5.0 ± 4.4 4 – 6.6 ± 4.8	–
	Number of patients with AC final closure after LS, *n* (%)	1 – 140 (85.7 %) 2 – 36 (75.6 %)	–	–	3 – 97 (83.2 %) 4 – 33 (79.4 %)	–
	Mortality, *n* (%)	1 – 23 (14.3 %) 2 – 11 (24.4 %)	–	–	3 – 20 (16.8 %) 4 – 9 (20.6 %)	–

TABLE 1 (*continued*)

1	2	3	4	5	6	7
Pliakos I. et al. (2012) [49] Retrospective cohort study; 5 points as per the Newcastle – Ottawa Quality Assessment Scale	Number of patients	27	–	–	31	–
	Brief description of patients (MPI, severity of the condition according to ASA, APACHE Scales, etc.)	There is no statistically significant difference in the severity of condition as per the APACHE II Scale, age, and gender of patients. APACHE II $_{av.}$ – 18.6	–	–	APACHE II $_{av.}$ – 17.3 Bogota bag – 8 "Zip" – 8 Wittmann patch – 6 Non-absorbable mesh – 5 Others – 4	–
	Complications, *n* (%)	No	–	–	ECF – 17 (54.8 %)	***p* < 0.001**
	Number of reoperations on average per patient, *n*	4	–	–	16	***p* < 0.001**
	AC final closure period, days (M ± SD)	20	–	–	14	***p* < 0.001**
	Number of patients with AC final closure after LS, *n* (%)	22 (81.5 %)	–	–	9 (29 %)	***p* < 0.001**
	Mortality, *n* (%)	10 (37 %)	–	–	14 (45 %)	$p > 0.05$

TABLE 1 (*continued*)

1	2	3	4	5	6	7
Anisimov A.Yu. et al. (2017) [27] Prospective cohort study; 6 points as per the Newcastle – Ottawa Quality Assessment Scale	Number of patients	8	–	14	–	–
	Brief description of patients (MPI, severity of the condition according to ASA, APACHE Scales, etc.)	APACHE II – 17–27 Pancreatogenic sepsis – 100 %	–	APACHE II – 14–24 Pancreatogenic sepsis – 92.86 %	–	–
	Complications, *n* (%)	Bleeding – 1 (12.5 %) ECF – 1 (12.5 %)	–	–	–	–
	Number of reoperations on average per patient, *n*	5	–	3	–	**$p = 0.010448$**
	Average duration of inpatient treatment, days (M ± SD)	43.3 ± 13.6	–	37.0 ± 15.8	–	$p = 0.347353$
	Mortality, *n* (%)	4 (50 %)	–	9 (64.3 %)	–	–
Pogorelov M.V. et al. (2020) [23] Combined cohort study; 5 points as per the Newcastle – Ottawa Quality Assessment Scale	Number of patients	4	–	12	–	–
	Brief description of patients (MPI, severity of the condition according to ASA, APACHE Scales, etc.)	With toxic peritonitis phase – 3	–	Less severe patients	–	–
	Complications, *n* (%)	No	–	Adhesive AIO – 3 (25 %) ECF – 1 (8.3 %) Intra-abdominal abscesses – 2 (16.7 %)	–	–
	Number of reoperations on average per patient, *n*	2	–	2	–	–
	Mortality, *n* (%)	1 (25 %)	–	0 (0 %)	–	–

Note. [a] – Friedman test (χ^2) for multiple arbitrary-sized contingency tables; [b] – Pearson's chi-square (X^2) test; [c] – Kruskal – Wallis H test (for comparing more than two groups; [d] – Mann – Whitney U test; [e] – Student's t-test; [f] – F-test (χ^2); [g] – Fisher's exact test; 95% CI – 95% confidence interval; RLT – relaparotomy; LS – laparostomy; AC – abdominal cavity; ECF – enterocutaneous fistula; GCS – Glasgow Coma Scale; ISS – Injury Severity Score.

ly significant difference in the severity of the condition as per the APACHE II Scale, age, gender of patients. The authors obtained statistically significant differences in the average duration of laparostomy (20 days with vacuum vs. 14 days with other types; $p < 0.001$), the number of reoperations (4 vs. 16, respectively; $p < 0.001$), the number of patients with successful primary laparostomy closure (22 vs. 9; $p < 0.001$), the frequency of enterocutaneous fistula formation (0 vs. 17, respectively; $p < 0.001$), but no statistically significant differences in mortality were obtained (10 vs. 14, respectively) [49].

A.C. Rodrigues Jr. et al. (2015) [50] compared vacuum laparostomy ($n = 17$) with the Bogota bag ($n = 10$) among survived patients with abdominal sepsis in a retrospective cohort study and obtained no statistically significant diffe rence in the time and number of successful closure of the abdominal cavity, as well as in the number of reoperations.

D.V. Cherdantsev et al. (2016) [13] compared traditional and vacuum laparostomy in a prospective cohort study and concluded that the use of the latter makes it possible to improve the intra-abdominal situation in a shorter time, reducing the number of reoperations, which helps to minimize the number of systemic and local complications and improve treatment outcomes of patients with severe abdominal sepsis [13].

V.M. Mutafchiyski et al. (2016) [20] in their combined (retro- and prospective) cohort study compared the results of treatment of patients with widespread peritonitis who underwent vacuum-assisted laparostomy in the main group (prospective study) and closed laparostomy using a permeable synthetic mesh in the control group. VAC-laparostomy showed statistically significantly lower rates of necrotizing fasciitis (2 % vs. 15.2 %, respectively; $p = 0.012$), overall mortality (28.57 % vs. 52.54 %, respectively; $p = 0.021$), shorter ICU stays (6.1 vs. 10.6 days, respectively; $p = 0.002$) and hospitalization (15.1 vs 25.9 days; $p = 0.000$). If a VAC-laparostomy should be prolonged for more than 9 days, its combination with a system of continuous dosed muscular-aponeurotic traction is recommended [20].

M.S. Bleszynski et al. (2016) [14] carried out a retrospective comparative analysis of the results of VAC-laparostomy and on-demand relaparotomy among patients having abdominal sepsis, the main cause (59 %) of which were intestinal perforations, mesenteric ischemia and anastomosis failure. The authors have obtained encouraging results concerning reducing mortality in VAC-laparostomy among septic patients, and they emphasize the difficulties in timely indications for on-demand relaparotomy [14].

A.Yu. Anisimov et al. (2017) [27] used the NPWT technique (Vivano Tec, Germany) for 8 patients with pancreatogenic sepsis, and in a control group of 14 subjects they used traditional omentobursostomy; otherwise, the volume of surgical interventions and conservative measures did not differ; the groups were comparable in the severity of patients as per the APACHE II, Balthazar Scales, clinical signs of sepsis as per R.C. Bone classification. Later there were 3 to 5 planned relaparotomies; on-demand reoperations were performed only when bleeding occurred [27]. Negative pressure ensured more effective continuous evacuation of exudate, early relief of systemic inflammatory reaction syndrome and IAHS [27]. Mortality in the main group was 50 % (4 of 8) versus 64.3 % (9 of 14) in the comparison group [27]. According to the authors, the NPWT method has its shortcomings and complications: petechial and arrosive bleeding occurred in 1 (12.5 %) patient, and in 1 (12.5 %) case the postoperative period was complicated by the development of intestinal fistula, but no statistically significant differences in the incidence of the above complications and mortality rate with and without NPWT were obtained by the authors [27].

In 2017, the first results of an international study (supervised by F. Coccolini) devoted to the epidemiology, indications and effectiveness of laparostomy in the global surgical community were published in the International Register of Open Abdomen (IROA) [19, 29]. 402 patients were registered, 369 of them – adults. The average age of adult patients – 57.39 ± 18.37 years [19, 29]. The reasons for performing laparostomy were: peritonitis (in case of septic shock and inability to perform radical surgery due to the severity of the patient's condition; if a delayed anastomosis was necessary; in case of oedema of intestinal loops with suspected development of IAHS) – 48.7 % of cases; trauma – 20.5 %; vascular pathology/bleeding (rupture of the abdominal aortic aneurysm) – 9.4 %; ischemia (planned intestine revision in case of mesenteric ischemia and resection) – 9.1 %; severe pancreonecrosis with MSF and IAHS – 4.2 %; postoperative abdominal syndrome – 3.9 %; others – 4.2 % [19, 29]. The most common method of temporary closure was the use of commercial negative pressure systems – 44.2 %. Complications developed in 38 % of the patients, 10.5 % of which were intestinal fistulas. Primary muscular-aponeurotic closure was achieved in 82.8 % of patients. The mortality rate was 17.2 % [19, 29]. The duration of laparostomy – 5.39 ± 4.83 days. A direct linear correlation was found between the duration of laparostomy and complications (Pearson correlation coefficient = 0.326; $p < 0.0001$) with the development of enterocutaneous fistulas (Pearson correlation coefficient = 0.146; $p = 0.016$) [19, 29].

M.V. Pogorelov et al. (2020) [23] compared the results of treatment of 16 children with widespread purulent peritonitis, in 4 of whom they used the technique of local negative pressure and programmed lavages, 12 – only programmed relaparotomy. The authors concluded that laparostomy with intra-abdominal VAC-therapy is a reliable and effective method of treating widespread peritonitis with multiple interstitial abscesses, including tertiary peritonitis; it reduces intra-abdominal pressure more rapidly and causes fewer complications [23].

I.B. Uvarov et al. (2022) [3] conducted a prospective comparative non-randomized clinical study to evaluate the effectiveness of vacuum-assisted laparostomy with staged lavages in comparison with on-demand relapa-

rotomies among patients with secondary widespread postoperative peritonitis (Table 1). No adverse events of severe and moderate degree associated with the use of negative pressure therapy (bleeding, bedsores of hollow organ walls and intestinal fistula formation, intestinal obstruction) have been reported [3]. The use of VAC-laparostomy in comparison with on-demand relaparotomy provides more effective relief of abdominal sepsis, is associated with lower mortality, fewer complications and severity, shorter stay in the intensive care unit and hospital after closure of the abdominal cavity [3].

1. Comparison of vacuum-assisted laparostomy with other options for multistage surgical treatment by the number of necessary repeated operations.

A. Comparison with on-demand relaparotomy: 2 studies [3, 14] (Fig. 2).

The relative risk was 1.91 (95% CI: 0.54–6.77; I^2 = 0 %; fixed effects model).

There are no statistically significant differences between vacuum-assisted laparostomy and on-demand relaparotomy in the number of necessary repeated operations (p = 0.319).

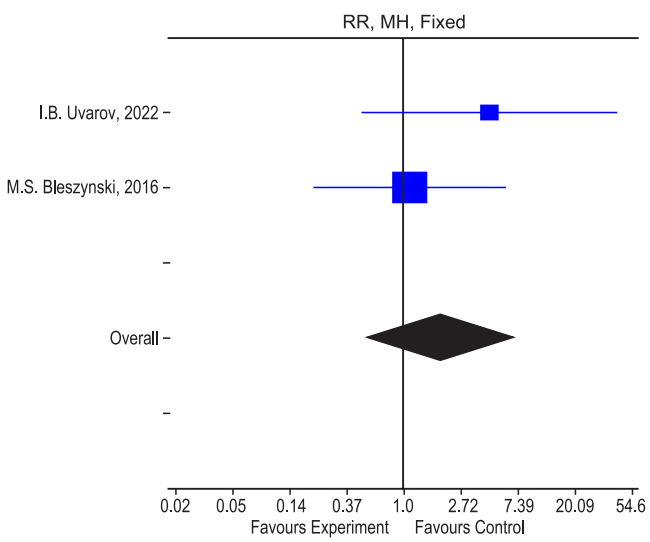

FIG. 2.

Forest plot showing the results of comparing vacuum-assisted laparostomy and relaparotomy "on demand" by the number of necessary repeated operations

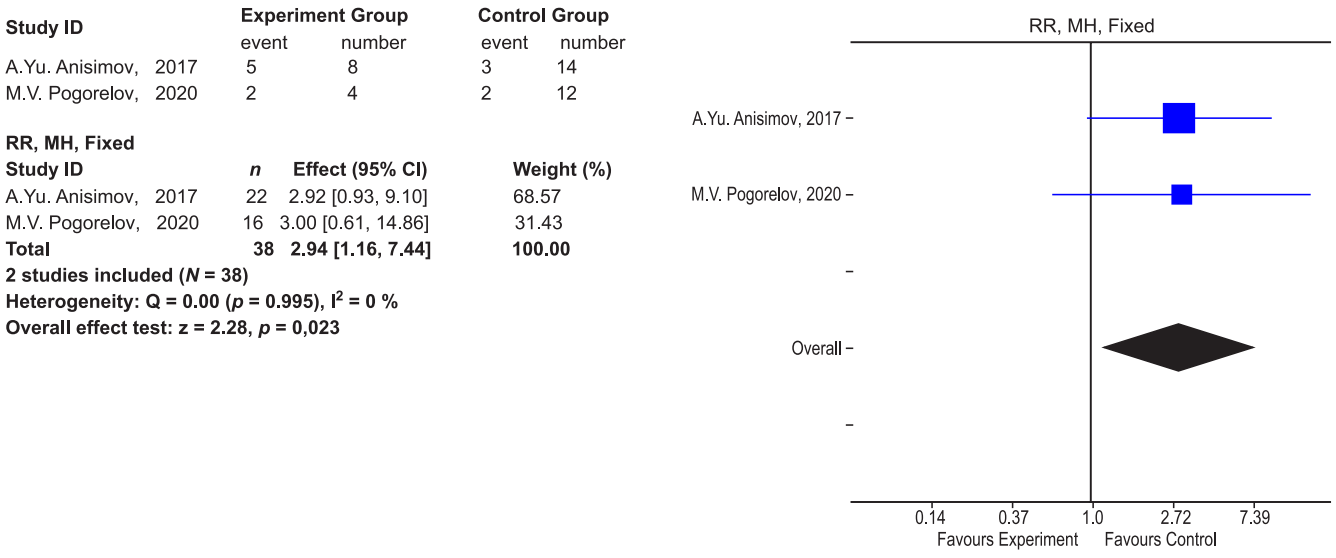

FIG. 3.

Forest plot showing the results of comparing vacuum-assisted laparostomy and programmed relaparotomy by the number of necessary repeated operations

B. Comparison with programmed relaparotomy.

A comparison is possible based on two studies [23, 27] (Fig. 3, 4).

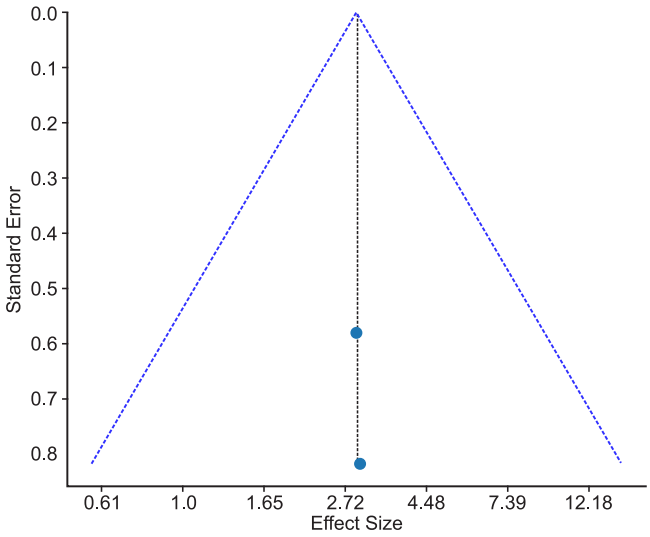

FIG. 4.

Funnel plot of evaluation of the systematic error of publications by the number of necessary repeated operations in vacuum-assisted laparostomy and programmed relaparotomy

In the study of N.Y. Patel et al. [48], information concerning the number of necessary repeated operations is presented in the form of median, minimum and maximum; comparison with the average number is impossible.

The relative risk was 2.94 (95% CI: 1.16–7.44; I^2 = 0 %; fixed effects model).

In the studies under consideration, the number of necessary reoperations during programmed relaparotomies is statistically significantly lower than during vacuum-assisted laparostomy (p = 0.023).

A symmetrical funnel plot indicates the absence of obvious systematic publication errors (no publication bias).

C. Comparison with other variants of laparostomy without vacuum: 5 studies [13, 20, 29, 49, 50] – 6 comparison groups (Fig. 5).

The relative risk was 0.57 (95% CI: 0.32–1.01; I^2 = 0 %; fixed effects model).

There are no statistically significant differences in the number of necessary reoperations with vacuum laparostomy and laparostomy without vacuum (p = 0.053).

2. Comparison of vacuum-assisted laparostomy with other variants of laparostomy without vacuum by the number of patients with successful closure of the abdominal cavity (Fig. 6).

The relative risk was 1.11 (95% CI: 0.90–1.36; I^2 = 67.37 %; random effects model).

There are no statistically significant differences in the number of patients with successful closure of the abdominal cavity after vacuum-assisted laparostomy or other variants of laparostomy without vacuum (p = 0.333).

3. Comparison of vacuum-assisted laparostomy with other multistage surgical treatment options by the average time of final closure of the abdominal cavity.

A. Comparison with on-demand relaparotomy: 2 studies [3, 14].

Study ID	Experiment Group		Control Group	
	event	number	event	number
V.M. Mutafchiyski, 2016	3	49	3	59
A.C. Rodrigues J., 2015	2	17	2	10
D.V. Cherdantsev, 2016	4	26	6	30
F. Coccolini, 2017	1	163	1	117
F. Coccolini, 2017	1	47	0	42
I. Pliakos, 2012	4	27	16	31

RR, MH, Fixed

Study ID	*n*	Effect (95% CI)	Weight (%)
V.M. Mutafchiyski, 2016	108	1.20 [0.25, 5.70]	9.93
A.C. Rodrigues J., 2015	27	0.59 [0.10, 3.55]	9.19
D.V. Cherdantsev, 2016	56	0.77 [0.24, 2.43]	20.33
F. Coccolini, 2017	280	0.72 [0.05, 11.36]	4.25
F. Coccolini, 2017	89	2.69 [0.11, 64.25]	1.93
I. Pliakos, 2012	58	0.29 [0.11, 0.75]	54.37
Total	**618**	**0.57 [0.32, 1.01]**	**100.00**

6 studies included (N = 618)

Heterogeneity: Q = 4.03 (p = 0.546), I^2 = 0 %

Overall effect test: z = 1.94, p = 0,053

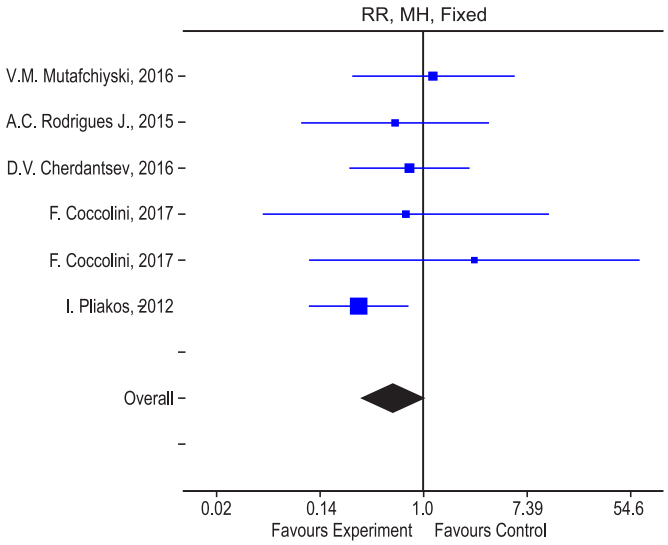

FIG. 5.

Forest plot showing the results of comparing vacuum-assisted laparostomy and laparostomy without vacuum by the number of repeated operations required

Study ID	Experiment Group		Control Group	
	event	number	event	number
T.K. Bee, 2008	9	31	5	20
N.Y. Patel, 2011	12	15	45	49
A.C. Rodrigues J., 2015	16	17	8	10
F. Coccolini, 2017	140	163	97	117
F. Coccolini, 2017	36	47	33	42
I. Pliakos, 2012	22	27	9	31

RR, MH, Fixed

Study ID	*n*	Effect (95% CI)	Weight (%)
T.K. Bee, 2008	51	1.16 [0.45, 2.97]	4.13
N.Y. Patel, 2011	64	0.87 [0.67, 1.14]	1.98
A.C. Rodrigues J., 2015	27	1.18 [0.84, 1.64]	16.84
F. Coccolini, 2017	280	1.04 [0.93, 1.15]	27.99
F. Coccolini, 2017	89	0.97 [0.78, 1.22]	22.20
I. Pliakos, 2012	58	2.81 [1.57, 5.01]	8.86
Total	**569**	**1.11 [0.90, 1.36]**	**100.00**

6 studies included (*N* = 569)
Heterogeneity: Tau² = 0.036, Q = 15.32 (*p* = 0.009), I² = 67.37 %
Overall effect test: z = 0.97, *p* = 0,333

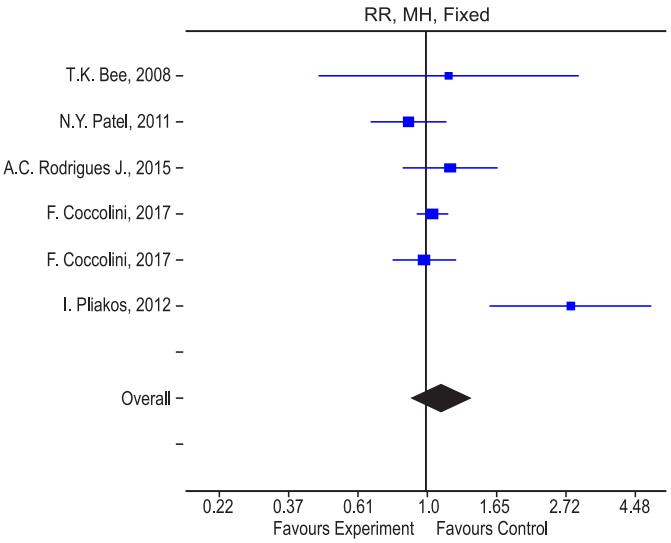

FIG. 6.
Forest plot showing the results of comparing vacuum-assisted laparostomy and laparostomy without vacuum by the number of patients with successful closure of the abdominal cavity

Study ID	Experiment Group			Control Group		
	mean	sd	number	mean	sd	number
V.M. Mutafchiyski, 2016	8.80	8.80	49	10.00	13.70	59
S. Batacchi, 2009	4.40	1.80	35	660	3.70	31
A.C. Rodrigues J., 2015	7.52	9.03	17	10.80	14.46	10
F. Coccolini, 2017	5.00	4.10	163	5.00	4.40	117
F. Coccolini, 2017	6.60	7.20	47	6.60	4.80	42

SMD, IV-Heg, Random

Study ID	*n*	Effect (95% CI)	Weight (%)
V.M. Mutafchiyski, 2016	51	1.16 [0.45, 2.97]	4.13
S. Batacchi, 2009	64	0.87 [0.67, 1.14]	1.98
A.C. Rodrigues J., 2015	27	1.18 [0.84, 1.64]	16.84
F. Coccolini, 2017	280	1.04 [0.93, 1.15]	27.99
F. Coccolini, 2017	89	0.97 [0.78, 1.22]	22.20
Total	**570**	**–0.17 [–0.43, 0.09]**	**100.00**

5 studies included (*N* = 570)
Heterogeneity: Tau² = 0.040, Q = 7.76 (*p* = 0.101), I² = 48.48 %
Overall effect test: z = 1.31, *p* = 0,192

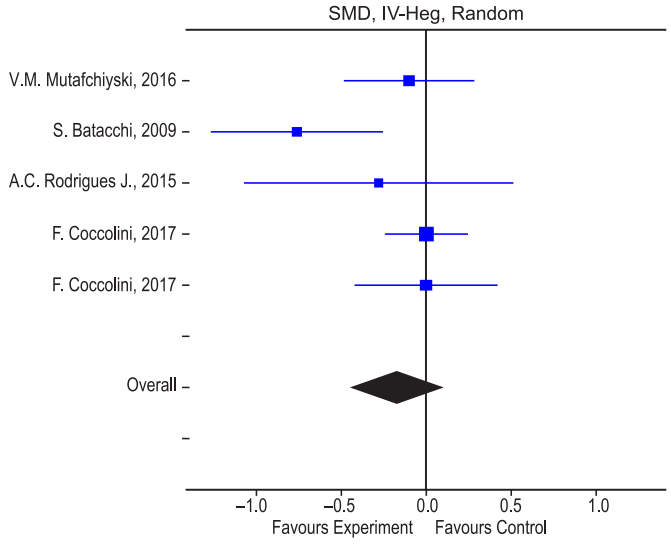

FIG. 7.
Forest plot showing the results of comparing vacuum-assisted laparostomy and other variants of laparostomy without vacuum according to the average timing of the final closure of the abdominal cavity

Comparisons cannot be done because one study provides data for one cohort [3], and the other does not [14].

B. Comparison with programmed relaparotomy: 3 studies [23, 27, 48].

It is impossible to make comparisons among the selected studies, because this information is not available in two studies [23, 27].

C. Comparison with other variants of laparostomy without vacuum: 4 studies [9, 20, 29, 50] – 5 comparison groups (Fig. 7).

SMD is –0.17 (95% CI: –0.43–0.09; I^2 = 48.48 %).

In the course of generalizing calculations of the above studies (I^2 statistics – 48.48 %; random effects model), it was revealed that **the average timing of the final closure of the abdominal cavity after vacuum-assisted laparostomy and other variants of laparostomy without vacuum did not differ** statistically significantly (p = 0.192).

4. Comparison of vacuum-assisted laparostomy with other multistage surgical treatment options for postoperative complications.

Study ID	Experiment Group		Control Group	
	event	number	event	number
V.M. Mutafchiyski, 2016	4	49	11	59
T.K. Bee, 2008	6	31	1	20
F. Coccolini, 2017	22	163	9	117
F. Coccolini, 2017	1	47	7	42
I. Pliakos, 2012	0	27	17	31

RR, MH, Fixed

Study ID	*n*	Effect (95% CI)	Weight (%)
V.M. Mutafchiyski, 2016	108	0.44 [0.15, 1.29]	24.53
T.K. Bee, 2008	51	3.87 [0.50, 29.80]	17.74
F. Coccolini, 2017	280	1.75 [0.84, 3.67]	26.63
F. Coccolini, 2017	89	0.13 [0.02, 1.00]	17.66
I. Pliakos, 2012	58	0.03 [0.00, 0.52]	13.44
Total	**586**	**0.53 [0.13, 2.12]**	**100.00**

5 studies included (*N* = 586)
Heterogeneity: Tau^2 = 1.740, Q = 17.48 (*p* = 0.002), I^2 = 77.12 %
Overall effect test: z = 0.90, *p* = 0,371

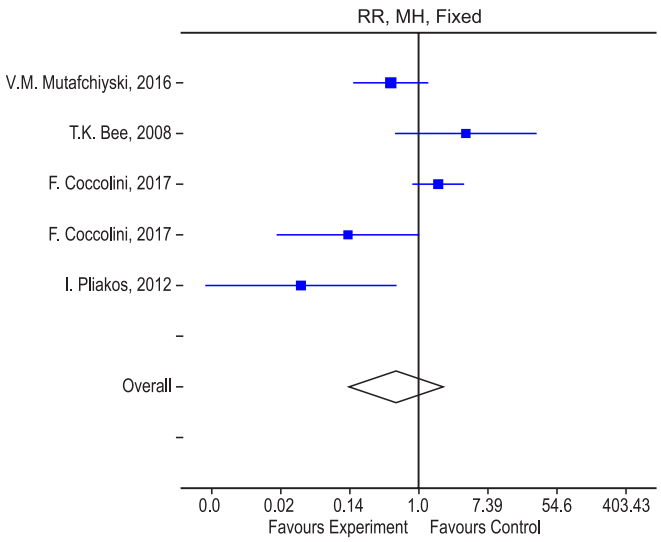

FIG. 8.
Forest plot showing the results of comparing vacuum-assisted laparostomy and laparostomy without vacuum by the frequency of development of enterocutaneous fistulas

Study ID	Experiment Group		Control Group	
	event	number	event	number
V.M. Mutafchiyski, 2016	5	49	19	59
T.K. Bee, 2008	12	31	9	20

RR, MH, Fixed

Study ID	*n*	Effect (95% CI)	Weight (%)
V.M. Mutafchiyski, 2016	108	0.32 [0.13, 0.79]	45.28
T.K. Bee, 2008	51	0.86 [0.45, 1.66]	54.72
Total	**159**	**0.55 [0.20, 1.52]**	**100.00**

2 studies included (*N* = 159)
Heterogeneity: Tau^2 = 0.382, Q = 3.34 (*p* = 0.068), I^2 = 70.02 %
Overall effect test: z = 1.16, *p* = 0,250

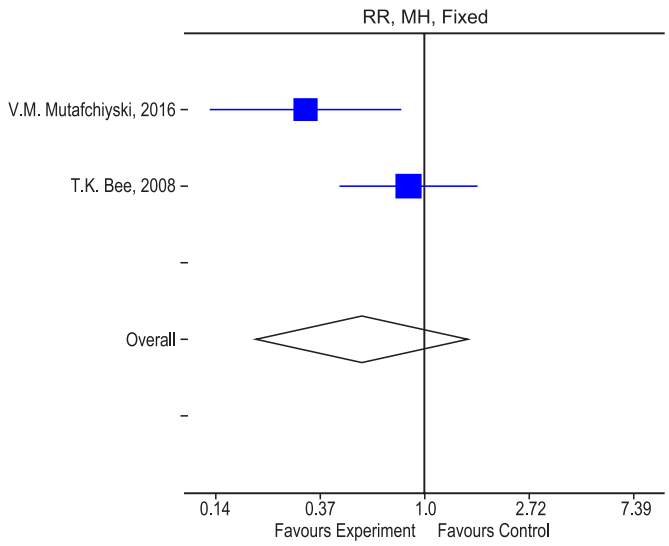

FIG. 9.
Forest plot showing the results of comparing vacuum-assisted laparostomy and laparostomy without vacuum by the frequency of intra-abdominal abscesses

A. Comparison with on-demand relaparotomy: 2 studies [3, 14].

In the presented studies, it is impossible to compare postoperative complications, because one study does not characterize them, and the second study does not provide any data.

B. Comparison with programmed relaparotomy: 3 studies.

In the presented studies [23, 27, 48], a comparison of postoperative complications is impossible, because there are no data on the compared cohorts.

C. Comparison with other variants of laparostomy without vacuum: 4 studies [20, 29, 47, 49] – 5 comparison groups.

In the presented studies, it is possible to compare enterocutaneous fistulas (Fig. 8):

The relative risk was 0.53 (95% CI: 0.13–2.12; I^2 = 77.12 %; random effects model).

There are no statistically significant **differences between vacuum-assisted laparostomy and other variants of laparostomy without vacuum by the frequency of development of enterocutaneous fistulas** (*p* = 0.371).

Study ID	Experiment Group			Control Group		
	mean	sd	number	mean	sd	number
I.B. Uvarov, 2022	9.50	1.50	52	10.00	1.40	78
M.S. Bleszynski, 2016	15.30	16.00	136	10.20	11.00	75

SMD, IV-Heg, Random

Study ID	*n*	Effect (95% CI)	Weight (%)
I.B. Uvarov, 2022	130	–0.48 [–0.84, –0.13]	49.14
M.S. Bleszynski, 2016	211	0.35 [0.07, 0.64]	50.86
Total	**341**	**–0.06 [–0.88, 0.76]**	**100.00**

2 studies included (*N* = 341)
Heterogeneity: Tau^2 = 0.322, Q = 12.93 (*p* = 0.001), I^2 = 92.26 %
Overall effect test: z = 0.14, *p* = 0,889

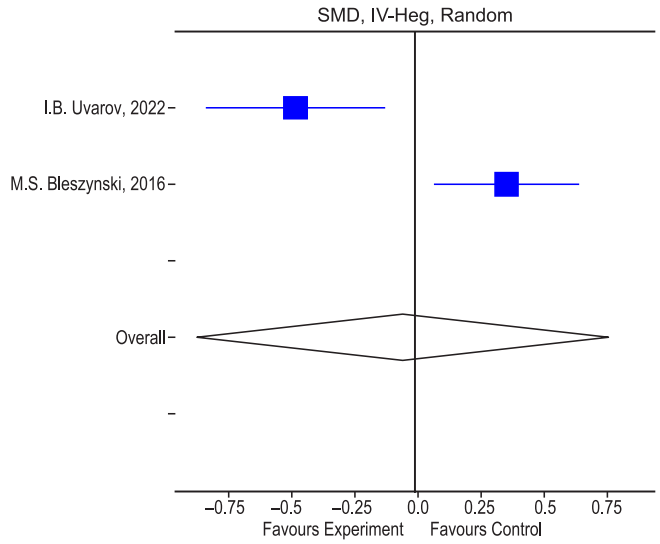

FIG. 10.
Forest plot showing the results of comparing vacuum-assisted laparostomy and relaparotomy "on demand" by the average length of treatment in the ICU

Study ID	Experiment Group			Control Group		
	mean	sd	number	mean	sd	number
V.M. Mutafchiyski, 2016	6.10	6.31	49	10.60	8.43	59
S. Batacchi, 2009	13.30	5.20	35	19.20	9.60	31

SMD, IV-Heg, Fixed

Study ID	*n*	Effect (95% CI)	Weight (%)
V.M. Mutafchiyski, 2016	108	–0.59 [–0.98, –0.20]	62.69
S. Batacchi, 2009	66	–0.77 [–1.27, –0.27]	37.31
Total	**174**	**–0.66 [–0.96, –0.35]**	**100.00**

2 studies included (*N* = 174)
Heterogeneity: Q = 0.30 (*p* = 0.588), I^2 = 0 %
Overall effect test: z = 4.21, *p* = 0,000

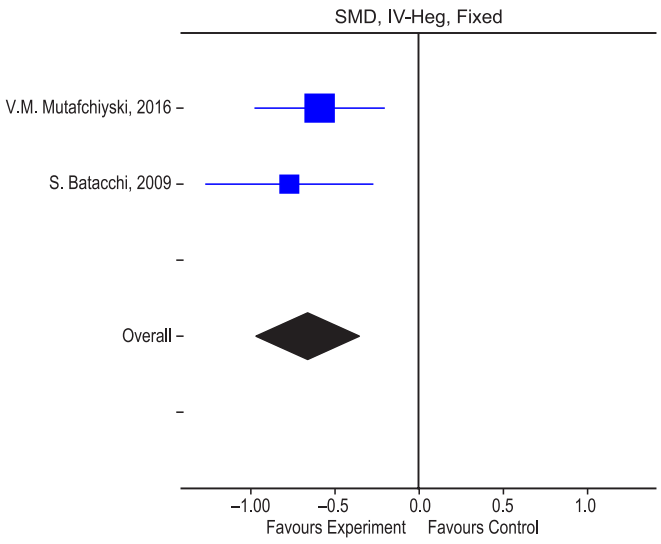

FIG. 11.
Forest plot showing the results of comparing vacuum-assisted laparostomy and other variants of laparostomy without vacuum by the average length of treatment in the ICU

D. Comparison by the frequency of intra-abdominal abscesses: 2 studies [20, 47] (Fig. 9).

The relative risk was 0.55 (95% CI: 0.20–1.52; I^2 = 70.02 %; random effects model).

There are no statistically significant **differences between vacuum-assisted laparostomy and other variants of laparostomy without vacuum by the frequency of intra-abdominal abscesses** (*p* = 0.250).

5. Comparison of vacuum-assisted laparostomy with other options for multistage surgical treatment according to the average duration of patients' stay in ICU.

A. Comparison with on-demand relaparotomy: 2 studies [3, 14] (Fig. 10).

SMD is –0.06 (95% CI: –0.88–0.76; I^2 = 92.26 %).

In the course of generalizing calculations of the above studies (I^2 statistics – 92.26 %; random effects model), it was revealed that the **average duration of stay in the ICU after vacuum-assisted laparostomy and on-demand relaparotomy did not differ** statistically significantly (*p* = 0.889).

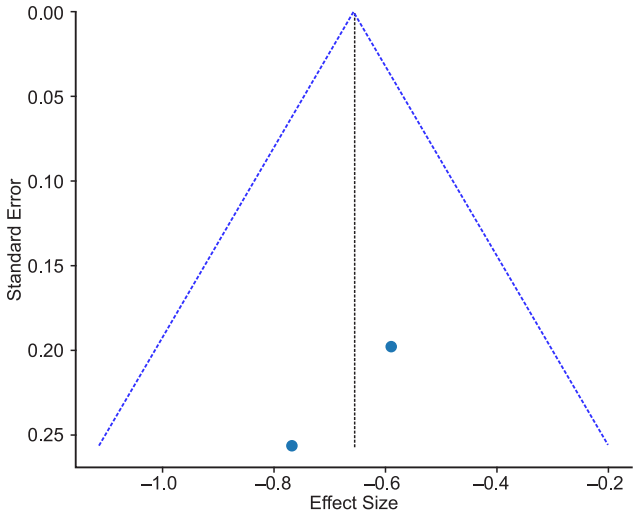

FIG. 12.

Funnel plot of evaluation of the systematic error of publications by the average duration of treatment in the ICU after vacuum-assisted laparostomy and other variants of laparostomy without vacuum

B. Comparison with programmed relaparotomy: 3 studies [23, 27, 48].

Comparison is not possible among the selected studies, because this information is not available.

C. Comparison with other variants of laparostomy without vacuum: 2 studies [9, 20] (Fig. 11, 12).

SMD is –0.66 (95% CI: –0.96÷–0.35; I^2 = 0 %).

In the course of generalizing calculations of the above studies (I^2 statistics – 0 %; fixed effects model), it was revealed that **the average duration of treatment in the ICU after vacuum-assisted laparostomy** was statistically significantly **less than with in other laparostomy variants without vacuum** (p = 0.000).

A symmetrical funnel plot indicates the absence of obvious systematic publication errors (no publication bias).

6. Comparison of vacuum-assisted laparostomy with other options for multistage surgical treatment according to the average duration of hospital stay.

A. Comparison with on-demand relaparotomy: 2 studies [3, 14] (Fig. 13).

The SMD is 0.10 (95% CI: –0.53–0.74; I^2 = 87.32 %).

In the course of generalizing calculations of the above studies (I^2 statistics – 87.32 %; random effects model), it was revealed that the **average duration of inpatient treatment after vacuum-assisted laparostomy and on-demand relaparotomy did not differ** statistically significantly (p = 0.749).

B. Comparison with programmed relaparotomy: 3 studies.

Comparison among the selected studies is impossible, because only one of them provides the average duration of inpatient treatment and the standard deviation [27], the other shows the median with the maximum and minimum duration of treatment [48], and the third has no information at all [23].

B. Comparison with other variants of laparostomy without vacuum: 2 studies [9, 20].

The study [48] shows the median with the maximum and minimum duration of treatment (Fig. 14, 15).

The SMD is –0.74 (95% CI: –1.05÷–0.43; I^2 = 0 %).

In the course of generalizing calculations of the above studies (I^2 statistics – 0 %; fixed effects model), it was revealed that **the average duration of inpatient treatment after vacuum-assisted laparostomy was statistically sig-**

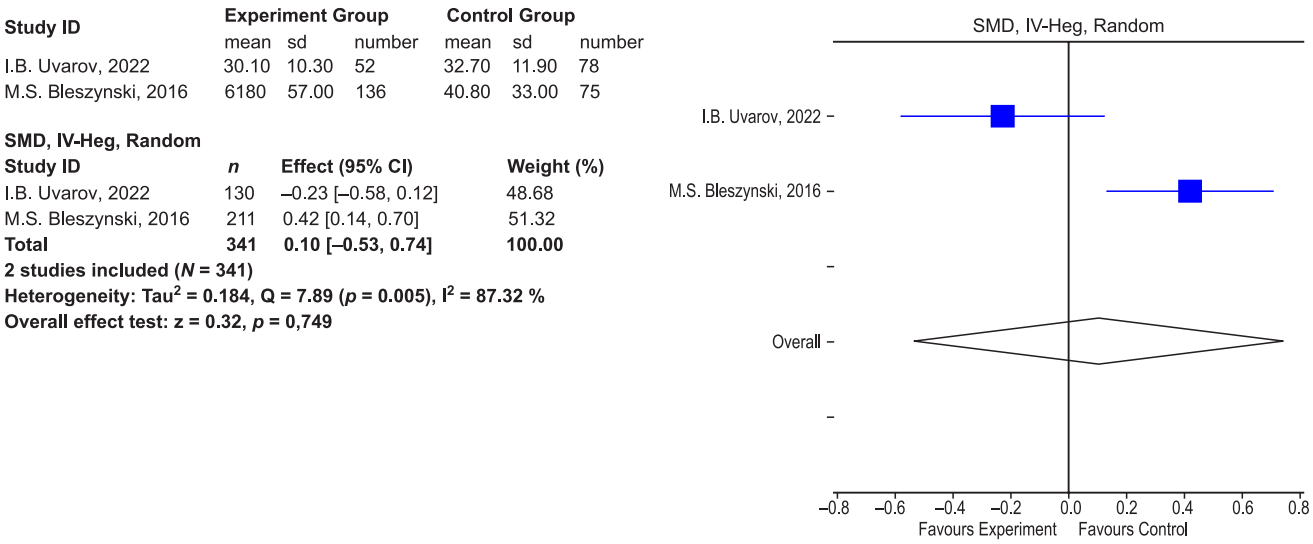

FIG. 13.

Forest plot showing the results of comparing vacuum-assisted laparostomy and relaparotomy "on demand" by the average duration of inpatient treatment

Study ID	Experiment Group			Control Group		
	mean	sd	number	mean	sd	number
V.M. Mutafchiyski, 2016	15.10	11.85	49	25.90	20.00	59
S. Batacchi, 2009	28.50	4.70	35	34.90	8.80	31

SMD, IV-Heg, Fixed

Study ID	*n*	Effect (95% CI)	Weight (%)
V.M. Mutafchiyski, 2016	108	–0.64 [–1.03, –0.25]	63.21
S. Batacchi, 2009	66	–0.91 [–1.42, –0.40]	36.79
Total	**174**	**–0.74 [–1.05, –0.43]**	**100.00**

2 studies included (*N* = 174)
Heterogeneity: Q = 0.71 (*p* = 0.401), I^2 = 0 %
Overall effect test: z = 4.69, *p* = 0,000

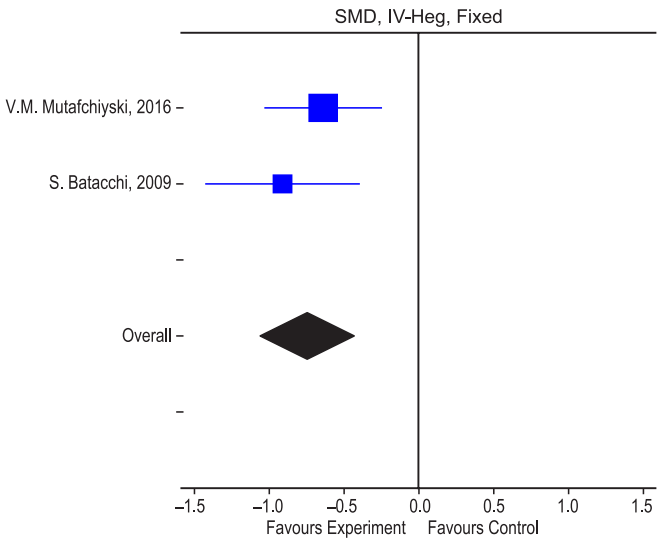

FIG. 14.
Forest plot showing the results of comparing vacuum-assisted laparostomy and other variants of laparostomy without vacuum by the average duration of inpatient treatment

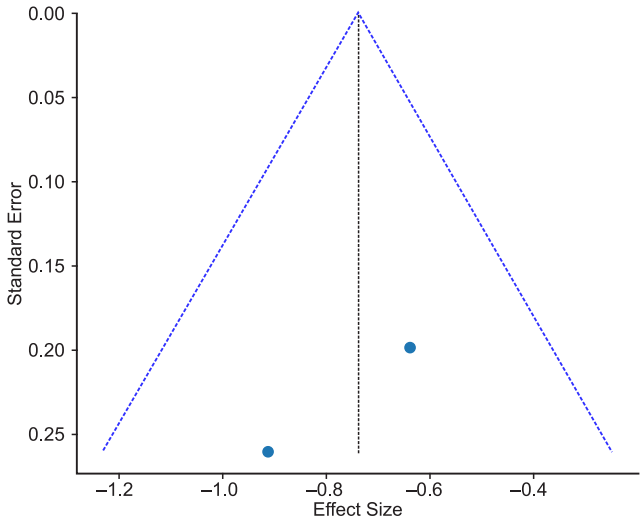

FIG. 15.
Funnel plot of evaluation of the systematic error of publications by the average duration of inpatient treatment after vacuum-assisted laparostomy and other variants of laparostomy without vacuum

nificantly less than that for other laparostomy variants without vacuum ($p = 0.000$).

A symmetrical funnel plot indicates the absence of obvious systematic publication errors (no publication bias).

7. Comparison of vacuum-assisted laparostomy with other multistage surgical treatment options for postoperative mortality.

A. Comparison with on-demand relaparotomy: 2 studies [3, 14] (Fig. 16).

In the presented studies, mortality after vacuum-assisted laparostomy – 18.1 % (34/188) (95% CI: 13.2–24.24 %), after on-demand relaparotomies – 34,64 % (53/153) (95% CI: 27.55–42.48 %).

The relative risk was 0.37 (95% CI: 0.12–1.19; $I^2 = 73.5$ %; random effects model).

In the studies under consideration, **postoperative mortality after vacuum-assisted laparostomy does not** significantly **differ from that after on-demand relaparotomies** ($p = 0.097$).

B. Comparison with programmed relaparotomy: 2 studies (Fig. 17).

In the presented studies [23, 27], postoperative mortality after vacuum-assisted laparostomy – 41.66 % (5/12) (95% CI: 19.26–68.11 %), after programmed relaparotomy – 34.61 % (9/26) (95% CI: 19.31–53.88 %).

The study of N.Y. Patel et al. [48] does not provide any information on postoperative mortality.

The relative risk was 1.58 (95% CI: 0.18–13.83; $I^2 = 55.68$ %; random effects model).

In the studies under consideration, **postoperative mortality after vacuum-assisted laparostomy does not** significantly **differ from that after programmed relaparotomies** ($p = 0.681$).

C. Comparison with other variants of laparostomy without vacuum: 6 studies [9, 13, 20, 29, 47, 49] – 7 comparison groups (Fig. 18, 19).

In the presented studies, postoperative mortality after vacuum-assisted laparostomy – 21.16 % (80/378) (95% CI: 17.34–25.57 %), after other variants of laparostomy without vacuum – 31.51 % (104/330) (95% CI: 26.74–36.72 %).

The relative risk was 0.72 (95% CI: 0.56–0.93; $I^2 = 0$ %; fixed effects model).

In the studies under consideration, **postoperative mortality is** statistically significantly **lower after vacuum-assisted laparostomy in comparison with other variants of laparostomy without vacuum** ($p = 0.012$).

Study ID	Experiment Group		Control Group	
	event	number	event	number
I.B. Uvarov, 2022	3	52	24	78
M.S. Bleszynski, 2016	31	136	29	75

RR, MH, Random

Study ID	*n*	Effect (95% CI)	Weight (%)
I.B. Uvarov, 2022	130	0.19 [0.06, 0.59]	39.89
M.S. Bleszynski, 2016	211	0.59 [0.39, 0.90]	60.11
Total	**341**	**0.37 [0.12, 1.19]**	**100.00**

2 studies included (*N* = 341)
Heterogeneity: Tau^2 = 0.540, Q = 3.77 (*p* = 0.052), I^2 = 73.5 %
Overall effect test: z = 1.66, *p* = 0,097

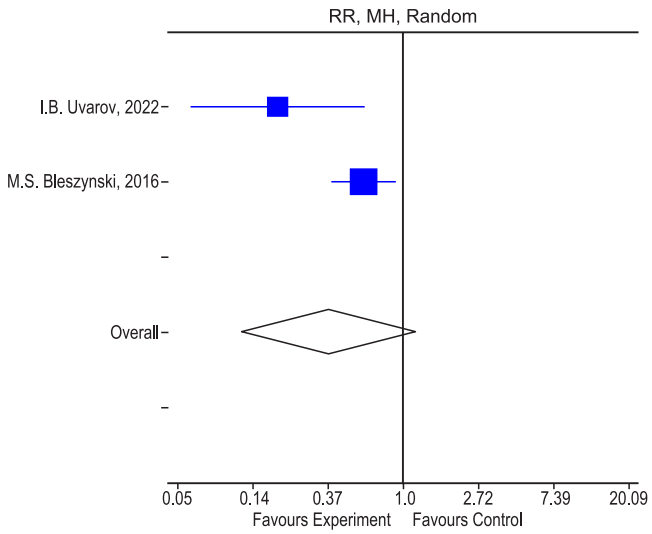

FIG. 16.
Forest plot showing the results of comparing vacuum-assisted laparostomy and relaparotomy "on demand" by postoperative mortality

Study ID	Experiment Group		Control Group	
	event	number	event	number
A.Yu. Anisimov, 2017	4	8	9	14
M.V. Pogorelov, 2020	1	4	0	12

RR, MH, Random

Study ID	*n*	Effect (95% CI)	Weight (%)
A.Yu. Anisimov, 2017	22	0.78 [0.35, 1.72]	69.30
M.V. Pogorelov, 2020	16	7.80 [0.38, 161.43]	30.70
Total	**38**	**1.58 [0.18, 13.83]**	**100.00**

2 studies included (*N* = 38)
Heterogeneity: Tau^2 = 1.604, Q = 2.26 (*p* = 0.142), I^2 = 55.68 %
Overall effect test: z = 0.41, *p* = 0,681

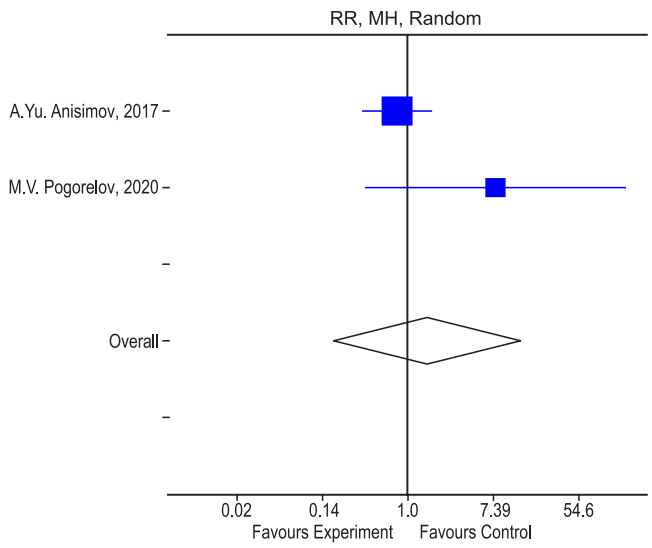

FIG. 17.
Forest plot showing the results of comparing vacuum-assisted laparostomy and programmed relaparotomy by postoperative mortality

The symmetrical funnel plot indicates the absence of obvious systematic publication errors (no publication bias).

DISCUSSION

It is difficult to disagree with the conclusion made by A.V. Sazhin et al. (2020) in their article [7]: "...To date, there are still no clear criteria that allow a practical surgeon to determine the tactics of surgical treatment of widespread peritonitis in a particular patient. A variety of peritoneal inflammation sources, clinical variants of the course of widespread peritonitis and clinical and laboratory changes, combined with the frequent need to use combinations of various treatment methods during surgery and in the postoperative period, explain the need for comprehensive studies that allow to objectively evaluate the results of a particular surgical treatment of peritonitis." A proper choice of a staged surgical treatment in severe and hemodynamically unstable patients having widespread peritonitis, abdominal trauma combined with compartment syndrome, peritonitis, sepsis can significantly improve their treatment outcomes [1, 2].

In our study, we aimed to compare all three methods of multistage management of such patients, given

Study ID	Experiment Group		Control Group	
	event	number	event	number
V.M. Mutafchiyski, 2016	14	49	31	59
T.K. Bee, 2008	8	31	5	20
S. Batacchi, 2009	8	35	11	31
D.V. Cherdantsev, 2016	6	26	14	30
F. Coccolini, 2017	23	163	20	117
F. Coccolini, 2017	11	47	9	42
I. Pliakos, 2012	10	27	14	31

RR, MH, Fixed

Study ID	*n*	Effect (95% CI)	Weight (%)
V.M. Mutafchiyski, 2016	108	0.54 [0.33, 0.90]	26.87
T.K. Bee, 2008	51	1.03 [0.39, 2.71]	5.81
S. Batacchi, 2009	66	0.64 [0.30, 1.39]	11.14
D.V. Cherdantsev, 2016	56	0.49 [0.22, 1.10]	12.42
F. Coccolini, 2017	280	0.83 [0.48, 1.43]	22.24
F. Coccolini, 2017	89	1.09 [0.50, 2.37]	9.08
I. Pliakos, 2012	58	0.82 [0.44, 1.53]	12.45
Total	**708**	**0.72 [0.56, 0.93]**	**100.00**

7 studies included (*N* = 708)
Heterogeneity: Q = 4.16 (*p* = 0.655), I^2 = 0 %
Overall effect test: z = 2.52, *p* = 0,012

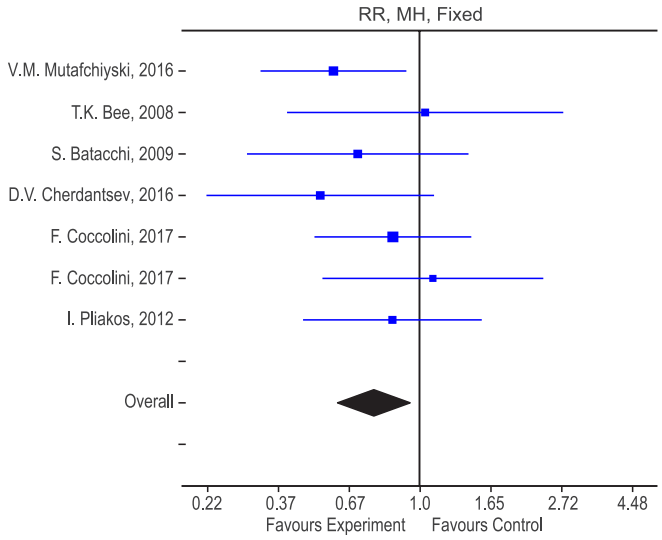

FIG. 18.
Forest plot showing the results of comparing vacuum-assisted laparostomy and laparostomy without vacuum by postoperative mortality

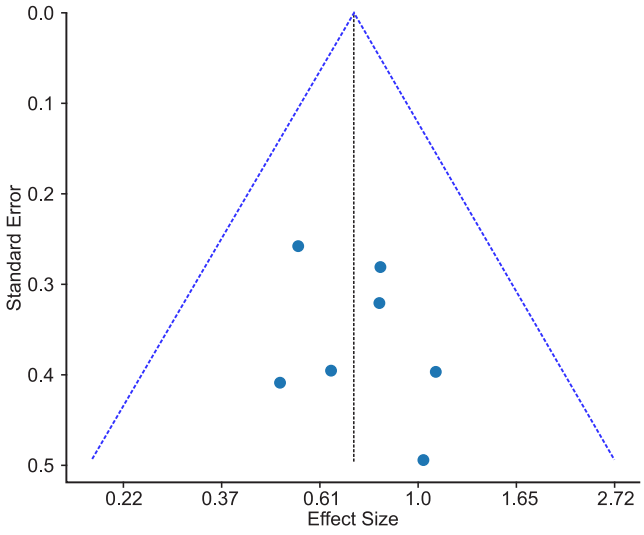

FIG. 19.
Funnel plot of evaluation of the systematic error of publications by postoperative mortality after vacuum-assisted laparostomy and other variants of laparostomy without vacuum

that such studies have not been conducted before. Indications for this or that method of repeated surgical intervention have not yet been clearly given. It is believed that on-demand relaparotomy is indicated in the case of a complication requiring surgery, with negative dynamics of the patient for whom, during the initial surgery for peritonitis or abdominal trauma, there was no need for repeated planned interventions on the abdominal cavity. If the mode of programmed staged re-operations is selected within the framework of *source control* or *damage control* strategies due to the severity of peritonitis, abdominal trauma or the severity of the patient's condition, the surgeon (during the first intervention) determines the need for repeated operations after a certain time interval. Laparostomy technique or "open abdomen" technique implies a negative dynamics in the patient's condition in the form of an increase in intra-abdominal pressure when trying to reduce the edges of aponeurosis and skin and therefore requires temporary closure of the laparotomy wound in other ways. The indications for programmed relaparotomy and laparostomy are nor dissimilar, but it is the presence of IAHS that requires the performance of "open abdomen" technique. The technique of vacuum-assisted laparostomy is promising, but not without its drawbacks. Discussions continue regarding the timing of laparostomy, especially in severely traumatized patients and patients with peritonitis, pancreonecrosis, how to avoid the formation of a "frozen abdomen", methods of final wound closure, complications associated with the possible use of vacuum, advantages and disadvantages of a particular laparostomy technique, expediency and method of reapproximation (medializations) of the edges of a laparotomy wound, and certainly about mortality.

In 2015, in an article by F. Coccolini et al. [10] "The open abdomen, indications, management and definitive closure", published in the World Journal of Emergency Surgery, it was noted that the primary closure of the laparotomy wound during laparostomy is most appropriate in the first 7–8 days after the start of using this technique, and then, in 2017, F. Coccolini et al. [28] specify that this is indicated in the case of elimination of the source of peritonitis, hypoperfusion, when the patient is hemodynamically stable, and when there is no risk of IAHS development or its progression. Subsequently,

the probability of both purulent-septic complications and complications associated with intra-abdominal hypertension increases, and either this requires the use of implants to close the defect of the anterior abdominal wall, or healing takes place by secondary tension with the expected formation of a postoperative hernia and its subsequent surgical treatment [19, 29].

J.J. Atema et al. (2015) [51] in their systematic review and meta-analysis of "open abdomen" in non-traumatized patients (74 studies, 1 RCT, 4,358 patients). MPI averaged 24–34 points, APACHE II – 12–30 points, and the average frequency of successful muscular-aponeurotic closure was 50.2 % (95% CI: 43.4–57.0 %; p (χ^2) < 0.001; I^2 = 90 %), with successful closure being statistically significantly more often observed with laparostomy wound medialization and vacuum techniques, less often with mesh without vacuum and "zip" techniques. The average frequency of enterocutaneous fistula formation was 12.1 % (95% CI: 10.1–14.4 %; p (χ^2) < 0.001; I^2 = 67 %); the highest rate (17.2 %) was observed with the use of mesh, the lowest (5.7 %) – with vacuum laparostomy with wound medialization. Mortality was 30 % (95% CI: 27.1–33.0 %; p (χ^2) < 0.001; I^2 = 69 %).

A.E. Sharrock et al. (2016) [11] conducted a systematic review and meta-analysis on the management of "open abdomen" in traumatized patients as part of *damage control* tactics (26 studies, 1,341 patients) and obtained the following results: the severity of injuries as per the ISS Scale ranged from 19 to 37 points; mortality was 6.07 % (95% CI: 2.61–9.52 %); average laparostomy closure time was 6.62 days (95% CI: 5.44–7.81); average hospital stay duration was 18.57 days (95% CI: 5.150–31.981); overall complication rate was 19.99 % (95% CI: 13.49–26.49 %), with a complication rate of 16.74 % (95% CI: 9.70–23.77 %) for early abdominal closure and 40.85 % (95% CI: 27.90–53.80 %) for late, mesh-assisted closure.

A. Cristaudo et al. (2017) [52] conducted a systematic review and meta-analysis on the analysis of complications and mortality among patients with "open abdomen" (228 studies, 6 RCTs, 13,650 patients). The average frequency of successful muscular-aponeurotic closure was 55 % (95% CI: 52–59 %), and it was also more frequent with laparostomy wound medialization and vacuum techniques (76 %); mortality was 27 % (95% CI: 25–29 %). The average frequency of enterocutaneous fistula formation was 8.5 % (95% CI: 7.4–9.7 %); when comparing vacuum laparostomy and vacuum combined with wound medialization techniques, their number was statistically significantly lower in the second case. The frequency of intra-abdominal abscesses – 13 % (95% CI: 11–16 %); the frequency of postoperative hernias – 15 % (95% CI: 12–19 %) [52].

F. Coccolini et al. (2017) [28] with the grade of recommendations and reliability of the evidence B1 did not recommend the management of laparostomy without negative pressure therapy – only with a mesh or a Bogota bag [28]. 3,125 patients with "open abdomen" were analyzed, 1,942 (62 %) managed to achieve early (within 4-7 days) muscular-aponeurotic closure, which was a factor reducing mortality (12.3 % vs. 24.8 %; RR = 0.53; p < 0.0001) and complication rate (RR = 0.68; p < 0.0001) [28]. Patients with abdominal sepsis are less prone to early muscular-aponeurotic closure, therefore, closure attempts should be made as early as possible after severe abdominal sepsis has been stopped [28].

In a joint study of the S.M. Kirov Military Medical Academy (St. Petersburg) and St. Petersburg Scientific Research Institute of Emergency Care named after I.I. Dzhanelidze, it was noted that the use of VAC-therapy in the treatment of secondary peritonitis reduced mortality from 59 % to 14 %, the frequency of complications in the form of fistula formation – from 7 % to 2.6 % (cit. according to [53]). With IAHS, the use of the method allows primary muscle-aponeurotic closure in 78 % of cases compared to 12.5 % achieved using classical treatment methods (cit. according to [53]).

The development of laparostomy technologies is nonstop. In the first decade of the XXI century, the vacuum-instillation technique of laparostomy management began to be widely used, and the evaluation of the results continues to this day [6]. V.A. Shapkina (2017) [6] evaluated the effectiveness of VAC-laparostomy in combination with fractional flow-instillation technique (n = 25) and without it (n = 24) in the treatment of widespread peritonitis in groups of patients comparable in initial severity (SAPS ≥ 8), MSF severity (SOFA ≥ 12) and severity of abdominal organ diseases (MPI ≥ 20; abdominal index ≥ 13). The author has shown a more rapid decrease in intoxication, normalization of the abdominal cavity, fewer complications (52 % vs. 72 %; fistulas – 47 % vs. 62 %; suppuration of the postoperative wound – 18 % vs. 23 %) and lower mortality (20.8 % vs. 26 %) in the vacuum-instillation laparostomy group [6].

At the same time, D.V. Cherdantsev et al. (2018) [54] published their experience of using vacuum-instillation laparostomy. The study included 47 patients with widespread purulent peritonitis who were divided into 2 groups: the first – 23 patients who had a standard vacuum-assisted laparostomy with the use of VivanoTec device (Hartmann, Germany) in constant vacuuming mode with negative pressure of 120 mm Hg; the second – 24 patients who had vacuum-instillation laparostomy in the perioperative period [54] (cit. according to [53]). The conclusions were made that there were no reliable data on mortality reduction when using vacuum-instillation laparostomy compared to vacuum-assisted laparostomy [54] (cit. according to [53]).

The emergence of systems and methods for wound medialization (ABRA system, abdominal reapproximation anchor system; VAWCM, vacuum-assisted wound closure and mesh-mediated fascial traction, etc.) has improved the treatment results of patients with "open abdomen" in terms of reduced time and increased proportion of primary closure of the abdominal cavity, fewer complications, in particular fistulas, and mortality, respectively [10, 11, 28, 51, 52].

According to many authors, the use of VAC-therapy in the treatment of secondary peritonitis can reduce

the number of repeated lavage relaparotomies, shorten the time of laparotomy wound closure, and reduce the risks of postoperative complications [28, 29, 53]. In our study, we have not obtained such data: on the contrary, when using programmed relaparotomy tactics, statistically significantly fewer repeated interventions were required.

According to the 2017 IROA data, the VAC-laparostomy technique has the lowest mortality rate in comparison with other types of laparostomy without vacuum [9], but ranks second in the risk of enterocutaneous fistula formation [7, 28, 29]. We have not obtained statistically significant differences in the frequency of enterocutaneous fistula occurrence between vacuum-assisted laparostomy and laparostomy without vacuum. At the same time, it can be stated that in terms of length of ICU stay, duration of inpatient care and, most importantly, mortality, statistically significantly better results were obtained while using vacuum than in "open abdomen" without vacuum. And if these differences are not associated with postoperative complications, the timing of the final closure of the abdominal cavity and the number of patients who managed to close the abdominal cavity, it is likely to be due to faster relief of IAHS when using vacuum, given that in the compared cohorts the patients were comparable in severity of condition, severity of peritonitis, hemodynamic parameters.

Obviously, like all meta-analysis, ours has significant limitations. We have found only one RCT (of low quality) comparing the results of VAC-laparostomy with other variants of laparostomy without vacuum; the others are presented by prospective, retrospective and combined cohort studies. There has been a restriction on the search for non-randomized studies since 2007; there has been no such restriction for RCTs. Only full-text articles without language restrictions have been used. Not all studies clearly differentiated by subgroups of patients with abdominal trauma, peritonitis, and other intra-abdominal conditions that caused the transition to the multistage treatment tactics, and, accordingly, the conclusions were not differentiated by these subgroups. We have not aimed to compare different methods of vacuum-assisted laparostomy with each other, but only evaluated possible advantages of vacuum over other technologies of multistage treatment without vacuum aspiration.

CONCLUSION

The results of comparing VAC-laparostomy with other multistage treatment options during our meta-analysis are summarized in Table 2.

The findings of this meta-analysis are as follows:

1. There are no statistically significant differences between vacuum-assisted laparostomy and on-demand relaparotomy in the number of necessary reoperations ($p = 0.319$). The level of evidence (LE) 2, the grade of recommendations (GR) B in accordance with the recommendations of the Center for Healthcare Quality Assessment and Control of the Ministry of Health of the Russian Federation [31].

TABLE 2

RESULTS OF COMPARISON OF VACUUM-ASSISTED LAPAROSTOMY WITH OTHER OPTIONS FOR MULTISTAGE TREATMENT

Methods compared with VAC-laparostomy	Comparison parameters						
	Number of repeated operations required	Number of patients with successful abdominal closure	Average timing of the final closure of the abdominal cavity	Postoperative complications	Average duration of patients' stay in the ICU	Average length of stay in hospital	Postoperative mortality
On-demand relaparotomy	$p = 0.319$	no data	no data	no data	$p = 0.889$	$p = 0.749$	$p = 0.097$
Programmed relaparotomy	**$p = 0.023$** [23, 27]	no data	no data	no data	no data	no data	$p = 0.681$
Laparostomy without vacuum	$p = 0.053$	$p = 0.333$	$p = 0.192$	$p = 0.371$ $p = 0.250$	**$p = 0.000$** [9, 20]	**$p = 0.000$** [20, 62]	**$p = 0.012$** [9, 13, 20, 29, 47, 49]

2. The number of required reoperations with programmed relaparotomies is statistically significantly lower than with vacuum-assisted laparostomy (RR = 2.94 (95% CI: 1.16–7.44); $p = 0.023$). LE 2, GR B [31].

3. There are no statistically significant differences in the number of required reoperations with vacuum laparostomy and laparostomy without vacuum ($p = 0.053$). LE 2, GR B [31].

4. There are no statistically significant differences in the number of patients with successful closure of the abdominal cavity after vacuum-assisted laparostomy or other variants of laparostomy without vacuum ($p = 0.333$). LE 1, GR C [31].

5. The average time of final closure of the abdominal cavity after vacuum-assisted laparostomy and other variants of laparostomy without vacuum do not differ statistically significantly ($p = 0.192$). LE 2, GR B [31].

6. There are no statistically significant differences between vacuum-assisted laparostomy and other variants of laparostomy without vacuum in the frequency of enterocutaneous fistula occurrence ($p = 0.371$). LE 2, GR B [31].

7. There are no statistically significant differences between vacuum-assisted laparostomy and other variants of laparostomy without vacuum in the frequency of intra-abdominal abscesses ($p = 0.250$). LE 2, GR B [31].

8. The average duration of stay in the ICU after vacuum-assisted laparostomy and on-demand relaparotomy do not differ statistically significantly ($p = 0.889$). LE 2, GR B [31].

9. The average duration of treatment in the ICU after vacuum-assisted laparostomy is statistically significantly shorter than with laparostomy without vacuum (SMD = –0.66 (95% CI: –0.96÷–0.35); $p = 0.000$). LE 2, GR B [31].

10. The average duration of inpatient treatment after vacuum-assisted laparostomy and on-demand relaparotomy does not differ statistically significantly ($p = 0.749$). LE 2, GR B [31].

11. The average duration of inpatient treatment after vacuum-assisted laparostomy is statistically significantly shorter than with laparostomy without vacuum (SMD = –0.74 (95% CI: –1.05÷–0.43); $p = 0.000$)). LE 2, GR B [31].

12. Postoperative mortality after vacuum-assisted laparostomy does not significantly differ from that after on-demand relaparotomies ($p = 0.097$). LE 2, GR B [31].

13. Postoperative mortality after vacuum-assisted laparostomy does not significantly differ from that after programmed relaparotomy ($p = 0.681$). LE 2, GR B [31].

14. Mortality after vacuum-assisted laparostomy is statistically significantly lower in comparison with other types of laparostomy without vacuum (HR = 0.72 (95% CI: 0.56–0.93); $p = 0.012$). LE 1, GR C [31].

KEY TAKEAWAYS

Based on the results of national and international studies and our meta-analysis, we can point out the validity and effectiveness of vacuum-assisted laparostomy in the treatment of severe abdominal trauma and urgent abdominal pathology with compartment syndrome, peritonitis and sepsis. The technique has a number of advantages over other types of laparostomy without vacuum. We also want to emphasize the expediency of further use of on-demand relaparotomies and programmed relaparotomies with appropriate indications.

Further systematic reviews and meta-analyses based on randomized clinical trials with a well-designed model and high-quality methodology are necessary to provide a higher level of evidence and grade of recommendations.

Conflict of interest

The authors of this article declare no conflict of interest.

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