Hernia
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REVIEW

An evidence map and synthesis review with meta-analysis on the risk of incisional hernia in colorectal surgery with standard closure

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Abstract

Purpose To assess the incidence of incisional hernia (IH) across various type of incisions in colorectal surgery (CS) creating a map of evidence to define research trends, gaps and areas of future interest.

Methods Systematic review of PubMed and Scopus from 2010 onwards. Studies included both open (OS) and laparoscopic (LS). The primary outcome was incidence of IH 12 months after index procedure, secondary outcomes were the study features and their influence on reported proportion of IH. Random effects models were used to calculate pooled proportions. Meta-regression models were performed to explore heterogeneity.

Results Ninetyone studies were included reporting 6473 IH. The pooled proportions of IH for OS were 0.35 (95% CI 0.27–0.44) I^2 0% in midline laparotomies and 0.02 (95% CI 0.00–0.07), I^2 52% for off-midline. In case of LS the pooled proportion of IH for midline extraction sites were 0.10 (95% CI 0.07–0.16), I^2 58% and 0.04 (95% CI 0.03–0.06), I^2 86% in case of off-midline. In Port-site IH was 0.02 (95% CI 0.01–0.04), I^2 82%, and for single incision surgery (SILS) of 0.06—95% CI 0.02–0.15, I^2 81%. In case of stoma reversal sites was 0.20 (95% CI 0.16–0.24).

Conclusion Midline laparotomies and stoma reversal sites are at high risk for IH and should be considered in research of preventive strategies of closure. After laparoscopic approach IH happens mainly by extraction sites incisions specially midline and also represent an important area of analysis.

Keywords Incisional hernia · Colorectal surgery · Abdominal wall incision · Evidence mapping · Incisional hernia risk · Hernia prevention · Midline and off-midline incision · Stoma reversal

Introduction

Colorectal resection for benign and malignant conditions is one of the most frequent indications for laparotomy. The most feared complication of colorectal surgery is abdominal sepsis secondary to an anastomotic leak, because it poses a great danger to a patient's life, requires repeated surgery and can end in permanent stoma formation. Nevertheless, abdominal closure failure, either early (burst abdomen) or late (incisional hernia) is also a frequent complication with

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associated high costs and a relevant impact on patient's quality of life. It is often overlooked and not considered in trials design. The common reported rate for colorectal surgery anastomosis leakage ranges from 1 to 19% [1] with a mortality rate of 15–35% [2, 3]. Burst abdomen incidence is 0.4–3.5% with a reported mortality of up to 45% [4], percentages of incisional hernia up to 40% have been described in the colorectal surgery field [5] with a pooled mortality ranging from 0 to 5% in complex abdominal cases [6].

Nowadays, for colorectal surgery, the abdominal cavity can be accessed by means of laparotomies in the midline or off-midline, or it can be accessed through trocar orifices used in minimally invasive surgery. In the previous context, it has been shown that incisional hernia risk is present on several type of incisions performed not only in the midline but also off-midline and transverse, in stoma reversal sites, as well as in trocar and specimen extraction sites for minimal invasive surgery.

Evidences and recommandations exists on the use of transverse and off-midline incisions to acces the abdominal cavity clearly showing a reduction of incisional hernia [7, 8]. On abdominal closure, despite several data from high quality trials [9, 10] showing the effectiveness of enhanced closure techniques, namely, small bites and prophylactic mesh augmentation, still little attention is being paid by surgeons when accessing or closing the abdominal cavity [11–13].

The aim of the present study is to explore the incidence of incisional hernia after surgical access to the abdominal cavity to accomplish resection, extraction or anastomosis of a bowel segment for colorectal benign and malignant diseases, irrespective of surgical approach to:

1. synthesize the known evidence for Incisional Hernia in different abdominal wall access options in colorectal surgery
2. create a map of the empirical research that has been undertaken on incisional hernia in colorectal surgery to inform discussions on what future research might usefully address

Methods

Review design and registration

A systematic review with meta-analysis and meta-regression assessing proportion of incisional hernia in colorectal studies was conducted according to the Preferred Reporting Items for Systematic reviews and Meta-analysis (PRISMA) statement [14] and Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines [15]. For the specific aim of this review and the heterogeneity of publications involved we also adopted the methodology of a mapping review which is a systematic search of a broad field to identify gaps in knowledge and/or future research needs that presents results in a user-friendly format (a visual figure or graph) [16].

The present review was registered in Research Registry with the following ID: reviewregistry1000.

Eligibility criteria

Types of studies

Randomized controlled trials, observational studies (case–control and case series) and studies from registries were eligible for the present review if they enrolled at least 15 patients, clearly stated the route of access to the peritoneal cavity through the abdominal wall, reported incisional hernia rates and have a follow-up longer than 12 months. Case reports, protocols and letters to the editor were not considered. Systematic reviews and meta-analyses were checked for references but not used for the present study. No restriction was applied on the technique to access the peritoneal cavity or the way of incisional hernia assessment (radiological, clinical, based on subsequent incisional hernia repairs). Papers on stoma construction, small bowel diseases (IBD, malignancy), perineal wound of abdomino-perineal rectal excision and appendectomies were excluded. The search was restricted to English language only.

Types of participants and interventions

Adult patients operated on for a diagnosis of colorectal disease were selected. In case of repeated publications of the same cohort, only the most recent study or the one with higher number of patients was analyzed.

For the present review open, laparoscopic, single incision and robotic procedures were included when adopted for primary resection, stoma reversal or stoma closure.

Type of outcome measures

Primary outcome was the proportion of incisional hernia in each type of incision. In case of comparative studies on prevention, the arm with enhanced closure technique (small bites or mesh augmentation) was not evaluated; in case of studies comparing different access technique (standard laparoscopy vs single incision or open vs laparoscopic) both arms were entered in the analysis separately for the correspondent incision.

Secondary outcomes: the bibliometric characteristics of the studies were entered to define their relationship with the incisional hernia reported proportion.

Information sources and literature search

We conducted a systematic literature search of Pubmed, Embase and Scopus databases in the last eleven years (from 01/01/2010 to 01/03/2021). The search was run on June 1st, 2021, the last was performed before submitting the paper. Search strategy with full search details and strings are presented in Supplementary Material 1.

Study selection and data extraction

The search and study selection were conducted in an unblinded manner, independently by two authors (CS and SCG), in case of disagreement a third author was involved (MLC) to reach consensus. Data extraction was performed with predefined electronic sheets by two authors (CS and SCG). Information as extracted from each included article on: study type, country, setting (elective/emergent), disease, total number of patients enrolled, type of incision (midline, off-midline), use of incision (formal laparotomy, extraction site, port-site); follow-up length; incisional hernia assessment; incisional hernia occurrence; incidence of pain, bulging, closure technique.

Risk of bias assessment

The internal validity of studies and factors influencing the quality of evidence across studies for different outcomes (i.e., external validity) were assessed using Methodological Index for Non-Randomized Studies (MINORS) [17] in case of observational studies (case–control and cohort studies) and Jadad score [18] in case of randomized controlled trials (RCT). Based on the study design, the studies were considered of good quality when an RCT was rated with a Jadad score of 6 or more a case–control study with a MINORS score of 16 or more or a case report with a MINORS score of 12 or more.

The risk of bias in individual studies was assessed by the same two reviewers (CS and SCG). Publication bias was evaluated using funnel plots and Egger regression symmetry tests [19].

Summary measures and planned methods of analysis

To generate evidence maps to show research trends and gaps papers were divided into seven categories according to the topic (type of incision used during intervention): midline, off-midline for open surgery. Extraction site midline, extraction site off-midline, port-site, Single Incision Laparoscopic Surgery (SILS) for minimally invasive surgery and stoma reversal. Studies were arbitrary divided in four categories according to design and reliability of data: RCTs on prevention of incisional hernia, general RCTs, national registries and retrospective studies. Based on the technique of assessment papers were further stratified in "radiological" when the diagnosis of incisional hernia was done with either CT or US and "non-radiological" when it was clinical, self-assessed by the patient or based on indirect estimations (incisional hernia repairs). To summarize the landscape of research on incisional hernia, tables were created based on the cross tabulation of article topic and article type, incisional hernia assessment, included population, mean follow-up. Longitudinal trends across type of incision and study type were presented using bubble plots generated by Excel 2016. Bubble dimension was used to depict continuous variables (follow-up, number of studies, sample size).

Single proportion meta-analyses were conducted to pool the incidence of incisional hernia in formal laparotomy, extraction site and port-site for each type of incision (midline, off-midline). The pool estimates with 95% confidence intervals (95% CIs) were obtained from a random intercept logistic regression model. The maximum likelihood incisional hernia approach was used for the estimation of the heterogeneity between studies. Heterogeneity was quantified using the I^2 statistic and was distinguished as low ($I^2 \leq 25\%$), moderate ($I^2 > 25\%$ and $< 75\%$), or high ($I^2 \geq 75\%$) [20].

Study-level characteristics including the type of study (study design), incisional hernia assessment, clinical condition, admission setting, type of incision and study quality that were prespecified as characteristics for assessment of incisional hernia and heterogeneity were evaluated using stratified analyses and meta-regression. $P \leq 0.05$ was considered statistically significant. All analyses were conducted using R Studio (RStudio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston).

Results

The initial search located 4921 records, 20 studies were added through cross-referencing. After screening 569 articles were assessed for eligibility in full text. After this step, 91 papers were chosen for the final analysis. Figure 1 shows the flowchart of the selection process and reasons for exclusions according to PRISMA.

The 91 studies enrolled 6473 incisional hernias reported after 106,147 different laparotomies.

Eleven studies were RCTs [21–31]; three focused on incisional hernia prevention by mesh implantation and eight compared outcomes of different approach techniques (laparoscopy vs open, single incision surgery vs laparoscopy,

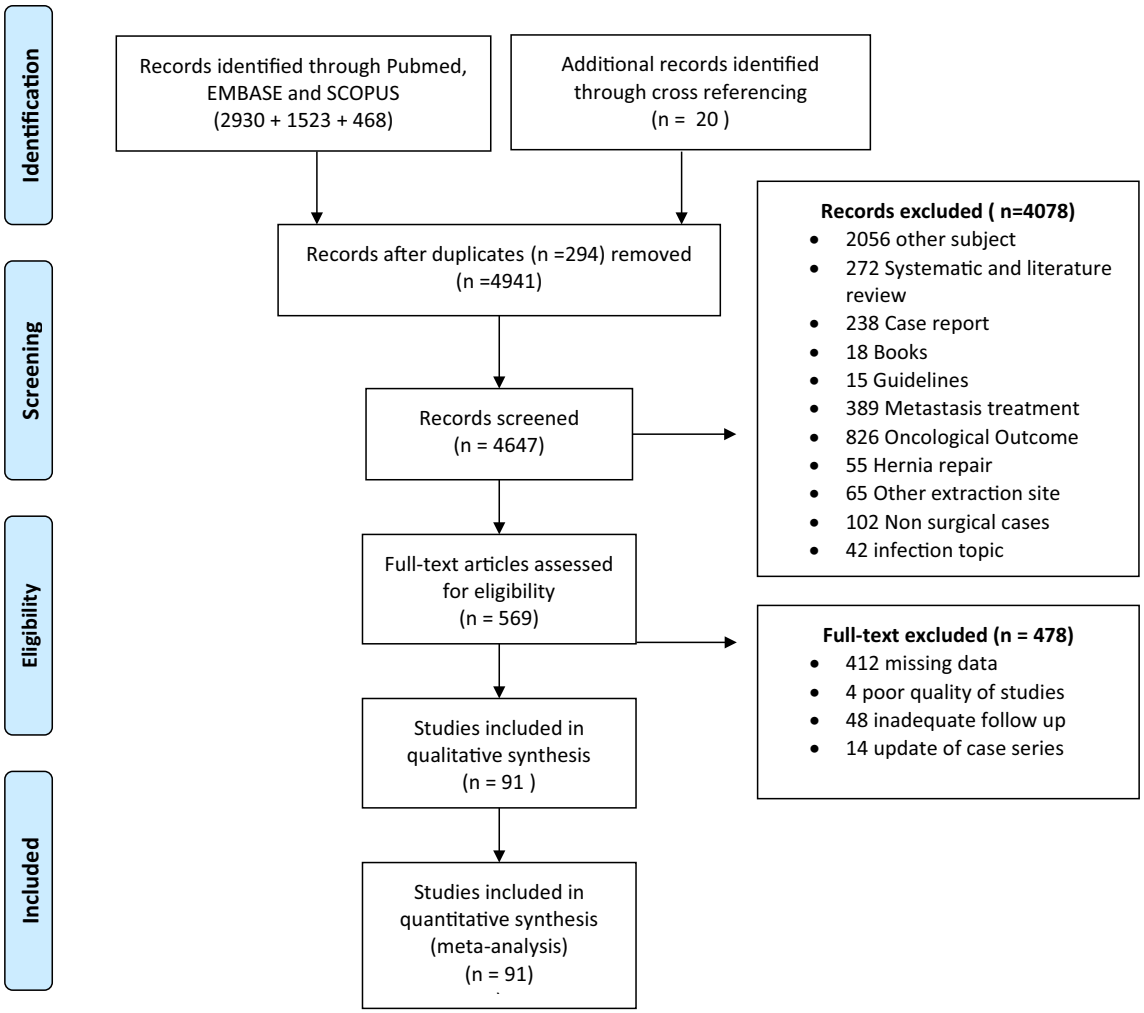

Fig. 1 PRISMA flowchart for study selection

midline vs transverse incision). Eighty papers were retrospective studies: 24 case control [32–55], 50 case series [56–105], six reported results from national registries [106–111]. Table 1 summarizes study characteristics.

Open surgery

Midline and off-midline laparotomies

Thirty-five articles were eligible for analysis of midline laparotomy in open surgery accounting for 75,508 patients, seven papers were RCT (two on incisional hernia prevention) [21, 23–26, 28, 29, 103], 22 retrospective studies [32, 33, 36, 37, 43, 44, 49, 54, 56, 57, 59, 63, 64, 66, 67, 70, 76, 78, 88, 103, 105], six reports from national registries [106–111]. The pooled proportion of incisional hernia varied significantly ($P < 0.01$) across studies: in RCTs on prevention it was 0.35 (95% CI 0.27–0.44) I^2 0%, in general RCTs it was 0.11 (95% CI 0.08–0.17) I^2 81%, in retrospective studies it was 0.14 (95% CI 0.10–0.20) I^2 97%, and in registries it was only 0.04 (95% CI 0.03–0.07) I^2 99% (Fig. 2). The pooled proportion of incisional hernia varied also according to the type of assessment of incisional hernia ($P < 0.01$) and was higher in trials adopting radiological in comparison to clinical assessment follow-up (0.26—95% CI 0.13–0.45—I^2 94% vs 0.10, 95% CI 0.07–0.13—I^2 99%).

Six articles dealing with off-midline incisions were retrieved accounting for 515 patients: two were RCT [21, 29] (377 patients); four were retrospective studies [35, 53, 88, 100] (138 patients). The pooled proportion of incisional hernia in RCT was 0.02 (95% CI 0.00–0.07), I^2 52% and in retrospective studies 0.03 (95% CI 0.00–0.32) I^2 87%, without statistical differences. No further analysis was available for this type of incision.

Table 1 .Characteristics of included studies

References	Nation	Study type	Total number of patients	Type of incision	IH	IH assesment	F-UP (months)	Quality assessment (Jadad score or MINORS)	Primary/ secondary outcome
Bhangu (2020) (ROCSS Trial) [13]	Europe	Rct Prevention	327	Stoma reversal	64	Non radiological	24	8	Primary
Caro Tarrago (2014) [15]	Spain	Rct Prevention	63	Open, midline	24	Non radiological	15	6.5	Primary
Garcia Urena (2015) [16]	Spain	Rct Prevention	54	Open, midline	17	Radiological	24	7.5	Primary
Bartels (2014) [12]	Netherlands	RCT	31	Laparoscopy, extr site midline	7	Non Radiological	41	4	Primary
			126	Laparoscopy, extr off midline	4				
			159	Open, midline	30				
			32	Open, off midline	2				
Braga (2011) [14]	Italy	RCT	332	Open, midline	22	Non Radiological	69	7.5	Secondary
Gervaz (2011) [17]	Switzerland	RCT	54	Laparoscopy, Extr site off mid	7	Non radiological	30	5	Secondary
			51	Open, midline	5				
Lee (2018) [18]	Canada	RCT	73	Laparoscopy, Extr site midline	10	Non radiological	30	5	Primary
			68	Laparoscoy, Extr site off midline	4				
Pecorelli (2016) [19]	Italy	RCT	309	Laparoscopy, Extr lap midline	18	Non radiological	131	6	Secondary
			295	Open, midline	24				
Petersson (2018) [20]	Sweden	RCT	345	Open, midline	59	Non radiological	61	4	Primary
			345	Open, off midline	3				
Tan (2015) [21]	Singapore	RCT	20	Laparoscopy, extr site midline	1	Non radiological	30	6	Secondary
			20	Laparoscopy, Extr site off midline	0				
Watanabe (2020) [22]	Japan	RCT	100	Laparoscopy, Ext site midline	12	Non radiological	42	8	Primary
			100	Laparoscopy, SILS	9				
Andersen (2018) [97]	Denmark	National registry	3090	Open midline	127	Non radiological	102	12	Primary
			6189	Stoma reversal	6				
Jensen (2020) [98]	Denmark	National registry	8383	Open midline	219	Non radiological	238	10	Primary

Table 1 (continued)

References	Nation	Study type	Total number of patients	Type of incision	IH	IH assesment	F-UP (months)	Quality assessment (Jadad score or MINORS)	Primary/ secondary outcome
Klaristenfeld (2015) [99]	USA	National registry	2793	Laparoscopy, extr site midline	115	Non radiological	25	14	Primary
			1823	Open midline	152				
Seo (2018) [100]	South Korea	National registry	8957	Open midline	156	Non radiological	36	14	Primary
Soderback (2018) [101]	Sweden	National Registry	28,913	Open midline	1352	Non radiological	60	10	Primary
Tang (2018) [102]	Canada	National Registry	13,593	Open midline	1347	Non radiological	60	12	Primary
Alli (2018) [47]	USA	Retrospective, case series	4579	Open midline	594	Non radiological	36	14	Secondary
			515	Stomal Reversal	129				
Aquina (2015) [48]	USA	Retrospective, case series	112	Open midline	30	Non radiological	56	10	Primary
Barranquero (2020) [80]	Spain	Retrospective, case series	129	Stomal reversal	15	Radiological	37		Primary
Benlice (2016) [49]	USA	Retrospective, case series	995	Laparoscopy, ext mid	109	Non radiological	112	16	Primary
			903	Laparoscopy, extr off mid	18				
			192	Open midline	23				
			2148	Laparoscopy, portsite	20				
			54	Laparoscopy, Sils	11				
Bevan (2010) [50]	USA	Retrospective, case series	401	Laparoscopy, portsite	3	Radiological	64	9	Primary
Bohm (2017) [23]	Germany	Retrospective, case control	71	Open midline	21	Non radiological	22	13	Primary
Brook (2018) [51]	UK	Retrospective, case series	193	Stoma reversal	26	Non radiological	21	12	Primary
Calvo Espino (2020) [81]	Spain	Retrospective, case series	202	Stoma reversal	47	Radiological	46	6	Primary
Cascales Campo (2020) [82]	Spain	Retrospective, case series	35	Open midline	9	Radiological	12	10	Primary
Chen (2018) [52]	China	Retrospective, case series	449	Open midline	36	Non radiological	64	16	Secondary
Chen (2019) [24]	Taiwan	Retrospective, case control	625	Open midline	44	Non radiological	71	18	Secondary
Choi (2021) [83]	Korea	Retrospective, case series	1472	Laparoscopy, ext midline	52	Non radiological	41	7	Primary
			1232	Laparoscopy, ext off mid	21				
Claes (2014) [53]	Belgium	Retrospective, case series	372	Open Midline	80	Radiological	33	16	Primary
De Keersmaeker (2015) [54]	Belgium	Retrospective, case series	100	Open Midline	69	Radiological	19	14	Primary
			153	Stoma Reversal	86				
De Robles (2018) [84]	Australia	Retrospective, case series	224	Stoma Reversal	12	Non Radiological	31	9	Primary

Table 1 (continued)

References	Nation	Study type	Total number of patients	Type of incision	IH	IH assesment	F-UP (months)	Quality assessment (Jadad score or MINORS)	Primary/ secondary outcome
De Souza (2011) [41]	USA	Retrospective, case control	231	Laparoscopy, extr mid	37	Radiological	18	15	Primary
			139	Laparoscopy, extr off mid	0				
Eklov (2020) [55]	Sweden	Retrospective, case series	216	Stoma Reversal	16	Non Radiological	30	14	Primary
El Hussuna (2012) [70]	Denmark	Retrospective, case series	159	Open Midline	8	Non Radiological	24	12	Secondary
Erguner (2013) [56]	Turkey	Retrospective, case series	30	Laparoscopy, extr off mid	1	Non Radiological	28	16	Secondary
Fazekas (2017) [57]	UK	Retrospective, case series	121	Stoma reversal	18	Non Radiological	27	14	Primary
Feo (2019) [25]	Italy	Retrospective, case control	49	Laparoscopy, ext mid	12	Radiological	45	20	Secondary
			50	Open Off Midline	0				
Fok (2021) [85]	Hong Kong	Retrospective, case seriesc	90	Stoma Reversal	15	Non Radiological	29	5	Primary
Fukuoka (2020) [86]	Japan	Retrospective, case series	423	Laparoscopy, ext mid	36	Radiological	48	9	Primary
Goldwag (2020) [87]	USA	Retrospective, case series	92	Stoma Reversal	24	Radiological	30	8	Primary
Gomez Ruiz (2020) [58]	Spain	Retrospective, case series	198	Open midline	4	Non radiological	28	14	Secondary
Harr (2016) [59]	USA	Retrospective, case series	113	Laparoscopy, ext mid	14	Non radiological	15	10	Primary
			146	Laparoscopy, extr off mid	1				
Huang (2015) [26]	China	Retrospective, case control	492	Laparoscopy, portsite	4	Non radiological	55	17	Secondary
			424	Open midline	10				
Ihnat (2011) [60]	Czech Republic	Retrospective, case series	51	Stoma reversal	16	Non radiological	24	15	Primary
			97	Laparoscopy, ext off mid	7				
Juratli (2018) [27]	Germany	Retrospective, case control	88	Open midline	19	Radiological	24	18	Primary
			88	Stoma reversal	19				
Kaneko (2018) [88]	Japan	Retrospective, case series	134	Stoma reversal	32	Radiological	47	3	Primary
Karakayali (2015) [28]	Turkey	Retrospective, case control	46	Laparoscopy, extr off mid	4	Non radiological	20	14	Secondary
Kelly-Schuette (2020) [61]	USA	Retrospective, case series	243	Stoma reversal	29	Non radiological	50	10	Primary
Kohler (2014) [77]	Austria	Retrospective, case series	14	Stoma Reversal	4	Non Radiological	26	10	Secondary
Krane (2013) [62]	USA	Retrospective, case series	626	Laparoscopy, ext mid	12	Non Radiological	61	16	Secondary

Table 1 (continued)

References	Nation	Study type	Total number of patients	Type of incision	IH	IH assesment	F-UP (months)	Quality assessment (Jadad score or MINORS)	Primary/secondary outcome
Ku (2019) [89]	Korea	Retrospective,	102	Laparoscopy, ext mid	22	Radiological	31	10	Secondary
			87	Laparoscopy, ext off mid	23				
La Chapelle (2019) [90]	USA	Retrospective, case series	164	Laparoscopy, ext mid	23	Non radiological	20	11	Primary
			259	Laparoscopy, ext off mid	26				
Lee (2012) [71]	Canada	Rettrospective, case series	68	Laparoscopy, ect mid	20	Non Radiological	30	16	Primary
			31	Laparoscopy, extr off mid	1				
Li (2017) [72]	China	Retrospective, case series	736	Stoma Reversal	13	Radiological	16	12	Primary
Lim (2013) [29]	South Korea	Retrospective, case control	92	Laparoscopy, ext mid	2	Non Radiological	20	16	Secondary
			55	Laparoscopy, extr off mid	0				
Liu (2013) [42]	Australia	Retrospective, case control	36	Stoma Reversal	13	Radiological	21	16	Primary
Llaguna (2010) [43]	USA	Retrospective, case control	45	Laparoscopy, extr site midline	9	Non radiological	26	9	Primary
			48	Laparoscopy, extr site off midline	5				
Lorenz (2019) [91]	Austria	Retrospective, case series	71	Stoma Reversal	12	Radiological	37	8	Primary
Lorenzon (2016) [63]	Italy	Retrospective, case series	40	Laparoscopy, extr site midline	4	Non radiological	41	16	Secondary
			40	Open, midline	4				
			40	Open, off midline	9				
Lujan (2018) [64]	USA	Retrospective, case series	224	Laparoscopy, extr site off midline	5	Non radiological	30	12	Secondary
Maggiori (2015) [44]	France	Retrospective, case control	64	Stoma reversal	12	Radiological	12	15	Primary
Makni (2013) [45]	Tunisia	Retrospective, case control	64	Laparoscopy, extr site of midline	1	Radiological	30	15	Secondary
			65	Open, midline	4				
Menningen (2011) [78]	Germany	Retrospective, case series	81	Stoma reversal	6	Non Radiological	24	15	Secondary
Mishra (2014) [30]	UK	Retrospective, case control	289	Laparoscopy, extr site off midline	18	Non radiological	44	16	Primary
			786	Open, midline	72				
			289	Laparoscopy, port site	10				

Table 1 (continued)

References	Nation	Study type	Total number of patients	Type of incision	IH	IH assesment	F-UP (months)	Quality assessment (Jadad score or MINORS)	Primary/ secondary outcome
Mongelard (2020) [69]	Denmark	Retrospective, case series	91	Stoma reversal	23	Radiological	48	16	Primary
Morita (2015) [31]	Japan	Retrospective, case control	94	Laparoscopy, extr site midline	1	Radiological	24	15	Primary
			92	Laparoscopy, extr site off midline	6				
Morpurgo (2013) [32]	Italy	Retrospective, case control	96	Laparoscopy, extr site off midline	4	Non radiological	35	13	Secondary
Navaratam (2014) [46]	UK	Retrospective, case control	139	Laparoscopy, extr site midline	5	Non radiological	24	14	Primary
			85	Laparoscopy, extr site off midline	13				
Oriel (2017) [92]	USA	Retrospective, case series	114	Stoma reversal	11	Non Radiological	68	10	Primary
Pares (2016) [65]	UK	Retrospective, case series	135	Laparoscopy, extr site midline	20	Radiological	42	14	Primary
			157	Laparoscopy, extrsite off midline	4				
Pizza (2020) [48]	Italy	Retrospective, case control	58	Stoma Reversal	19	Radiological	12	20	Primary
Pogacnik (2014) [33]	USA	Retrospective, case control	110	Laparoscopy, extr site midline	8	Non radiological	30	16	Primary
			332	Open, midline	43				
Sadava (2014) [73]	Argentina	Retrospective, case series	331	Laparoscopy, extr site off midline	20	Non radiological	54	9	Primary
			710	Laparoscopy, extr site off midline	43				
Saeed (2012) [74]	UK	Retrospective, case series	43	Stoma reversal	2	Radiological	12	9	Primary
Samia (2013) [75]	USA	Retrospective, case series	305	Laparoscopy, extr site midline	27	Non radiological	42	12	Primary
			164	Laparoscopy, extr site off midline	4				
Shapiro (2015) [34]	Israel	Retrospective, case control	36	Laparoscopy, Extr site midline	4	Radiological	34	18	Primary
			78	Laparoscopy, extr site off midline	0				
Sharp (2013) [76]	USA	Retrospective, case series	285	Stoma reversal	44	Non radiological	30	11	Primary

Table 1 (continued)

References	Nation	Study type	Total number of patients	Type of incision	IH	IH assesment	F-UP (months)	Quality assessment (Jadad score or MINORS)	Primary/secondary outcome
Sikorski (2015) [93]	UK	Retrospective, case series	100	Laparoscopy, ext off mid	4	Non radiological	42	13	Secondary
			100	Open, midline	18				
Song (2019) [35]	China	Retrospective, case control	142	Laparoscopy, extr site midline	0	Non radiological	35	15	Secondary
			32	Laparoscopy, SILS	0				
Spinelli (2018) [66]	Italy	Retrospective, case series	20	Laparoscopy, SILS	0	Non radiological	25	7	Secondary
Tanis (2012) [94]	Netherland	Retrospective, case series	30	Laparoscopy, ext mid	2	Non radiological	44	9	Secondary
			22	Open midline	4				
Tokode (2011) [95]	UK	Retrospective, case series	51	Stoma reversal	8	Non radiological	12	6	Secondary
Varathan (2020) [36]	Switzerland	Retrospective, case control	269	Laparoscopy, extr site off midline	10	Non radiological	13	14	Primary
			269	Laparoscopy, PORT site	3				
Veenhof (2010) [37]	Neterlands	Retrospective, case control	25	Laparoscopy, extr site midline	1	Non radiological	18	14	Secondary
			25	Open, off midline	3				
Vestweber (2016) [67]	Germany	Retrospective, case series	329	Laparoscopy, SILS	16	Non radiological	19	11	Secondary
Vignali (2013) [79]	Italy	Retrospective, case control	98	Open, midline	31	Non radiological	62	14	Secondary
			98	Laparoscopy, extr site midline	17				
Vignali (2018) [38]	Italy	Retrospective, case series	128	Laparoscopy, extr site off midline	22	Non radiological	48	19	Secondary
Widmar (2020) [39]	USA	Retrospective, case control	97	Laparoscopy, extr site midline	18	Non radiological	30	17	Primary
			67	Laparoscopy, extr site off midline	2				
Williams (2012) [68]	UK	Retrospective, case series	15	Laparoscopy, extr site off midline	0	Radiological	24	14	Primary
Wong (2020) [96]	Australia	Retrospective, case series	552	Open, midline	77	Non radiological	32	6	Primary

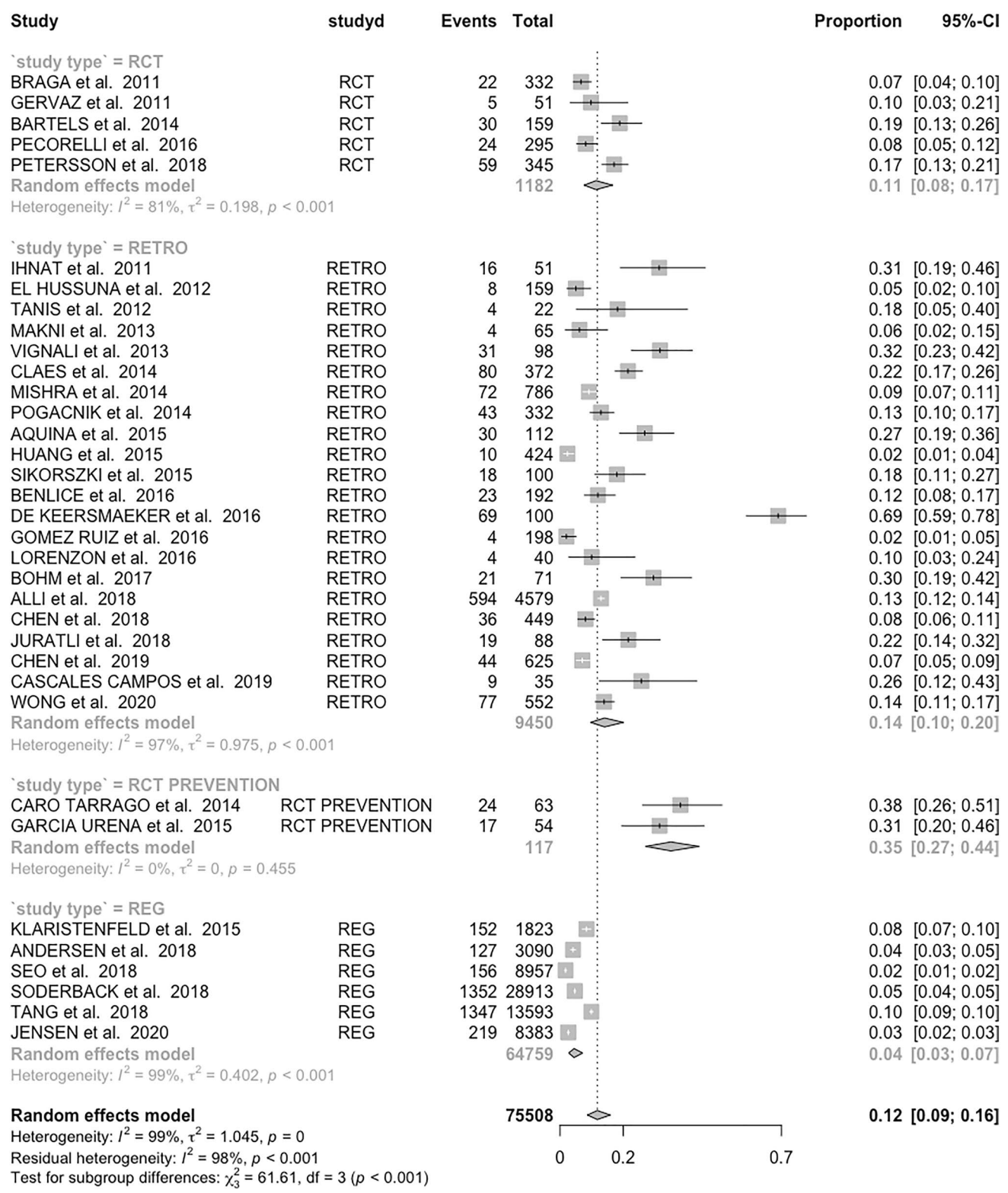

Fig. 2 Pooled proportion meta-analysis of the incidence of IH by study type for open midline laparotomy

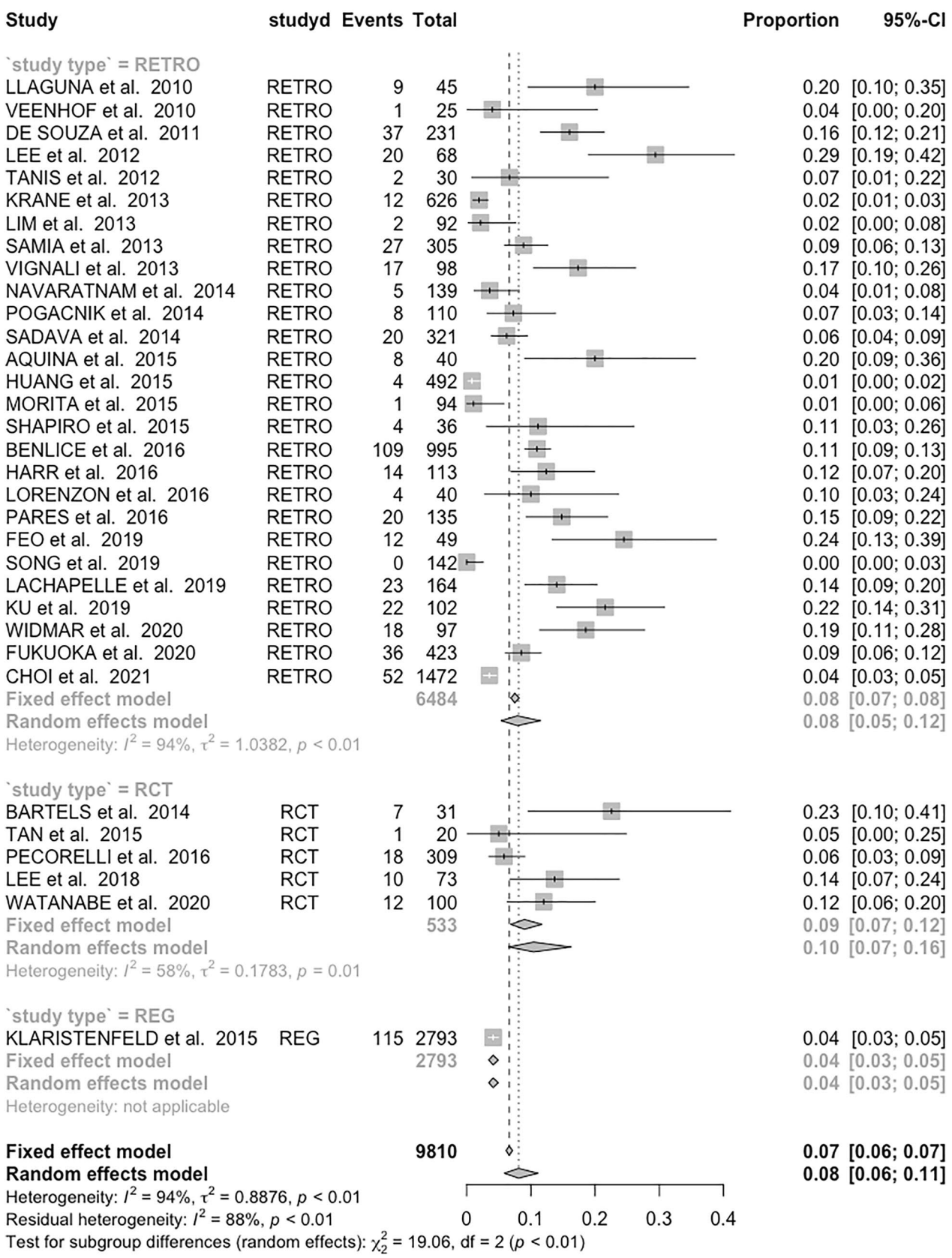

Fig. 3 Pooled proportion meta-analysis of the incidence of IH by study type for midline extraction site in laparoscopic colon resections

Proportion of incisional hernia cases in RCT were compared among midline (seven studies,1299 patients) and off midline incisions (two studies, 377 patients) with a lower occurrence in case of adoption of an off-midline incision 0.02 (95% CI 0.00–0.07), I^2 52%, vs 0.16 (95% CI 0.10–0.25), I^2 91%, P 0.01.

Minimally invasive surgery

Midline and off-midline extraction sites

Thirty-three studies were eligible for analysis of the results of midline extraction site for 9810 patients: five studies were RCT [21, 27, 28, 30, 31] (533 patients), 27 retrospective [34–36, 39, 41, 45, 47, 49–51, 53–55, 57, 59, 65, 74, 77, 82–85, 88, 93, 94, 96, 100] (6484 patients) and one registry [108] (2793 patients). incisional hernia occurrence varied significantly ($P < 0.01$) according to study type: the pooled proportion in RCT was 0.10 (95% CI 0.07–0.16), I^2 58%; in registry 0.04 (95% CI 0.03–0.05), I^2 94% and 0.08 (95% CI 0.05–0.12), I^2 94% in retrospective studies (Fig. 3).

Thirty-one studies (5823 patients) were eligible for off-midline incisions used for extraction of specimens: 4 RCT [21, 26, 27, 30] (268 patients) and 27 retrospective studies [34, 38, 39, 41, 43–47, 50, 52, 55, 57, 59, 65, 71, 77, 83–85, 89, 93, 94, 96, 98, 101, 103, 104] (5555 patients). The pooled proportion of incisional hernia was 0.04 (95% CI 0.03–0.06), I^2 86% and did not vary significantly across study type.

Overall an off-midline extraction site resulted in a lower proportion of incisional hernia compared to midline (0.04—95% CI 0.03–0.06, I^2 86% vs 0.08—95% CI 0.06–0.11, I^2 94%; $P < 0.01$). The difference was not confirmed when only RCTs were analysed.

Port-site

The search retrieved five studies [44, 52, 59, 60, 78] analysing 3204 patients, all the papers were retrospective. The overall pooled proportion of incisional hernia was 0.02 (95% CI 0.01–0.04), I^2 82%; Fig. 4.

SILS The search retrieved five studies (535 patients): one RCT [31], four retrospective case series [51, 59, 99, 102]. The pooled proportion of incisional hernia is 0.06—95% CI 0.02–0.15, I^2 81%.

Open vs minimally invasive surgery

A comparison has been made between open laparotomies and laparoscopic extraction sites to define if the length of incision represented a contributing factor. Incisional hernia proportions in RCTs did not differ among midline laparotomy and midline extraction site (0.16, 95% CI 0.10–0.25 vs 0.10, 95% CI 0.07–0.16, P 0.22) and among off-midline laparotomy and off-midline extraction site (0.01, 95% CI 0.01–0.03 vs 0.06 95% CI 0.03–0.09, P 0.17).

Stoma reversal

Twenty-eight papers were eligible for evaluation reporting results on 10,752 patients: one study was RCT on prevention [22] (327 patients), 26 were retrospective studies [37, 40, 42, 48, 56, 58, 61, 62, 67–69, 72, 73, 75, 79–81, 86, 87, 90–92, 95, 97, 101, 105] (4236 patients) and 1 was a report from a national registry [106] (6189 patients). The proportion of incisional hernia was 0.20 (95% CI 0.16–0.24) in the single RCT, 0.15 (95% CI 0.12–0.20) I^2 92%, in retrospective studies, 0 (95% CI 0–0) in the registry (Fig. 5). The test for subgroup differences was statistically significant showing that

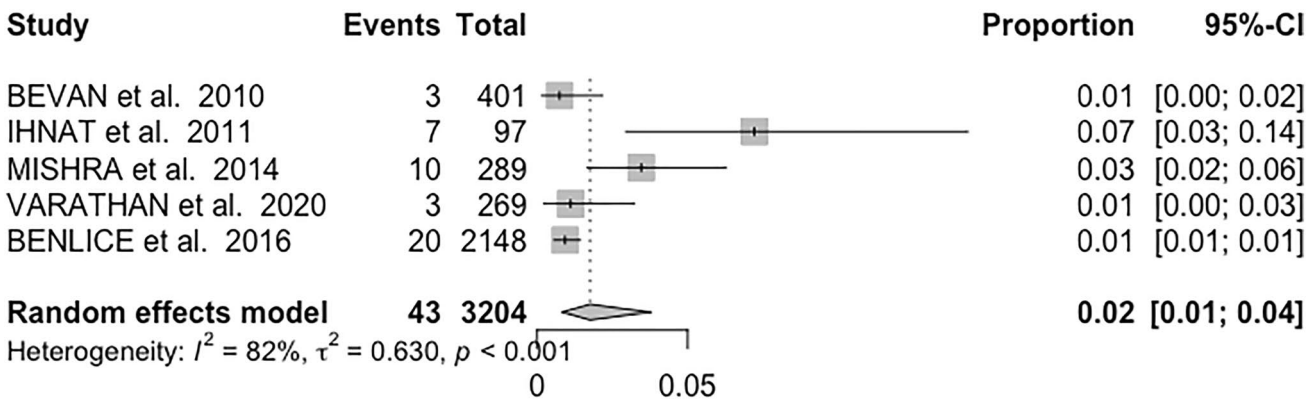

Fig. 4 Pooled proportion meta-analysis of the incidence of IH in laparoscopic port site

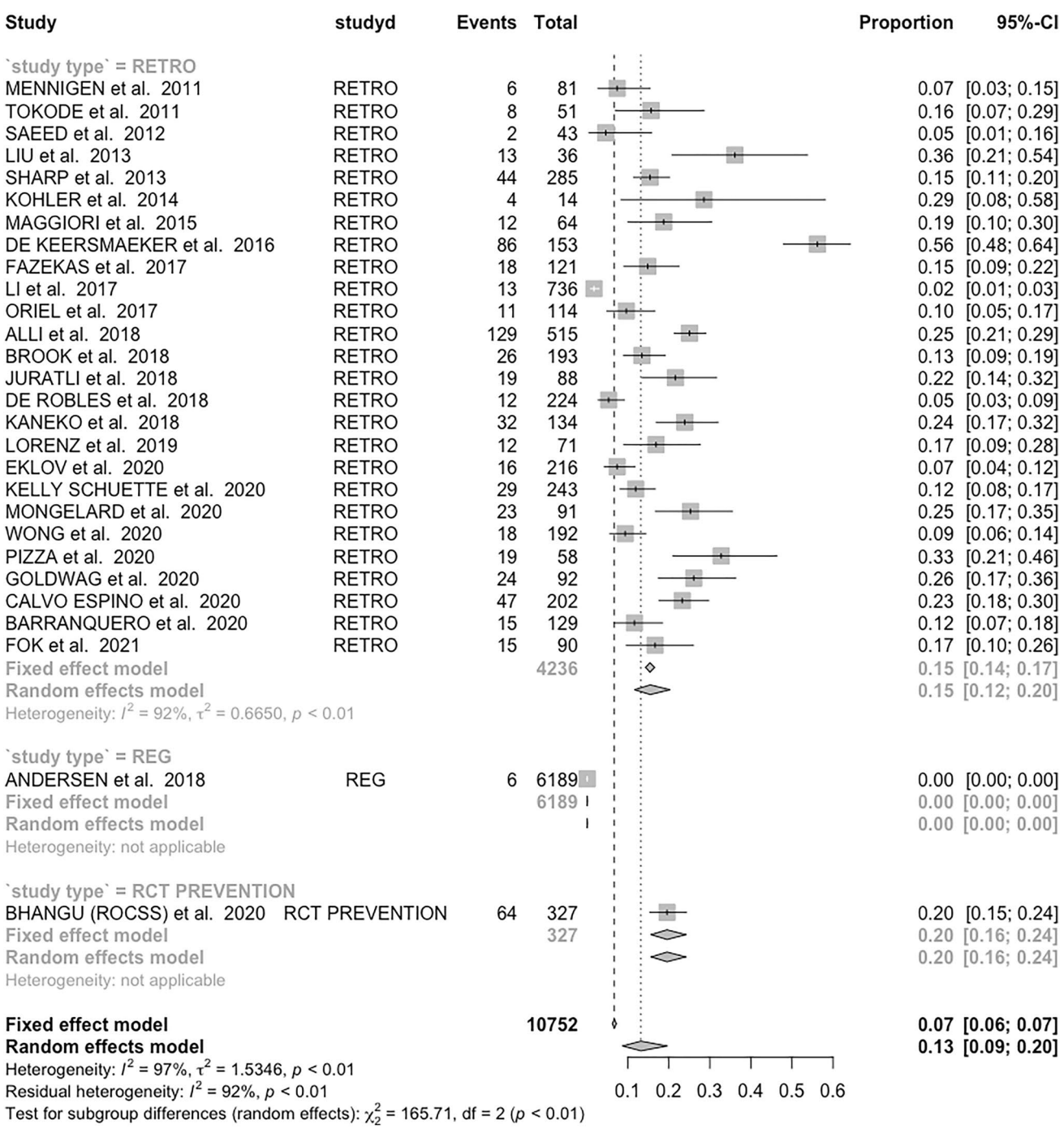

Fig. 5 Pooled proportion meta-analysis of the incidence of IH by study type for stoma reversal site

the proportion of patients in RCT and retrospective studies are higher than those reported by the registry ($P < 0.001$).

Stratified analyses and meta-regression

Table 2 shows stratified analyses for each type of technique. Study level factors that could explain some of the variance were tested in the subsequent meta-regression through a mixed effect regression model including all the considered studies. Follow-up, study design, incisional hernia assessment, type of incision and study quality were the factors selected for the multivariable meta-regression (Table 3). Accordingly, study quality was not eventually associated, while incisional hernia assessment, follow-up period, study

Table 2 Subgroup analyses for each type of incision examined

Subgroup by study characteristics	No of studies	IH	[95% CI]	Heterogeneity I^2 (%)	*P* value
Open midline					
Setting					
Mixed	6	0.09	[0.05; 0.17]	99.0	0.300
Elective	18	0.14	[0.10; 0.19]	95.0	
Study design					
RCT prevention	2	0.35	[0.27; 0.44]	0.0	<0.001
RCT	5	0.11	[0.08; 0.17]	81.3	
Registry	6	0.04	[0.03; 0.07]	99.4	
Retrospective	22	0.14	[0.10; 0.20]	97.0	
Risk factors					
No risk factor	2	0.20	[0.08; 0.40]	65.0	0.660
One risk factor	13	0.16	[0.10; 0.26]	98.0	
More than one	6	0.13	[0.07; 0.21]	99.4	
Clinical condition					
Mixed	10	0.14	[0.10; 0.19]	96.0	0.380
Diverticulitis	1	0.10	[0.04; 0.21]	–	
CCR	23	0.11	[0.07; 0.17]	99.0	
IBD	1	0.06	[0.02; 0.15]	–	
Clinical assessment					
Radiological	6	0.26	[0.13; 0.45]	94.0	<0.001
Non radiological	29	0.10	[0.07; 0.13]	99.0	
Open off-midline					
Study design					
RCT	2	0.02	[0.00; 0.07]	52.1	0.690
Retrospective	4	0.03	[0.00; 0.32]	87.0	
IH port					
Setting					
Mixed	1	0.03	[0.02; 0.06]	81	0.127
Elective	4	0.01	[0.01; 0.04]	–	
Clinical condition					
Mixed	2	0.01	[0.006; 0.014]	0.0	<0.001
Diverticulitis	2	0.04	[0.03; 0.07]	0.0	
CCR	1	0.01	[0.00; 0.03]	–	
Stomal reversal					
Setting					
Elective	12	0.17	[0.13; 0.21]	77.8	
Study design					
RCT prevention	1	0.20	[0.00; 0.03]	–	<0.001
Registry	1	0.001	[0.0004; 0.002]	–	
Retrospective	15	0.15	[0.10; 0.23]	94.9	
Risk factors					
One risk factor	10	0.12	[0.04; 0.30]	98.8	0.825
More than one	3	0.10	[0.02; 0.36]	96.3	
Clinical condition					
Mixed	7	0.14	[0.07; 0.25]	95.2	0.484
CCR	6	0.09	[0.02; 0.39]	98.7	
IBD	1	0.07	[0.03; 0.15]	–	
Clinical assessment					
Radiological	10	0.15	[0.12; 0.20]	82.6	0.387
Non radiological	7	0.08	[0.02; 0.32]	98.4	

Table 2 (continued)

Subgroup by study characteristics	No of studies	IH	[95% CI]	Heterogeneity I^2 (%)	*P* value
IH SILS					
Setting					
Elective	5	0.06	[0.02; 0.15]	81.4	
Study design					
RCT	1	0.09	[0.05; 0.16]	–	0.038
Retrospective	4	0.04	[0.01; 0.22]	88.5	
Risk factors					
No risk factor	3	0.05	[0.04; 0.08]	0.0	<0.001
One risk factor	1	0.00	[0.12; 0.33]	–	
More than one	1	0.20	[0.00; 1.00]	–	
Clinical condition					
Mixed	1	0.20	[0.12; 0.33]	–	<0.001
Diverticulitis	2	0.05	[0.03; 0.07]	0.0	
CCR	2	0.05	[0.00; 0.36]	30	
Clinical assessment					
Non radiological	5	0.06	[0.02; 0.15]	81.4	
Extraction lap off-midline					
Setting					
Mixed	1	0.04	[0.03; 0.06]	–	0.127
Elective	21	0.06	[0.04; 0.10]	79.3	
Study design					
RCT	4	0.05	[0.03; 0.11]	81.3	0.305
Retrospective	23	0.03	[0.02; 0.05]	97.6	
Risk factors					
No risk factor	1	0.03	[0.01; 0.08]	–	0.424
One risk factor	13	0.04	[0.02; 0.07]	84.5	
More than one	6	0.02	[0.01; 0.04]	46.2	
Clinical condition					
Mixed	10	0.04	[0.02; 0.08]	91.6	0.504
Diverticulitis	2	0.06	[0.03; 0.15]	69.8	
CCR	14	0.04	[0.02; 0.05]	31.9	
IBD	1	0.02	[0.00; 0.10]	91.6	
Clinical assessment					
Radiological	6	0.01	[0.00; 0.05]	67.7	0.089
Non radiological	21	0.04	[0.03; 0.07]	78.9	
Extraction lap midline					
Setting					
Mixed	1	0.07	[0.04; 0.14]	–	0.602
Elective	20	0.09	[0.06; 0.13]	90.1	
Study design					
RCT	5	0.10	[0.07; 0.16]	57.7	0.002
Registry	1	0.04	[0.03; 0.05]	–	
Retrospective	22	0.08	[0.05; 0.12]	93.9	
Risk factors					
No risk factor	5	0.05	[0.01; 0.20]	87.6	0.295
One risk factor	8	0.07	[0.04; 0.13]	95.4	
More than one	10	0.12	[0.07; 0.18]	90.2	
Clinical condition					
Mixed	11	0.10	[0.07; 0.14]	91.3	< 0.0001
CCR	16	0.07	[0.04; 0.12]	90.7	

Table 2 (continued)

Subgroup by study characteristics	No of studies	IH	[95% CI]	Heterogeneity I^2 (%)	*P* value
IBD	1	0.02	[0.01; 0.03]	–	
Clinical assessment					
Radiological	3	0.07	[0.02; 0.21]	78.6	0.756
Non radiological	25	0.08	[0.05; 0.12]	94.0	

Table 3 Meta-regression for predictors of the proportion of IH

Association measure		
Factors	Beta (95% CI)	*P* value
Intercept	0.128 (0.061–0.195)	0.0002
Study design (reference = RCT)		
RCT prevention	0.142 (0.026–0.259)	0.016
Registry	−0.113 (−0.182 to −0.043)	0.001
Retrospective	0.125(−0.033 to 0.058)	0.589
Follow-up	0.000 (0.000–0.001)	
Study quality (reference = poor)	0.004 (−0.025 to 0.033)	0.789
Type of incision (reference = ext.lap midline)		
ext.lap off midline	−0.058 (−0.099 to −0.018)	0.005
Open off-midline	−0.040 (−0.117 to 0.036)	0.299
Open midline	0.578 (0.016–0.100)	0.007
SILS	0.036 (−0.013 to 0.041)	0.358
Stoma reversal	0.048 (0.003–0.092)	0.037
Assessment (reference = radiological)		
Non radiological	−0.056 (−0.092 to −0.020)	0.002
τ^2	0.006	

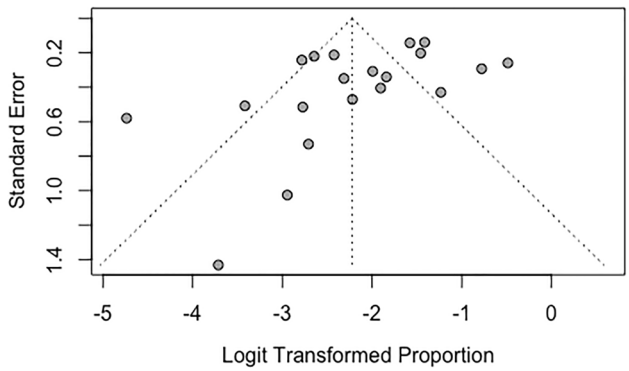

Fig. 6 Funnel plot for publication bias

design and type of incision showed a significant effect in the proportion of incisional hernia explaining 39.62% of the between-study variance ($R^2 = 0.40$, τ^2 total = 0.006). Compared to RCTs, RCTs for prevention were associated with a significant increase in the proportion of incisional hernia, whereas studies using the registries were associated with a significant decrease (reduction). In terms of type of incision compared to extraction lap midline, extraction lap off-midline showed a significant decrease, while open midline and stoma reversal showed both a significant increase in the incisional hernia proportion.

Risk of bias across studies

Publication bias was visually assessed by funnel plots for meta-analyses that included ten or more studies (Fig. 6). On examination, the plot was approximately symmetrical for the meta-analysis of all studies independently by the type of incision used in the surgical intervention and a strong evidence of heterogeneity was observed as well. The Egger test estimate for the asymmetry was not significant ($P = 0.061$).

Evidence maps

Concerning number of enrolled patients (Fig. 7) open midline incision is the most represented population in studies

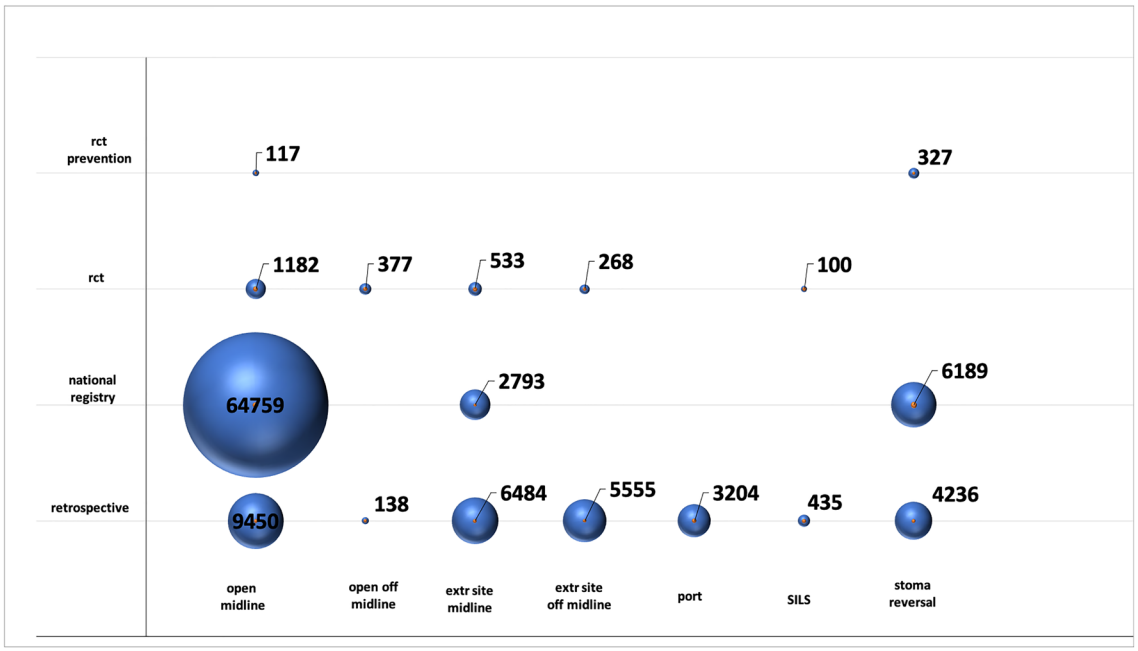

Fig. 7 Bubble plot mapping study type by type of incision, size of the bubble represents number of enrolled patients

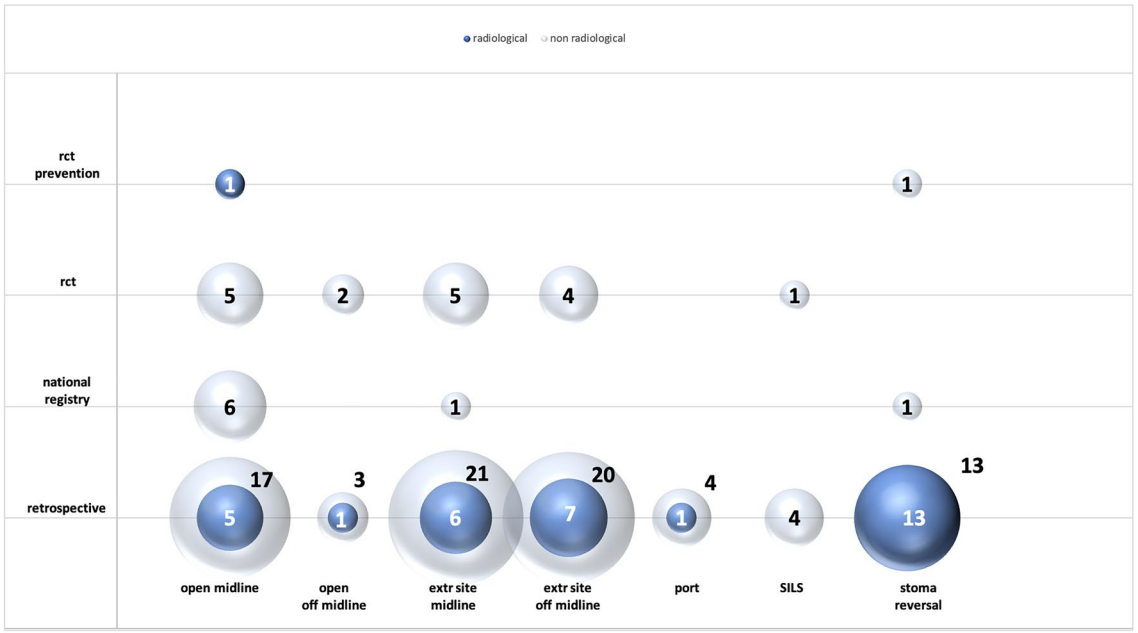

Fig. 8 Bubble plot mapping technique of IH assessment according to study type and type of incision, size of the bubble represents number of studies using radiological (deep blue) or non-radiological assessment

overall, nevertheless the percentage of patients enrolled in RCT on prevention is only 0.15%. Registry studies, as expected, contributed for 86%. Open off-midline incisions were the least represented type (515 patients) but had the highest number of subjects enrolled in RCT (73.2%). Stoma reversal studies analysed a total number of 10,752 patients, among them 3% were those enrolled in prevention trials. SILS had fewer patients enrolled (535 s) and majority in retrospective trials (81%).

Regarding technique of incisional hernia assessment (Fig. 8) among RCT on prevention, irrespective of incision type, only 33% adopted radiology. For midline

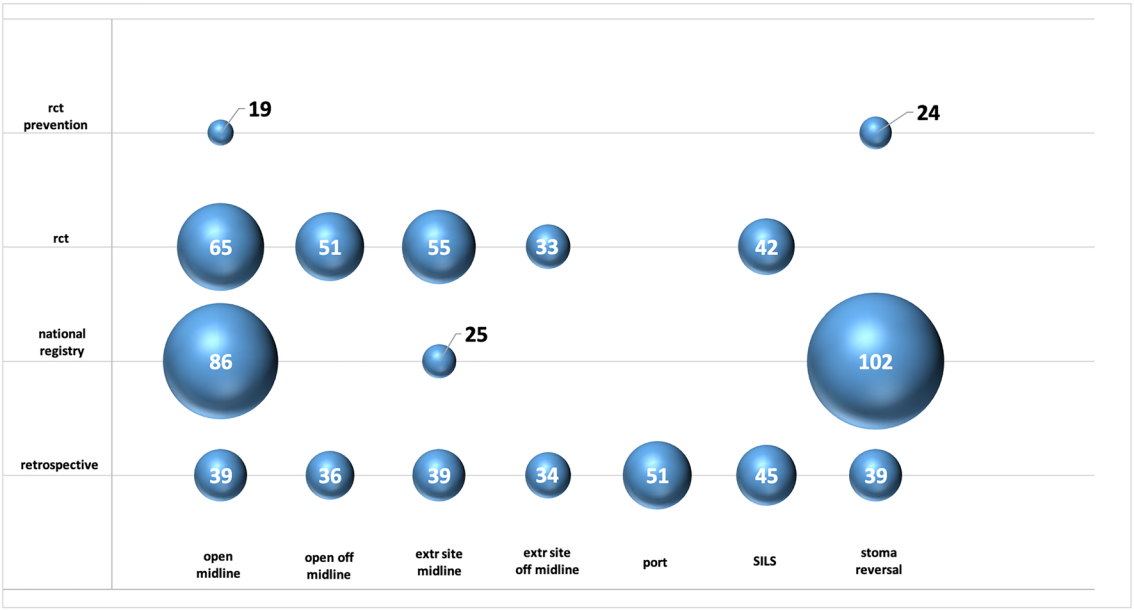

Fig. 9 Bubble plot mapping length of follow-up according to study type and type of incision, bubble size represents mean length of follow-up in months across examined literature

open laparotomy the radiological diagnosis was used in 17% of studies (six studies). Stoma reversal incisional hernia had the highest rate of radiological evaluation performed in 46% of papers (13 studies). None of the studies on SILS assessed incisional hernia by radiological techniques.

By follow-up length (Fig. 9), stoma reversal had the longest time of observation (102 months; range 12–267) in registries. The mean follow-up for RCT on prevention was 19 months (range 15–24) for open midline incision and 24 months for stoma reversal (one trial). The lowest mean follow-up length is registered in trials on off-midline extraction site in laparoscopy (33 months; range 30–41 in RCT and 34 months; range 13–112 months in retrospective studies).

Discussion

In our study the proportion of patients reporting incisional hernia is clearly the highest after a midline access. The development of an incisional hernia is an early complication of laparotomies [112, 113], and it is also known that the rate of incisional hernia increases at longer follow-up [114]. Patients factors, surgical factors and postoperative complications have been shown to act as promotors of midline incisional hernia. Nevertheless, probably the main cause of this event should be searched in the particular anatomy and mechanics of the abdominal wall. The *linea alba* is the midline point of equilibrium, where the large abdominal muscles exert their tension representing the central tendon of a complex digastric muscle, its longitudinal division represents the most important perturbation of this balance. Accordingly, during the early wound healing phase, the *linea alba* is exposed to shear forces from lateral muscles, which contribute to recti divarication and incisional hernia development. Midline incision is the most used traditionally among surgeons since perceived as the most versatile and safe: it can be enlarged at any time following the main longitudinal axis of the body gaining access to vital structures in case of emergency or complex procedure.

According to our study non-midline access are linked with a lower incidence of incisional hernia. This type of abdominal wall incisions is not influenced by the same mechanism of lateral traction and even if atrophy of the incised fibres can result, it is less likely the development of an abdominal wall defect. Moreover, abdominal wall closure guidelines from European Hernia Society [8] strongly recommend them in surgical practice to reduce incisional hernia occurrence. Nevertheless, in the past years, off-midline incisions were adopted mainly in dedicated trials and did not find widespread use. Probably the need for muscle section, the fear of atrophy and nerve damage, the perceived limited possibility to extend the length, in particular in obese patients, and the rise in the use of minimally invasive surgery, have contributed to reduce the interest in changing the consolidated midline approach.

The present paper offers the opportunity to have possible explanation of the concept [115] that laparoscopic colorectal

resection should be preferred to open at least because of a reduced incidence of incisional hernia. After our metaregression analysis, we can ascribe this reduction mainly to the use of off-midline incision for extraction of colic specimen (Pfannenstiel, right and left oblique incisions), and discourage midline extraction sites because of a similar risk of failure in comparison to wider laparotomies. It seems clear again that the violation per se of the linea alba is one of the main mechanism of hernia formation in minimal invasive techniques, without considering the real incidence of port site hernias (in particular open entry in the umbilical region [116]).

Our paper confirms the particular nature of stoma reversal sites: despite being usually off-midline incisions, the risk of incisional hernia remains high, some reasons can be hypothesized: the first being the higher risk of local infection due to the presence of bowel contamination and the second being their features of "iatrogenic hernias" with the subsequent modifications in local tissue anatomy and the need for a mesh to be safely closed as recently showed [22].

Interestingly, incisional hernia proportions rise in relation to quality and main objective of the study. RCT designed for prevention (may be due to a focused strategy of follow-up) are more prone to detect a higher number of incisional hernia in comparison to non-prevention focused trials, even if randomized. A lengthy and radiological follow-up could provide us even with greater numbers of incisional hernia; however, little is known on their real clinical impact and the exact percentage of following repairs, especially when dealing with small asymptomatic defects. A possible answer could be offered by data coming from registries. Nonetheless, our analysis has shown the inaccuracy of non-focused registries (i.e., hernia registries) in identifying the occurrence of incisional hernia and the low reliability of data when coming as a secondary outcome. A registry on laparotomy closure is not realistic, but more awareness in the research of this complication could be advisable. Despite the enrolment of great numbers of patients, the registries clearly reflect an underestimation made by surgeons of the real proportion of patients with incisional hernia but could possibly show, in a more pragmatic way in comparison to RCT, the true number of patients with symptoms generated by their hernias and seeking cure. In this light it would remain open the question on who are the real patient target that should receive benefit from a preventive strategy, such as mesh augmentation.

A recent survey has shown that the need for a more accurate abdominal closure and the culture of prevention is growing in the surgical community but still has to be completely accepted [117]. However, the adoption of an abdominal wall closure technique with a suture length to wound length (SL/WL) of at least 4:1 is suboptimal among surgeons and the use of mesh is highly feared for complications [117], in particular in a contaminated environment, such as colorectal surgery. Incisional hernia is regarded as a secondary outcome in oncological series, thus underestimated and frequently neglected, as testified by the impossibility to find, except for preventive trial, a reliable description of the abdominal closure technique. Our paper is aimed to provide the surgeons with estimates of this complications and give a possible insight on tailored preventive strategies. This way, a suggested pragmatic approach could support mesh prevention for midline laparotomies during open elective colorectal resections and stoma reversal sites. Transverse incisions for resection are recommended by guidelines [8] and they are effective in incisional hernia reduction but not widely adopted because out of common surgical teaching and without a clear definition of closure steps. Off-midline should be preferred to midline incisions for specimen retrieval after laparoscopic colorectal resection in terms of incisional hernia formation, the latter (if used) should be closed with a SW/WL ratio at least 4:1 technique or mesh augmentation taking in consideration patient's risk factors and the results of our analysis that found incisional hernia rates not so different from a formal midline laparotomy. Data on SILS need further clarifications, since this approach is not widespread for colon resections and probably the final strategy will be deduced from studies conducted in other clinical scenarios. Port site closure should follow current guidelines on minimal invasive surgery that recommend closure of larger access incision (10 mm) and probably avoid the umbilical placement, whenever possible [8].

Several limitations can be found in the present analysis. Firstly, despite a large number of selected papers and patients examined we found considerable statistical heterogeneity between studies, which can be explained by variation of patient's cohorts, risk factors, surgical procedures, methods of diagnosis and duration of follow-up. In this matter the evaluations with the conventional funnel plots and Egger test estimates are limited due to visual qualitative assessment, and are considered as an inaccurate source for the evaluation of the publication bias especially in meta-analyses of proportions. To assess the sources of this variability and explain some heterogeneity meta-regression analysis was done on the study-level characteristics. Nevertheless, data coming from preventive trials are reliable for midline incisions, off-midline incisions and stoma reversal site. Second, except from trials in prevention, the closure technique of the midline incision is almost a neglected topic in all the included papers, no data were extracted on the type material, suture size, SW/WL ratio or technique, accordingly so far we can say which type of incision should be avoided in terms of incisional hernia incidence but no defined indications in colorectal surgery can be done on the effect of different closure methods. Moreover, patients risk factors, clinical setting and operative diagnosis were sparsely reported, making difficult to evaluate their real contribution in the different studies. Third, the trials selected and used to derive proportions,

despite being of high quality, are characterized by a low rate of radiological follow-up and a low maximum follow-up, accordingly our data could be further underestimated. Even if meta-regression model did not show any effect of these two variables on the total proportion of incisional hernia, it has been shown in our meta-analysis and in other papers [118] that these variables clearly enhance the detection rate, accordingly more focused studies on incisional hernia are needed in this context to provide more accurate estimates.

The main strength is that our paper defines the incidence of incisional hernia in different type of incisions performed for colorectal surgery and it provides reliable data from which calculation for future studies on prevention can be started.

In summary, the present systematic review supports the concept that a midline incision represents the higher risk approach to the peritoneal cavity in terms of postoperative incisional hernia occurrence irrespectively from the length of incision adopted. A transverse or off-midline access to the peritoneum has the lowest risk but it is currently not extensively adopted in the general practice and the technique of closure is not standardized. The risk of incisional hernia in a laparoscopic port is very low, probably underestimated, and could be influenced by patient characteristics and port position with respect to the midline. Stoma reversal sites are incision at high risk for incisional hernia and for their special features should be considered in preventive strategies of closure (i.e., mesh augmentation). The occurrence of incisional hernia is increased by the design of the studies as well as from the technique of assessment of the laparotomy integrity.

The evidence map collected in the present study shows that midline open incision and stoma reversal site represent the leading studied type of abdominal wall incisions in colorectal surgery being the former the higher risk in terms of incisional hernia and the latter a particular type of high risk off-midline incision. More studies are needed to define the risk of incisional hernia and subsequent need for preventive strategies in minimally invasive surgery in particular the current knowledge on risk for port access and SILS incisions can be only derived from other surgical specialities [119, 120].

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10029-021-02555-w.

Declarations

Conflict of interest None of the authors have conflicts of interests relevant to the present paper.

Ethical approval Since the study type is a systematic review not directly involving patients the ethical approval has not been requested.

Human and animal rights Does not apply.

Informed consent The authors declare that no personal patient data are presented in the paper.

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