Worldwide incidence of surgical site infections in general surgical patients: A systematic review and meta-analysis of 488,594 patients

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WORLDWIDE INCIDENCE OF SURGICAL SITE INFECTIONS IN GENERAL SURGICAL PATIENTS: A SYSTEMATIC REVIEW AND META-ANALYSIS OF 488,594 PATIENTS

ABSTRACT

Background: Establishing worldwide incidence of general surgical site infections (SSI) is imperative to understand the extent of the condition to assist decision-makers to improve the planning and delivery of surgical care. This systematic review and meta-analysis aimed to estimate the worldwide incidence of SSI and identify associated factors in adult general surgical patients.

Materials and Methods: A systematic review was undertaken using MEDLINE (Ovid), CINAHL (EBSCO), EMBASE (Elsevier) and the Cochrane Library to identify cross-sectional, cohort and observational studies reporting SSI incidence or prevalence. Studies of less than 50 participants were excluded. Data extraction and quality appraisal were undertaken independently by two review authors. The primary outcome was cumulative incidence of SSI occurring up to 30 days postoperative. The secondary outcome was the severity/depth of SSI. The I^2 statistic was used to explore heterogeneity. Random effects models were used in the presence of substantial heterogeneity. Subgroup, meta-regression sensitivity analyses were used to explore the sources of heterogeneity. Publication bias was assessed using Hunter's plots and Egger's regression test.

Results: Of 2091 publications retrieved, 62 studies were included. Of these, 57 were included in the meta-analysis across six anatomical locations with 488,594 patients. The pooled 30-day cumulative incidence of SSI was 11% (95% CI 10% to 13%). No prevalence data were identified. SSI rates varied across anatomical location, surgical approach, and priority (i.e., planned, emergency). Multivariable meta-regression showed SSI is significantly associated with duration of surgery (estimate 1.01, 95% CI 1.00-1.02, P=.014).

Conclusions and Relevance: 11 out of 100 general surgical patients are likely to develop an infection 30 days after surgery. Given the imperative to reduce the burden of harm caused by SSI, high-quality studies are warranted to better understand the patient and related risk factors associated with SSI.

Key words: surgical site infection, incidence, systematic review, meta-analysis, operation.

MAIN TEXT

1. Introduction

Over 300 million operations are performed worldwide, annually (1). General surgical procedures are the most commonly performed, particularly in higher income and middle-income countries (2, 3). Most surgical wounds heal by primary closure; where the incision is closed by fixing the edges together with stitches, staples, adhesive glue or clips (4). However, healing can be delayed when complications arise. Surgical site infection (SSI), defined as wound infections occurring within 30 days after surgery (5), is a potential complication experienced after surgery that results in poorer patient outcomes and increased costs (6).

SSIs can occur at or near the surgical incision, giving rise to local signs and symptoms (e.g. heat, redness, pain and swelling) (5). The Centres for Disease Control (CDC) classifies SSIs as superficial incisional (i.e. involving only skin and subcutaneous tissue), deep incisional (i.e. involving deeper soft tissues of the incision) and organ/space (i.e. involving any part of the anatomy other than incised body wall layers, that was opened or manipulated during an operation) (5). Despite improvements in surgical techniques, wound therapies and instrument sterilization methods, SSIs are a common (yet preventable) complication (7-9). However, the global incidence of SSIs among adult patients undergoing general surgical is not clear.

There is a paucity of rigorous and comprehensive systematic reviews and meta-analyses reporting the incidence and prevalence of general surgical SSIs (generated from observational work). A recent review investigated SSIs and its associated factors among surgical patients but only focused on a single country (i.e. Ethiopia) and an unspecified surgical population (10). Establishing worldwide incidence of SSIs in general surgical patients is imperative to understand the extent of the condition, its burden on society, and the demographic and clinical risk factors that predispose general surgical patients to develop SSIs. Such information will enable the identification of demographic and clinical trends over time, across patient subgroups and will assist decision-makers to improve the planning and delivery of surgical care.

This review is guided by the following research questions:

1.2. Review Questions

- What is the incidence of SSIs within 30 days of general surgery, in adults (≥16 years)?
- What is the incidence of different types of SSI within 30 days of general surgery, in adults?
- To what extent do clinical and patient factors predict the incidence and prevalence of SSIs?

2. Methods

The conduct of this review was underpinned by systematic review guidelines developed by the Cochrane Collaboration (11). The reporting of our review methodology reflects the Meta-Analyses and Systematic Reviews of Observational Studies (MOOSE) guidelines (12), the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (13), guidelines for undertaking systematic reviews of incidence and prevalence studies (14, 15) and guidelines for assessing the methodological quality of systematic reviews (AMSTAR)(16). The level of compliance to the 16 AMSTAR checklist items is reported as an online supplement. The study protocol was registered a priori with PROSPERO International Prospective Register of Systematic Reviews (***ID CRD42020189591***).

2.1. Study eligibility

Primary studies were eligible if they reflected our a priori inclusion criteria, (i.e. adult patients ≥16 years, observation/cross-sectional/cohort design, planned or emergent, laparoscopic or laparotomy, general surgical procedures in any country, studies reporting incidence or prevalence of SSI). Refer to Table S1 in the Supplement for a detailed outline of study eligibility. While the most widely used, and robust definition of SSI is based on the CDC criteria (5, 17), severity varying according to tissue depth and occurring up to 30 days postoperative (5), the criteria for SSI diagnosis and measurement may differ depending on the clinical context, and where and when the study was published (18, 19). Therefore, studies reporting the diagnosis of SSI, as defined by study authors, were included in this review. Where authors did not specify a definition or diagnosis timeframe, we contacted them for clarification, and still included these studies regardless of whether a response was received.

2.2. Search strategy

Potentially eligible studies were identified by searching the electronic databases of MEDLINE (Ovid), CINAHL (EBSCO), EMBASE (Elsevier) and the COCHRANE Library. Using a Boolean search strategy developed in collaboration with a health librarian (refer to Table S2 in the Supplement for a detailed outline). Eligible studies available in English and full text published between January 2010 and February 2021 were included. The year 2010 was selected because of the universal implementation of enhanced recovery after surgery (ERAS) protocols that focus on improving perioperative care to lower both recovery time and postoperative complications (20). To maximise the identification of eligible articles, ancestry searching was undertaken using the reference lists of included studies.

2.3. Eligibility screening

All results were downloaded to EndNote version X8 [EndNote®, Clarivate Analytics, US]. Duplicates were removed, and titles and abstracts were independently screened by two reviewers (MR and BMG) according to the selection criteria. Next, full-text copies of potentially eligible studies were independently scrutinised by two reviewers (MR and BMG).

2.4. Data extraction

Two reviewers (MR and EH) extracted data from included papers using a standardised data extraction tool, specifically developed by the study team. This included information about the country of origin, year published, study design, participant demographics and baseline characteristics, surgical characteristics, and numbers of events or measures of association and corresponding effect sizes (where applicable). Where studies reported on different subgroups or strata (surgical approach, SSI bundle intervention or surgical site), all non-overlapping data were extracted and included in the analyses, provided the sample size was ≥50 patients in each stratum. Any differences in data extraction results were discussed and resolved by consensus.

2.5. Risk of bias (quality) assessment

The methodological quality of included studies was independently assessed by two reviewers (MR and EH), using a validated tool developed to assess the risk of bias specifically developed for cohort studies (21). Studies were given a score of 0–8 based on the degree to which they fulfilled eight criteria relating to research methods (design, sampling frame, sample size, outcome measures, measurement, and response rate), interpretation of the results and applicability of the findings (21). Scores for each item reflected one of three possibilities (no=0, yes=1, unsure/not reported=0); half marks (0.5) were awarded if one of the sub-questions were met. Any differences in quality assessments were discussed and resolved by consensus.

2.6. Data synthesis

We synthesised the data extracted from each study based on relevant outcomes. The Cochrane Q test with a P< 0.05 was considered significant and the I^2 statistic (50% reflecting heterogeneity) was used to assess the heterogeneity between studies. In the presence of substantial heterogeneity, as this was expected, we used a random-effects model to pool the

30-day cumulative incidence and present results as pooled with 95% confidence intervals (CIs). Given point estimates may not be reliable in the presence of serious heterogeneity, our conclusions are thus based on the 95% CIs (22).

There is high heterogeneity in most incidence and prevalence studies (22), hence, we developed an a priori data analytical plan to explore the causes of variation. We hypothesised that clinical and patient factors would be associated with the reported prevalence and incidence of SSI. Our analytic plan included conducting sub-group analyses for categorical factors (i.e. geographic regions, data sources, surgical approach [planned, emergency; laparoscopic, open]) and meta-regression for continuous variables (e.g. year of study, duration of operation and patient age) with a P-value of <.10 considered significant due to the low power of these tests (15, 23).

Hunter plots were used to assess the publication bias as Hunter et al. (24) have shown the classical funnel plot to be inappropriate for proportion studies such as prevalence or incidence (24). However, as Egger's linear regression test is commonly reported, the slope and p-value of this test are also presented. All analyses were conducted using STATA v.13.1 (StataCorp, College Station, TX, USA).

3. Results

3.1. Study Inclusion

A flowchart of the search is summarised in Figure 1. Of the 2091 publications retrieved, 62 studies met the eligibility criteria and were included in the qualitative systematic review (25-86). Justification for study exclusion is in Table S3 (Supplement). All included studies were based on incidence; none reported prevalence. Included within the meta-analysis were 57 studies (Figure 1), and of these 10 (34, 37, 40, 41, 43, 63, 76, 82, 83, 85) had more than one stratum, due to reporting more than one surgical subgroup. A maximum of 74 data points spanning six anatomical locations (appendix, bowel, gallbladder, gastric, hepatobiliary and hernia repair [i.e., abdominal, inguinal]) were meta-analysed. The number of strata included across analyses varied due to missing data points and/or to avoid duplicate data.

3.2. Study characteristics

Methodological, patient and procedural characteristics of included studies are described in Table 1 and further in Table S4 (Supplement). Most studies were retrospective (n=44; 71.0%) (25-28, 30-32, 34-36, 40, 41, 43, 44, 48-54, 56, 58, 59, 62-66, 68, 73-75, 77-79, 84, 86-88) and conducted at a single site (n=35; 55.6%) (26, 27, 29-32, 34, 37, 39, 40, 43, 46, 49-51, 54, 56, 58, 60, 61, 68, 70, 71, 73-75, 78, 81-85). Twenty-two (35.5%) studies relied on extracting data from National registry databases (e.g. American College of Surgeons National Surgical Quality Improvement Program, Japan's National Clinical Database) (25, 30, 34-36, 41, 42, 44, 48, 52, 53, 57, 59, 62, 64-66, 76, 79, 80, 86). The highest proportion of studies were conducted in the US (n=18, 29.0%) (25, 30, 34-36, 44, 48, 53, 57-59, 62, 64, 66, 78, 80, 84, 86) and 17 (27.4%) studies (25, 30, 34-36, 52, 53, 59, 63-66, 76, 79, 80) had samples over 10,000 patients (range 10,371- 48,746) (Table 1). The CDC guidelines were predominately used to define SSI (n=41, 68.3%) or a variant of CDC (e.g. European Centre for Disease Prevention and Control guidelines, National Health Safety network guidelines; n=16, 26.7%) and patients were followed up for at least 30 days after surgery (n=60, 96.8%) (Table 2). The follow-up period was unclear in two studies (26, 32), thus they were excluded from the meta-analysis (Table 2). Of the 62 studies included, 42 (67.7%) reported on the sources of funding.

3.3. Quality assessment/risk of bias

Quality assessment scores of included studies are summarised in Table S5 (Supplement). The highest possible score was 8 and the mean of all quality scores was 6.3 (range 3-8). Twenty-five studies (40.3%) received high methodological scores (i.e. ≥7) (29, 35-38, 41, 44, 45, 48, 50, 51, 53-55, 57, 60, 62, 66, 69, 71, 73, 79, 80, 85, 86). Another 29 (46.8%) received a medium score (i.e. 5-6) (25-28, 30, 31, 33, 34, 39, 40, 43, 46, 52, 56, 58, 59, 61, 63, 64, 67, 68, 70, 74-76, 78, 81-83), the remaining 8 (12.9%) studies scored ≤4.5 (low quality) (32, 42, 47, 49, 65, 72, 77, 84). Most studies used an appropriate study design and sampling method (n=56, 90.3%), and described the setting and participants in detail (n=48, 77.4%). Just over 50% of studies included insufficient information about how SSI incidence was diagnosed and measured (n=37, 59.7%) and described the response/inclusion rate (n=33, 53.2%).

3.4. Meta-analysis of SSI

The overall 30-day cumulative incidence of SSI stratified by anatomical location is summarised across studies in Table 3 and displayed at the individual-study level by surgical subgroup in Figure 2. Across 57 studies, there were 74 unique reports of overall SSI cumulative incidence. The overall SSI cumulative incidence for general surgery, across the 57 studies with 488,594 patients, was 11% (95% CI 10.0%-13.0%; I^2 =99.7). The highest 30-day SSI cumulative incidence were associated with hepatobiliary, across 46,203 patients, at 19% (95% CI 15.0-23.0%; I^2 98.8) and bowel/colon/rectum operations for 242,452 patients at 15% (95% CI 13.0-17.0%; I^2 99.5).

3.5 Sensitivity, subgroup and meta-regression analysis

After removing the high and moderate risk of bias studies, the cumulative incidence for general surgery in the low risk of bias subgroup was similar to overall estimates at 10% (95% CI 7.0-14.0%; I^2 99.8; 25 studies, 205,816 patients) (Table 3). Subgroup analysis by type of surgery was used to explore heterogeneity. Studies with only laparotomy patients reported a higher incidence at 13.0% (95% CI 10.0-16.0%; 32 studies, 60,679 patients), while the pooled incidence in patients who underwent laparoscopic surgery was 8.0% (95% CI 5.0-11.0%; 23 studies, 67,476 patients). Studies including only emergency surgical patients reported a higher incidence at 17.0% (95% CI 10.0-27.0%; 12 studies, 18,659 patients) compared to elective only patients at 11.0% (95% CI 8.0-14.0%; 32 studies, 131,792 patients) (Table 3). Across all analyses, heterogeneity was significant. All forest plots based on Table 3 results are provided in Figures S1-S15 in the Supplement.

Based on meta-regression results, associations between SSI incidence and study/patient characteristics including publication year, mean age, gender (% males), ASA score (ASA category ≥3) and mean duration of operation (mins) were assessed by univariate and multivariate mixed-effect meta-regression analyses. Scatter plots are provided in Figures S16-S20 (Supplement). Only ASA ≥3 (estimate 6.1, 95% CI 2.1-17.9, P=0.001; 50 observations) and duration of operation (estimate 1.0, 95% CI 1.0-1.0, P<.001; 23 observations) were significant in univariate models. When examined in multivariate analysis, longer duration of operation (estimate 1.0, 95% CI 1.0-1.0, P=.014) and studies with a higher proportion of ASA ≥3 patients (estimate 0.7, 95% CI 0.1-5.6, P=.746) resulted in a higher incidence of SSIs, explaining 38.8% of the variance (intercept 0.1, 95% CI 0.0-0.0, P<.001). However, ASA ≥3 had minimal effect and did not remain significant in the multivariate model.

Publication bias was apparent by the visually asymmetrical shape of the Hunter plot (Figure S21 in the Supplement). Egger's linear regression test was statistically significant (slope =-2.1, t =-22.1, P<.001).

4. Discussion

4.1. Main findings

In this systematic review and meta-analysis, we quantified the worldwide incidence of SSI after general surgery procedures. Our meta-analysis of almost half a million general surgery patients estimated the global 30-day cumulative incidence of SSI at 11% with relatively tight confidence intervals of 10% to 13%. Our finding falls just below the 12.3% incidence rate reported by the GlobalSurg study which included 12,539 gastrointestinal surgery patients worldwide (89). Our result confirms the substantial clinical impact of SSI in hospitalised general surgical adult patients. The impact of SSI following surgery has been well described in large surveys such as those conducted by the CDC in the US (90) and the ECDC (91), which reported on different surgical specialties as well as the GlobalSurg Collaborative group (89). These impacts include a longer length of hospital stay, reduced health-related quality of life, higher mortality, (56, 92) with costs estimated to be between USD$10,443 and USD $25,546 per infection (93, 94).

4.2. Methodological issues across studies

Included studies share disparities relative to the definition and measurement of the outcome SSI, design, and overall study quality. Moreover, where we were uncertain of the follow-up period because studies were unclear or did not specify this, we excluded these studies from the meta-analyses. We extracted data based on clear a priori operational definitions for the outcome of SSI. Another issue was that 71% of studies in this review used retrospective cohort designs. These studies may be at greater risk of bias given that not all relevant risk factors have been identified and documented. Additionally, the measurement of risk factors and outcomes may not be as accurate or complete as would be using a prospective design. In this review, variations in pooled estimates of SSI rates based on the data sources (medical records, national database registry, surveillance) ranged from 7% to 21%, with national databases and surveillance methods reporting the lowest incidence rates of SSI. This result is hardly surprising when considering the 'true' rate of SSI is often underestimated using routine surveillance data (95). While 87% of included studies received either a high or moderate methodological quality score, just over 50% of studies did not report who collected SSI data or how SSI was diagnosed.

4.3. Statistical heterogeneity between studies

As expected in meta-analyses of epidemiological studies, heterogeneity was high because of patient baseline characteristics, study design and characteristics, data collection methods, differences in definitions and measures, statistical methods, and large sample sizes. The I^2 statistic depends on the sample size of the included studies; with very large (highly precise) studies even minuscule differences in effect size may result in high I^2 statistics (96, 97). Therefore, statistical heterogeneity will increase by including studies with larger sample sizes, because the variance of the studies' effects will decrease as the sample size increases (96, 98). Nonetheless, small (imprecise) studies are also associated with large treatment effect estimates, and it is also possible that between-study heterogeneity increases when sample sizes are smaller (97). Thus, undertaking sensitivity and subgroup analyses to explore sources of heterogeneity and checking the robustness of the pooled effect estimate is recommended (22, 97, 98). We undertook subgroup and sensitivity analyses to assess the clinical and methodological characteristics of included studies. Potential sources of heterogeneity were explored using meta-regression (i.e., anatomical location, approach, procedure, age, gender, BMI, operative time, ASA).

4.4. Strengths and Limitations of this study

Several limitations must be considered when interpreting our results. First, it is possible that we may have missed some studies and excluded the grey literature and trial registries websites which may have also contributed to publication bias as evidenced in our results. Nonetheless, our search strategy was rigorous and developed a priori, in consultation with a health librarian. Second, a review is only as good as the included studies. The overall quality scores for most included studies were high, however, the use of retrospective study designs predominated. Third, similar to previous systematic reviews and meta-analyses, we excluded studies with less than 50 as small studies tend to be of lower quality and high bias may inflate the pooled effect estimate and are not likely to reflect the population (99, 100). Finally, pooling incidence data in the presence of substantial heterogeneity is considered somewhat contentious (101). Notwithstanding, it is recognised that I^2 is influenced by sample size; large sample sizes like ours is bound to yield high I^2 statistics, near 100%. Despite these limitations, the strength of this review is the rigorous methods used, the large number of included patients and the categorisation of risk factors for SSI across six general surgery subspecialties.

4.5. Comparisons with other studies

The incidence of SSI in hepatobiliary surgery has been poorly described in the literature, but some earlier data show a higher incidence of SSI compared with other types of general surgery, with reported rates between 20% and 50% (102, 103). In our analyses, the cumulative incidence rate of SSI differed across procedures and surgical sites with hepatobiliary procedures having the highest incidence at 19%. Mentor et al.'s recent meta-analysis of 21 studies with 52,407 patients estimated the overall SSI rate for hepatobiliary surgery to be 21% (104). This result is similar to our estimate across hepatobiliary procedures. Highly exocrine solid organs (i.e., liver, pancreas) with complex and fragile (biliary) vascular supply means a greater potential for complications such as necrosis, leaks, and fistulas that are less common in other types of surgery and would directly contribute to SSI. Higher rates of SSI in this subspecialty may also be related to risk factor profiles in relation to patient factors (e.g. age, BMI, diabetes, smoking), preoperative interventions (e.g. biliary drainage, radiotherapy, chemotherapy), and intraoperative risk factors (e.g. open surgery, prolonged operative time, significant blood loss). SSI results in prolonged hospital stay and increased healthcare costs (105), and the higher rate of occurrence in this subspecialty suggests a greater burden of costs associated with SSI in patients undergoing hepatobiliary surgery. That said, laparoscopic surgery has consistently shorter lengths of hospital stay, lower pain scores, earlier mobilisation, and faster return to function (including food intake), and these are, directly or indirectly, related to the prevention of SSI.

Our results suggest that SSI rates for bowel, colon and rectum procedures were slightly lower than hepatobiliary procedures, with a 15% cumulative incidence. SSI rates also varied according to the use of surgical approach. Laparotomy procedures had a higher incidence rate of 13% compared to minimally invasive laparoscopic procedures at 8%. Others have reported lower SSI rates when minimally invasive techniques are used in gastrointestinal, hepatobiliary and spinal operations (89), however valid comparisons are only comparable in well-designed RCTs. Notably, our findings are inconsistent with the wider literature which indicates that the duration of operation is associated with longer laparoscopic operating times when matched for operation (106-109). Clearly laparoscopic operations are more time-consuming because the quick manoeuvres traditionally done with the surgeon's hands take much longer when using deep instruments. As expected, emergency general surgical procedures had a 17% SSI incidence rate; considerably higher compared to elective procedures where the cumulative incidence rate was 11%. Unsurprisingly, SSI rates were doubled (20% vs 10% respectively) in contaminated/dirty surgery, such as colon surgery compared to clean-contaminated surgery.

ASA category is a measure of patient acuity and was a significant predictor of SSI in the univariate, but not in the multivariate meta-regression analysis. This is likely due to the much smaller number of observations retained, as not all studies had included both ASA and duration of operation as a variable of interest, or could be extracted and pooled for this analysis. The only statistically significant predictor of SSI in the multivariate meta-regression was the duration of operation. Others have established that operations lasting two hours and greater increase the potential for bacterial contamination because of increased microbial exposure to the surgical field, and increases the extent of tissue trauma and blood loss, leading to tissue hypoxia (110, 111). Hence, designing and implementing surgical techniques and organisational procedures that reduce patients' duration of operation, even by a few minutes, may contribute to reducing SSI risk.

5. Conclusions

In conclusion, this meta-analysis revealed the overall pooled incidence of SSI was 11%, with 5% incidence of superficial SSI, 1% incidence of deep SSI, and 5% incidence of organ space SSI. SSI estimates also varied in relation to surgical speciality and surgical procedure. There is an ethical and economic imperative to reduce the burden of harm caused by SSI to improve patient safety. Healthcare organisations wanting to reduce the incidence of SSI across the spectrum of general surgical subspecialties may benefit from investigating these SSI types and should consider interventions for all types of SSI.

Data statement

The data that our review is based on is available in the manuscripts of the included articles.

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Research registration Unique Identifying Number (UIN)

1. Name of the registry: PROSPERO

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Declaration of conflict of interest statement

None.

Provenance and peer review

Not commissioned, externally peer-reviewed.

Appendix A. Supplementary data

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Table 1. Characteristics of Eligible Studies

First author, year	Setting (number, type) Location	Methods[a]	Outcome data source	Sample	ASA (%)	Elective (%)	Laparoscopic (%)	Wound class (%)
Althumairi, 2016	Multi-site (n=NR, NR), USA	Retrospective (2012-2013), cohort[a]	ACS NSQIP Colectomy Targeted PUF- patient records.	N=19,686 Colorectal resection	2: 53.8% 3: 43.0% 4: 3.2%	100.0%	62.5%	-
Balogun, 2019	Single-site (Teaching), Nigeria	Retrospective (Jul 2010-Jun 2017), descriptive[a]	Patient medical records	N=59 Appendiceal perforation	1: 10.2% 2: 44.1% 3: 42.4% 4: 3.4%	0.0%	NR	-
Banaszkiewicz, 2017	Single-site (NR), Poland	Retrospective (Jun 2012-Jun 2016), analytical[a]	Patient medical records	N=187 Rectal resection	1/2: 35.8% 3/4: 64.2%	72.7%	0.0%	-
Bilgiç, 2020	Multi-site (n=2, University), Turkey	Retrospective (Jan 2010/Jul 2014-Dec 2018), analytical[a]	Physical examination, medical record	N=214 Pancreaticoduodenectomy or total pancreatectomy	1: 14.0% 2:50.5% 3: 35.5%	NR	NR	-
Bislenghi, 2019	Single-site (University), Belgium	Prospective (Oct 2016-Jan 2017), observational	Assessment and surveillance forms, photographs of surgical site	N=287 Colon surgery	1/2: 55.0% >3: 45.0%	NR	55.1%	1: 48.4% 2: 34.8% 3: 0.7% NR: 16.1%
Chacon, 2019	Single-site (NR), USA	Retrospective (2012-2016), cohort	ACS NSQIP PUF	N=21,443 Hepatectomy	1/2: 27.2% 3: 66.1% 4/5: 6.6%	93.3%	NR	1: 14.7% 2: 78.2% 3: 5.0% 4: 2.1%
Chen-Xu, 2018	Single-site (NR), Portugal	Retrospective (Jan 2010 - Dec 2016), cohort[a]	Patient medical records	N=654 Hepatobiliary and pancreatic surgery	1: 9.2% 2: 65.4% 3: 24.6% 4: 0.8%	100.0%	0.0%	-

Dsouza, 2020	Single-site (NR), India	Retrospective (Apr 2011-Dec 2017), cohort[a]	Treating doctors daily progress notes, physical examination	N=195 Abdominoperineal excision group	-	NR	52.8%	-
Du, 2019	Multi-site (n=26; Tertiary), China	Prospective (Jan 2015-Jun 2016), surveillance	Real-Time Nosocomial Infection Surveillance System (RT-NISS)	N=5,729 Colon and rectal resection	1/2: 86%	88.0%	58.3%	-
Elliott, 2017	Multi-site (n=NR, NR), USA	Retrospective (Jan 2014-Dec 2015), analytical[a]	ACS NSQIP PUF	a. 10,371 Pancreaticoduodenectomy	-	NR	NR	-
	Single-site (University), USA	Retrospective (Jul 2013-Jun 2015), analytical[a]	NSQIP UCLA only	b. 201 Pancreaticoduodenectomy	-	NR	NR	-
Ely, 2020	Multi-site (n=NR, NR), USA	Retrospective (Jan 2016-Dec 2017), cohort[a]	ACS NSQIP PUF	N=30,579 Cholecystectomy	1: 10.8% 2: 60.0% 3: 28.0% 4: 1.2%	100.0%	100.0%	1: 4.5% 2: 81.7% 3: 13.2% 4: 0.7%
Fafaj, 2020	Multi-site (n=NR, NR), USA	Retrospective (2013-2019), cohort[a]	Americas Hernia Society Quality Collaborative (AHSQC) registry	N=1507 umbilical hernia repair	1: 8.0% 2: 59.0% 3: 32.0% 4: 1.0%	100.0%	21.4%	-
Fields, 2019	Multi-site (n=NR, NR), USA	Retrospective (2016), cohort[a]	ACS NSQIP PUF	N=11,475 Appendectomy	3/4: 15.3%	NR	100.0%	3/4: 74.7%
Ghali, 2018	Single-site (University), Tunisia	Prospective (Jan 2015-May 2015), cohort	Patient medical records, interviews with patient, doctors and nurses	N=349 General surgery	1/2: 96.0%	NR	NR	1/2: 81.1% 3/4: 18.9%
Gomila, 2017	Multi-site (n=10, 30% tertiary), Spain	Prospective (2011-2014), cohort	VINCat healthcare-associated infection surveillance program	N=3,701 Colon and/or rectum resection	3/4: 40.3%	100.0%	62.1%	-

Goulart, 2018	Single-site (NR), Portugal	Prospective (Aug 2015-Aug 2016), cohort	Patient medical records	N=130 Colon and/or rectum resection	-	100.0%	45.4%	-
Guzmán-García, 2019	Single-site (Public), Mexico	Retrospective (Oct 2011-Mar 2012), cohort[a]	Clinical survey	N=755 Abdominal surgery (90 colorectal, 241 appendectomy, 331 cholecystectomy, 91 Hernia repair)	1: 65.0% 2: 22.1% 3/4: 12.8%	0.0%	33.8%	1: 10.5% 2: 54.8% 3: 10.7% 4: 24.0%
Hamza, 2018	Multi-site (n=NR, Government), Kuwait	Retrospective (Jan-Dec 2016), surveillance (descriptive)	National audit-Physical examination, medical record	a. 377 Colon and small bowel surgery	1/2: 55.2% 3/4: 31.0% NR: 13.8%	86.2%	16.7%	2: 66.6% 3/4: 32.9% NR: 0.5%
				b. 1,722 Gastric surgery	1/2: 84.1% 3/4: 15.9% NR: 15.5%	97.6%	95.5%	2: 96.7% 3/4: 3.3% NR: 0.1%
Hassan, 2020	Single-site (University), USA	Retrospective (Aug 2013-Jul-2017), cohort	Patient medical records from surgical database	N=234 Ventral and incisional hernia repairs	1/2: 33.3% 3: 63.7% 4: 3.0%	NR	0.0%	1: 80.8% 2: 5.6% 3: 7.3% 4: 6.0%
Honda, 2018	Multi-site (n=169, university, specialised and other), Japan	Prospective (Aug 2014-Jul 2015), cohort	National Clinical Database (Japan)	N=2,837 Gastrectomy	≥3: 18.5%	98.8%	48.1%	-
Hu, 2016	Single-site (specialised centre), China	Retrospective (Nov 2012-Oct 2015), observational	Patient medical records	N=290 Abdominal surgery	<3: 82.8% ≥3: 17.2%	100.0%	26.6%	≥3: 100%
Jackson, 2017	Multi-site (n=28, 57% Teaching), USA	Retrospective (Jan 2012-Dec 2013), cohort	Premier Quality Advisor database (US)	N=8,959 Colon resection[f]	-	NR	NR	-

Jeong, 2013	Multi-site (n=10, 90% tertiary), Korea	Prospective (Jun 2010-Aug 2011), cohort	Patient medical records- SSI surveillance program	N=2,091 Gastric surgery	1: 62.9% 2: 32.6% 3: 4.5%	100.0%	34.6%	1/2: 2082 (99.6%) 3: 9 (0.4%)
Juvany, 2018	Single-site (NR), Spain	Prospective (Jan-Dec 2015), descriptive[a]	Physical examination, medical record	N=101 Incisional hernia repair	1: 6.9% 2: 84.2% 3: 8.9%	100.0%	2.0%	1/2: 100%
Kalakouti, 2017	Single-site (Tertiary), UK	Prospective (Mar 2015-Mar 2016), observational	Patient medical records	N=123 Colorectal resection	-	74.8%	NR	-
Karamanos, 2017	Multi-site (n= >50, NR), USA	Retrospective (2013-2015), quality improvement	Michigan Surgical Quality Collaborative (MSQC) database	N=4,983 Ventral or incisional hernia repair	1: 5.6% 2: 50.0% 3: 43.3% 3: 3.1%	100.0%	0.0%	1: 88.4% 2: 8.5% 3: 1.4% 4: 1.7%
Karavokyros, 2017	Single-site (NR), Greece	Retrospective (Jan 2012-Dec 2016), cohort[a]	Patient medical records	N=81 Hepatic resection	-	NR	1.2%	-
Khan, 2020	Single-site (Tertiary teaching), Pakistan	Prospective (Nov 2016-Aug 2017), cross-sectional	Patient medical records, physical examinations, telephone follow-up via CDC surveillance methods	N=331 General surgery (appendectomy, exploratory laparotomy, cholecystectomy, mesh repair, thyroidectomy)	-	NR	NR	-
Kim, 2019	Single-site (University), Korea	Retrospective (Jan 2015-Dec 2015), analytical[a]	Patient medical records	N=1,067 Gastrectomy	≤3: 23.5% >3: 76.5%	100.0%	57.5%	-
Kubo, 2013	Single-site (University), Japan	Retrospective (Apr 2010-Mar 2012), cohort	Patient medical records	N=464 Colon and/or rectal resection	-	100.0%	27.2%	-

Kurita, 2015	Multi-site (n=1737, NR), Japan	Retrospective (Jan-Dec 2011), cohort	National Clinical Database (Japan)	N=33,917 Gastrectomy	≥3: 8.9%	99.1%	35.0%	-
Lawson, 2013	Multi-site (n=305, NR), USA	Retrospective (2011), cohort	ACS NSQIP PUF	N=27,011 Colectomy	1/2: 44.8% 3: 44.5% 4/5: 10.7%	81.9%	41.6%	2: 72.2% 3: 12.3% 4: 15.5%
Lee, 2019	Multi-site (n=131, NR), UK	Prospective (16 Jan -13 Mar 2017) cohort	National audit-Routine collected anonymised data	N=1,078 Small bowel resection	-	42.3%	8.2%	-
Lee, 2020	Single-site (University), Korea	Retrospective (Jan 2017-Feb 2019), analytical[a]	Patient medical records	N=492 Colon and/or rectal resection	1: 15.9% 2: 81.9% 3: 4.7%	100.0%	100.0%	-
Lei, 2020	Single-site (University), China	Retrospective (Jan 2011-Aug 2017), analytical[a]	Patient medical records	N=581 Colon and/or rectal resection	1: 55.4% 2: 34.4% 3: 10.2%	100.0%	87.8%	-
Liu, 2020	Multi-site (n=140, NR), USA	NR (Jan 2016-Jun 2017), cohort	ACS NSQIP PUF	N=5,969 Pancreato-duodenectomy	1/2: 21.1% 3: 71.4% 4/5: 7.5%	100.0%	0.0%	1: 2.1% 2: 80.3% 3: 14.4% 4: 3.1%
Loor, 2017	Single-site (Tertiary), USA	Retrospective (Jan 2010-Dec 2015), surveillance	Institution SSI surveillance database	N=2201 Cholecystectomy	1: 16.4% 2: 54.0% 3: 30.2% 4: 0.8%	94.1%	96.6%	1/2: 95.8% 3/4: 4.2%
Mangieri, 2020	Multi-site (n=NR, NR), USA	Retrospective (2015 -2016), cohort	ACS NSQIP PUF	N=24,000 Colectomy and proctectomy	-	100.0%	NR	3/4: 19.0%
Martin, 2018	Single-site (Tertiary), Switzerland	Retrospective (2012-2017), quality improvement (surveillance)	Patient medical files monitored by independent Swiss national infection	N=1,263 Colorectal resection	1/2: 55.8% 3/4: 44.2%	57.9%	58.1%	≥2: 55%

			surveillance committee					
Mauser, 2019	Single-site (Tertiary), South Africa	Prospective (Jan 2017-Jan 2018), cohort	Patient interviews	N=98 Bowel resection	-	0.0%	0.0%	3: 100%
McCracken, 2019	Multi-site (NR, NR), USA	Retrospective (Jan 2014-Dec 2015), analytical[a]	ACS NSQIP PUF	N=6,471 Pancreato-duodenectomy	1: 0.3% 2: 22.9% 3: 70.2% 4: 6.6% 5: <0.1% NR: <0.1%	NR	1.9%	-
Meijerink, 2017	Multi-site (n=2, Public & Private), England/ Norway	Retrospective (Sep 2012-Jan 2015), cohort (surveillance)	SSI surveillance data (English and Norwegian)	a. 4,378 Colorectal resection (Norway)	≥3: 43.7%	69.7%	NR	≥3: 9.6%
				b. 8,538 Colorectal resection (England)	≥3: 35.4%	91.7%	NR	≥3: 17.7%
				c. 650 Cholecystectomy (Norway)	≥3: 35.2%	79.2%	NR	≥3: 6.2%
				d. 535 Cholecystectomy (England)	≥3: 19.7%	100.0%	NR	≥3: 0.4%
Midura, 2018	Multi-site (n=NR, NR), USA	Retrospective (2012–2015), cohort[a]	ACS NSQIP PUF	N=45,724 Colorectal resection	1: 2.8% 2: 49.8% 3: 44.5% 4: 2.9%	100.0%	76.2%	-
Morikane, 2016	Multi-site (n=378, NR), Japan	Retrospective (2012-2014), surveillance	National database-JANIS	N=36,052 Gastrectomy	1: 19.6% 2: 65.6% 3: 14.1% 4: 0.6% 5: 0.1%	94.6%	31.6%	1: 3.5% 2: 91.2% 3: 3.2% 4: 2.0%
Mullen, 2018	Multi-site (n=517, NR), USA	Retrospective (2014),	ACS NSQIP PUF	N= 48,746 Colon and/or rectum resection[f]	1: 1.4% 2: 20.5% 3: 49.1%	72.0%	NR	1: 1.0% 2: 75.0%

		propensity-matched			4: 25.8% 5: 3.2%			3: 12.3% 4: 11.7%
Nakagawa, 2016	Multi-site (n=17, 100% general), Japan	Prospective (Aug 2011-May 2013), cohort	Patient medical records- through the Japan Nosocomial infections surveillance	N=155 Colon and/or rectum resection	>3: 85.8%	100.0%	0.0%	1: 2.6% 2: 93.5% 3: 3.9%
Okubo, 2018	Single-site (Specialised centre), Japan	Retrospective (May 2013-Dec 2015), cohort[a]	Patient medical records	N=427 Hepatopancreatobiliary	1: 26.5% 2: 69.8% 3: 3.7%	100.0%	0.0%	-
Olmez, 2020	Single-site (NR), Turkey	Retrospective (Jan 2013-Jul 2019), analytical[a]	Patient medical records- phone contacts with patient	N=209 Colorectal surgery	1: 1.5% 2: 27.7% 3: 65.5% 4: 5.3%	100.0%	25.4%	-
Park, 2015	Single-site (University), Korea	Retrospective (Jan 2010-May 2014), cohort[a]	Patient medical records	N=327 Colon and/or rectum resection	1: 15.3% 2: 72.2% 3: 12.2% 4: 0.3%	97.6%	82.9%	2: 85.0% 3: 15.0%
Qiao, 2020	Single-site (specialised centre), China	Retrospective (Nov 2017-Dec 2018), cohort	Hospital records and patient interviews	N=590 Radical gastrectomy	≤3: 100%	100.0%	48.8%	2/3: 100%
Rosen, 2017	Multi-site (n=9, NR), USA/ Netherlands	Prospective (Feb 2011-Dec 2014), longitudinal	Physical examination, medical record	N=104 Incisional hernia repair	-	100.0%	0.0%	2: 23% 3: 77%
Silvestri, 2017	Single-site (University), Italy	Retrospective (Jun 2010-Jul 2014), analytical[a]	Patient medical records-through Hospital Infection Committee surveillance program	N=687 Colon and/or rectum resection	1: 4.9% 2: 54.9% 3: 38.2%	78.0%	41.5%	-

Sugiura, 2015	Single-site (Specialised centre), Japan	Retrospective (Jul 2012-May 2014), cohort[a]	Patient medical records	N=218 Pancreatoduodenectomy	-	NR	NR	-
Tanaka, 2017	Single-site (University), Japan	Retrospective (Jan 2012-Dec 2013), analytical[a]	Physical examination, medical record	N=432 Colon and/or rectum resection	1/2: 8.3% 3: 91.7%	99.3%	85.2%	-
Troillet, 2017	Multi-site (n=164, public & private), Switzerland	Prospective (Oct 2011-Sep 2015), surveillance	Patient medical records under the Swissnoso SSI surveillance system	a. 15,439 Appendectomy	1: 47.9% 2: 46.4% 3: 4.8% 4: 0.3% 5: 0.02%	2.1%	88.7%	2: 11.4% 3: 59.2% 4: 29.4%
				b. 20,402 Cholecystectomy	1: 18.2% 2: 61.6% 3: 18.3% 4: 1.5% 5: 0.1%	68.3%	91.3%	2: 67.6% 3: 26.3% 4: 6.1%
				c. 17,030 Herniorrhaphy	1: 34.1% 2: 51.8% 3: 13.9% 4: 0.8% 5: 0.04%	96.1%	33.8%	1: 97.3% 2: 2.2% 3: 0.3% 4: 0.2%
				d. 3,077 Gastric bypass	1: 1.8% 2: 53.2% 3: 43.3% 4: 1.0% 5: 0.03%	100.0%	48.8%	2: 99.2% 3: 0.7% 4: 0.1%
				e. 24,724 Colorectal and rectal resection	1/2: 57% ≥3: 43%	73.7%	42.8%	2: 66.0% 3: 17.2% 4: 16.8%

Tschan, 2015	Single-site (University), Switzerland	Prospective (NR), observational	Patient medical file Observational data form	N=167 Abdominal surgery	>2: 64.7%	100.0%	0.0%	>2: 9.0%
van Boxel, 2013	Multi-site (n=2, Public), UK	Retrospective (Feb 2011-Jun 2012), descriptive[a]	Telephone questionnaire	N=211 Cholecystectomy	-	100.0%	100.0%	-
Vo, 2017	Single-site (NR), USA	Retrospective (Oct 2013-Dec 2016), cohort[a]	Patient medical records	N=89 Colorectal resection	2: 10.1% 3: 78.7% 4: 11.2%	100.0%	76.4%	-
Watanabe, 2017	Multi-site (n=>3,500, NR), Japan	Retrospective (Jan 2011-Dec 2012), analytical[a]	National Clinical Database (Japan)	N=33,411 Low anterior resection	-	NR	43.8%	-
Williams, 2019	Multi-site (n=~700, NR), USA	Retrospective (Jan 2016-Dec 2016), cohort	ACS NSQIP PUF	N=12,026 Umbilical hernia repair	1: 7.5% 2: 53.9% 3: 36.2% 4: 2.3%	91.8%	19.4%	-
Xavier, 2014	Single-site (Teaching), Brazil	Prospective (Oct-Dec 2011), descriptive	Data collection form based on CDC surveillance, physical examination	N=990 General surgery	1: 29.2% 2: 33.3% 3: 13.5% NR: 24.0%	100.0%	NR	3: 67.7%
Zhang, 2018	Single-site (specialised centre), China	Prospective (Dec 2015-Jul 2017), cohort[a]	Patient medical records, Physical examination	N=184 Intestinal fistula resection	<3: 82.6% ≥3: 17.4%	100.0%	22.8%	-

ACS NSQIP PUF: American College of Surgeons National Surgical Quality Improvement Program Participant Use Data File; JANIS Japan Nosocomial Infections Surveillance; ASA: American Society of Anesthesiologists score; CDC: Centres for Disease Control and Prevention; NNIS: National Nosocomial Infection Surveillance System; NR: not reported; UCLA: University of California, Los Angeles; WC: would class.

Note: Dash indicates not reported or subgroup data could not be extracted.
[a]Indicates that the study design was allocated by review authors.

Table 2. Eligible study outcome summary

First author, year	SSI definition, follow-up	Total SSI (%)	Superficial SSI (%)	Deep SSI (%)	Organ/Space (%)	Duration of operation (minutes/%)
Appendix						
Balogun, 2019[ǂ]	NR, Hospital discharge	11/59 (18.6%)	-	-	-	-
Fields, 2019	CDC, 30 days	101/11 475 (0.9%)	101 (0.9%)	-	-	-
Ghali, 2018 (a)	CDC, 30 days	9/92 (9.8%)	-	-	-	-
Guzmán-García, 2019 (b)	CDC, 30-90 days	37/241 (15.4%)	-	-	-	-
Khan, 2020 (b)	CDC, 30 days	17/52 (32.7%)	-	-	-	-
Troillet, 2017 (a)	CDC, 30 days	609/15 439 (3.9%)	200 (1.3%)	59 (0.4%)	350 (2.3%)	63
Bowel (small bowel, colon and rectum)						
Althumairi, 2016	CDC, 30 days	2024/19 686 (10.3%)	1176 (5.9%)	197 (1.0%)	796 (4.0%)	<180: 58.3% 180–300: 31.7% >300: 10.0%
Banaszkiewicz, 2017	ECDC, 30 days	27/187 (14.4%)	-	-	-	-
Bislenghi, 2019	CDC, 30 days	35/287 (12.2%)	17 (48.6%)	1 (0.4%)	17 (48.6%)	<180 min: 79.0% >180 min: 21.0%
Dsouza, 2020[ǂ]	Uncited wound infection definition provided, unclear SSI follow-up	69/195 (35.3%)	-	-	-	-
Du, 2019	CDC/NHSN, 30days	206/5729 (3.60%)	85 (1.5%)	45 (0.8%)	76 (1.3%)	≤120: 17.8% 120–240: 62.2% ≥240: 20.0%
Gomila, 2017	CDC, 30days	669/3701 (18.1%)	-	-	336 (9.1%)	-
Goulart, 2018	CDC/NHSN, 30 days	26/130 (20.0%)	12 (9.2%)	1 (0.8%)	13 (10.0%)	-
Guzmán-García, 2019 (a)	CDC, 30-90 days	39/90 (43.3%)	-	-	-	-
Hamza, 2018 (a)	CDC/NHSN, 30 days	58/377 (6.5%)	34 (2.2%)	9 (2.4%)	15 (4.0%)	-

Hu, 2016 (a)	NNIS/CDC, 30 days	97/288 (33.7%)	-	-	-	-
Jackson, 2017	CDC/NHSN, 30-90 days	279/8959 (3.1%)	-	-	-	-
Kalakouti, 2017	CDC, 30 days	26/123 (21.1%)	-	-	-	-
Kubo, 2013	CDC, 30 days	115/464 (24.8%)			53 (11.4%)	229±88
Lawson, 2013	CDC, 30 days	2943/27 011 (10.9%)	1672 (6.2%)	-	-	163.5+89.0 145 (104-201)[b]
Lee, 2019	CDC, 30 days	200/1078 (18.6%)	130 (12.1%)	70 (6.5%)	-	-
Lee, 2020	CDC, 30-90 days	15/492 (3.0%)	5 (1.02%)	2 (0.4%)	10 (2.0%)	-
Lei, 2020	NNIS/NICE, 30 days	57/581 (9.8%)	37 (6.4%)	12 (2.1%)	31 (5.3%)	>240: 22.5% ≤240: 77.5%[h]
Mangieri, 2020	CDC, 30 days	1900/24 000 (7.9%)	854 (3.5%)	122 (0.5%)	924 (3.9%)	-
Martin, 2018	NNIS/NICE, 30 days	271/1263 (21.4%)	53 (4.2%)	65 (5.1%)	153 (12.1%)	190±100 >180: 45%
Mauser, 2019	CDC, 30 days	59/98 (60.2%)	44 (44.8%)	15 (15.3%)	-	-
Meijerink, 2017 (a)	ECDC, 30 days	214/4378 (4.9%)	-	-	-	-
Meijerink, 2017 (b)	ECDC, 30 days	287/8538 (3.4%)	-	-	-	161 (115–220)[b h]
Midura, 2018	CDC, 30 days	2263/45 724 (4.9%)	-	-	-	-
Mullen, 2018	CDC, 30-90 days	6064/48 746 (12.4%)	2777 (5.7%)	768 (1.6%)	2519 (5.2%)	157 (110–224)[b h]
Nakagawa, 2016	NHSN/CDC, 30 days	24/155 (15.5%)	-	-	-	-
Olmez, 2020	CDC, 30 days	46/209 (22.0%)	31 (14.8%)	9 (4.3%)	6 (2.9%)	≥180: 138 (66.0%)
Park, 2015	NNIS (modified CDC), 30 days	45/327 (13.8%)	22 (6.7%)	5 (1.5%)	18 (5.5%)	190.1
Silvestri, 2017	NNIS (modified CDC), 30 days	137/687 (19.9%)	52 (7.5%)	15 (2.2%)	70 (10.2%)	≤180: 50.5% >180: 49.5%
Tanaka, 2017	CDC, 30 days	74/432 (17.2%)	-	-	31 (7.2%)	250±110 ≥335: 15.5% <335: 84.5%
Troillet, 2017 (e)	CDC, 30 days	3516/24 724 (14.2%)	1182 (4.8%)	491 (2.0%)	1843 (7.5%)	-
Vo, 2017	NNIS (modified CDC), 30 days	16/89 (18.0)	7 (7.9%)	1 (1.1%)	9 (10.1%)	-

Watanabe, 2017	CDC (Japanese translation), 30-90 days	4319/33 411 (12.9%)	1394 (4.2%)	507 (1.5%)	2418 (7.2%)	-
Zhang, 2018	CDC, 30 days	46/174 (26.4%)	-	-	-	-
Gallbladder						
Ely, 2020	CDC, 30-90 days	293/30 579 (0.96%)	137 (0.44%)	61 (0.20%)	98 (0.32%)	56.9±32.1
Ghali, 2018 (c)	CDC, 30 days	1/92 (1.1%)	-	-	-	-
Guzmán-García, 2019 (c)	CDC, 30-90 days	6/331 (1.8%)	-	-	-	<60: 18.1% 60–120: 76.3% >120: 5.6%[h]
Khan, 2020	CDC, 30 days	12/58 (20.7%)	-	-	-	-
Loor, 2017	NHSN/CDC, 30 days	45/2201 (2.0%)	-	-	-	-
Meijerink, 2017 (c)	ECDC, 30 days	25/650 (3.9%)	-		-	-
Meijerink, 2017 (d)	ECDC, 30 days	14/535 (2.6%)	-		-	120 (70–250)[b h]
Troillet, 2017 (b)	CDC, 30 days	448/20 402 (2.2%)	236 (1.2%)	49 (0.2%)	163 (0.8%)	87
van Boxel, 2013	CDC, 30 days	16/211 (7.6%)	-	-	-	-
Gastric						
Hamza, 2018 (b)	CDC/NHSN, 30 days	13/1722 (0.7%)	4 (0.2%)	2 (0.1%)	7 (0.4%)	90[e]
Honda, 2018	CDC (Japanese translation), 30-90 days	66/2837 (2.3%)	66 (2.3%)	-	-	-
Jeong, 2013	CDC/NNIS, 30 days	71/2091 (3.3%)	-	-	-	-
Kim, 2019	CDC/NNIS, 30 days	58/1038 (5.6%)	-	-	46 (4.4%)	177 (145–211)[b]
Kurita, 2015	CDC (Japanese translation), 30-90 days	1458/33 917 (4.3%)	668 (2.0%)	288 (0.8%)	910 (2.7%)	-
Morikane, 2016	NHSN, 30 days	3156/36 052 (8.8%)	-	-	-	-
Qiao, 2020	NNIS, 30 days	84/590 (14.2%)	-	-	61 (10.3%)	2.99±0.88[h]
Troillet, 2017 (d)	CDC, 30 days	135/3077 (4.4%)	67 (2.2%)	11 (0.4%)	57 (1.9%)	113
Hepatobiliary						
Bilgiç, 2020	CDC, 30 days	52/214 (24.3%)	33 (15.4%)	3 (1.4%)	16 (7.4%)	-
Chacon, 2019	CDC, 30 days	2475/21 443 (11.5%)	759 (3.5%)	193 (0.9%)	1523 (7.1%)	243.5±125.7

Chen-Xu, 2018	Clavien-Dindo classification, 30 days	68/654 (10.4%)	68 (10.4%)	-	-	-
Elliott, 2017 (a)	CDC, 30-90 days	2057/10 371 (19.8%)	719 (6.9%)	207 (2.0%)	1287 (12.4%)	-
Elliott, 2017 (b)	CDC, 30-90 days	58/201 (28.9%)	28 (13.9%)	8 (4%)	24 (11.9%)	-
Ghali, 2018 (b)	CDC, 30 days	9/66 (13.6%)	-	-	-	-
Karavokyros, 2017	CDC, 30 days	15/81 (18.5%)	-	-	15 (18.5%)	417±113
Liu, 2019	CDC, 30 days	1213/5969 (20.3%)	432 (7.2%)	0 (0.0%)	841 (14.1%)	-
McCracken, 2019	CDC, 30 days	1555/6471 (24.0%)	-	-	-	<3.58h: 10.6% 3.58-5.1h: 23.6% 5.11-6.75h: 32.1% >6.75h: 33.7%
Okubo, 2018	CDC, 30 days	26/427 (6.1%)	-	-	-	-
Sugiura, 2015	CDC, 30 days	83/218 (38.1%)	-	-	75 (34.4%)	<480: 65.6% ≥480: 34.4%
Tschan, 2015 (a)	CDC, 30 days	15/88 (17.0%)	-	-	9 (10.2%)	-
Hernia repair						
Fafaj, 2020	CDC, 30 days	25/1507 (1.7%)	22 (1.5%)	3 (0.2%)	0 (0.0%)	-
Guzmán-García, 2019 (d)	CDC, 30-90 days	7/91 (7.7%)	-	-	-	-
Hassan, 2020	CDC, 30 days	46/234 (19.7%)	40 (17.1%)	6 (2.6%)	-	-
Juvany, 2018	CDC, 30 days	16/101 (15.8%)	11 (10.9%)	5 (4.9%)	0 (0.0%)	67±33
Karamanos, 2017	CDC, 30 days	167/4983 (3.4%)	-	-	-	-
Khan, 2020 (a)	CDC, 30 days	68/181 (37.6%)	-	-	-	-
Rosen, 2017	CDC, 30 days	21/104 (20.2%)	9 (8.7%)	10 (9.6%)	2 (1.9%)	244 (60–505)[c]
Troillet, 2017 (c)	CDC, 30 days	169/17 030 (1.0%)	119 (0.7%)	38 (0.2%)	12 (0.1%)	66
Williams, 2019	CDC, 30 days	210/12 026 (1.7%)	167 (1.4%)	28 (0.2%)	15 (0.1%)	-
Multiple general surgical sites						
Ghali, 2018	CDC, 30 days	30/349 (8.6%)	14 (4.0%)	3 (0.9%)	13 (3.7%)	92±71 (15-485)[d h]
Guzmán-García, 2019	CDC, 30-90 days	91/755 (12.1%)	37 (4.9%)	20 (2.6%)	34 (4.5%)	<60: 18.1% 60–120: 76.3% >120: 5.6%

Hu, 2016	NNIS/CDC, 30 days	99/290 (34.1%)	54 (18.6%)	13 (4.5%)	32 (11.0%)	<3: 77.9% ≥3: 22.1%
Tschan, 2015	CDC, 30 days	24/167 (14.4%)	-	-	14 (8.4%)	4.6±2.1[h]
Xavier, 2014	CDC, 30 days	6/96 (6.3%)	5 (5.2%)	-	-	120 (60-480)[d]
Zhang, 2018	CDC, 30 days	49/184 (26.6%)	26 (14.1%)	9 (4.9%)	14 (7.6%)	<180: 73.9% ≥180: 26.1%

CDC: US Centers for Disease Control; ECDC: European Centre for Disease Prevention and Control (ECDC) guidelines; NHSN: National Health Safety Network (US); NICE: National Institute for Health & Care Excellence (UK); NNIS: National Nosocomial Infection Surveillance System (US)

Note: Dash indicates not reported or subgroup data could not be extracted.

[a]Presented as mean or mean ± standard deviation unless otherwise specified: [b]Median (IQR); [c]Median (range); [d]Mean (range); [e]Mean (IQ1-IQ3); [f]Median (NR); [g]Not reported [h]Reported total population median duration of operation was transformed into a mean (minutes) for meta-regression; [ƚ] Data not used in meta-analysis.

Table 3. Meta-analyses summary results including sensitivity and subgroup analyses for cumulative incidence (CI) of SSI

SSI Incidence	Study (n)	Strata (n)[a]	Patients (n)	Pooled estimates[b]	*95 % CI*	I^2
Total 30-day General surgery CI	57	74	488 594	0.11	0.10-0.13	99.7
Surgical Location						
Appendix	5	5	27 299	0.08	0.04-0.14	99.0
Bowel/Colon/Rectum	30	31	242 452	0.15	0.13-0.17	99.5
Gallbladder	8	9	55 059	0.03	0.02-0.04	96.1
Gastric	8	8	81 324	0.05	0.03-0.07	99.3
Hepatobiliary	11	12	46 203	0.19	0.15-0.23	98.8
Hernia repair	9	9	36 257	0.08	0.06-0.11	98.5
SSI Types						
Superficial	37	43	378 638	0.05	0.04-0.06	99.4
Deep	32	38	336 565	0.01	0.01-0.02	98.1
Organ Space	37	43	341 846	0.05	0.04-0.06	99.7
Wound Type						
Clean	6	6	5,323	0.08	0.02-0.18	96.9
Clean-Contaminated	8	9	27 566	0.10	0.05-0.16	99.1
Contaminated	8	8	4 485	0.23	0.14-0.33	93.7
Dirty-Infected	4	4	4 647	0.13	0.05-0.24	95.4
Surgical type						
Open	32	36	60 679	0.13	0.10-0.16	99.1
Laparoscopic	23	24	67 476	0.08	0.05-0.11	99.4
Surgical priority						
Emergency only	12	13	18 659	0.17	0.10-0.27	99.2
Planned only	32	33	131 792	0.11	0.08-0.14	99.5
Region Subgroups						
Africa	2	2	447	0.17	0.14-0.21	-
East Asia	18	18	119,223	0.12	0.09-0.14	99.4
South Asia (India)	1	1	486	0.31	0.26-0.36	-
Europe	16	23	108 426	0.10	0.07-0.13	99.6
Middle East	3	4	2,522	0.13	0.02-0.33	99.0

SSI Incidence	Study (n)	Strata (n)[a]	Patients (n)	Pooled estimates[b]	*95 % CI*	I^2
North America	17	18	257,525	0.09	0.06-0.13	99.9
South America	1	1	96	0.06	0.03-0.13	-
Risk of Bias						
Low risk of Bias studies only	25	26	205,816	0.10	0.07-0.14	99.8
Moderate risk of Bias studies only	27	35	243,464	0.11	0.09-0.14	99.6
High risk of Bias studies only	7	7	39,642	0.12	0.07-0.18	98.0
High risk of Bias studies removed	52	61	449,280	0.11	0.09-0.13	99.7
Data source						
National database/registry	21	25	389 213	0.07	0.05-0.10	99.7
Surveillance designed forms	14	19	92 024	0.11	0.07-0.15	99.7
Patient medical records	19	19	6650	0.16	0.11-0.20	95.7
Patient medical records & physical exam	5	5	1035	0.21	0.17-0.25	61.0

[a] Some studies have multiple subgroups per meta-analysis

[b] Only Random effects models were used, applying Double arsine Freeman-Turkey transformation

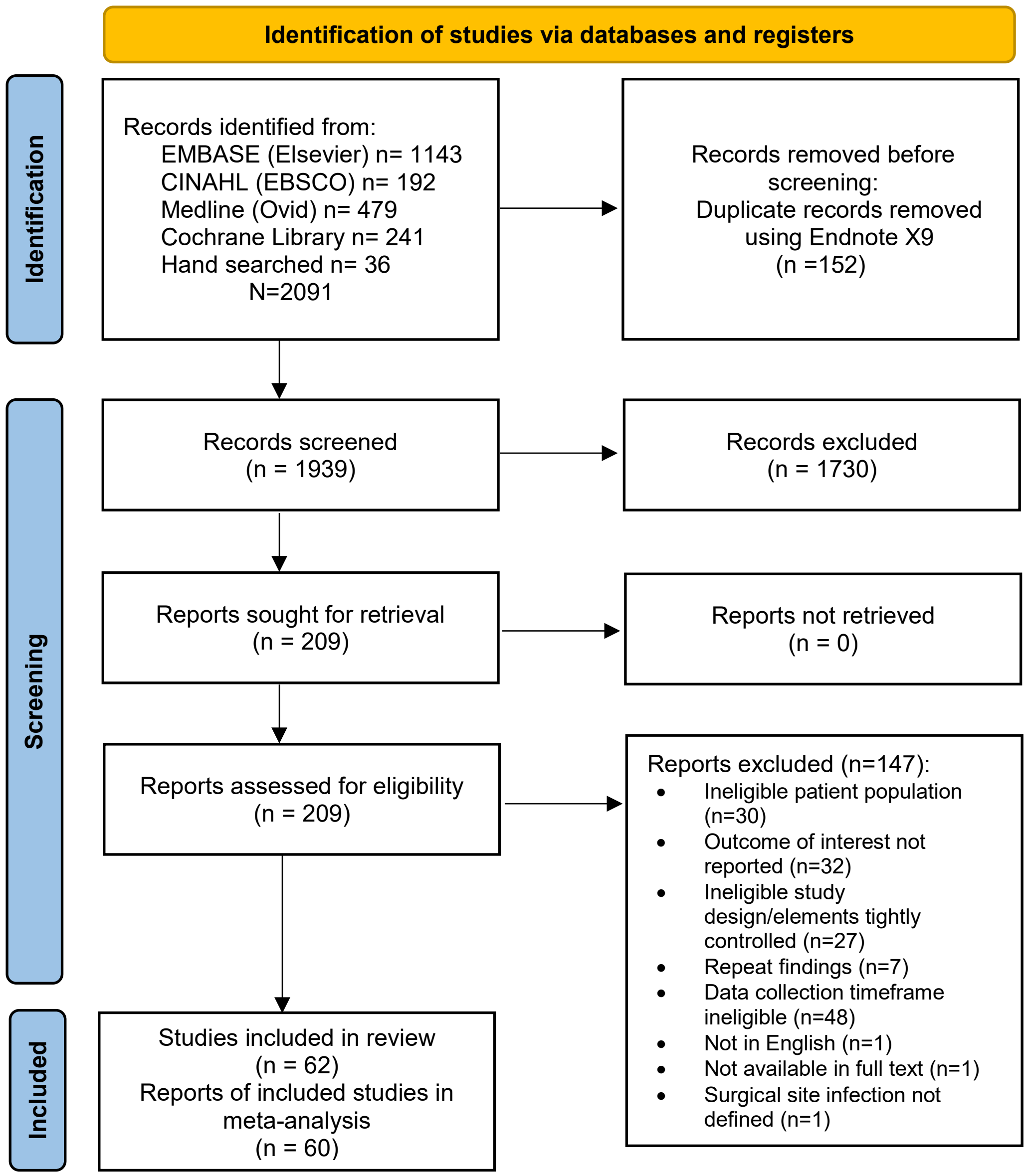

Figure 1. Selection of articles for the systematic review and meta-analysis (13)

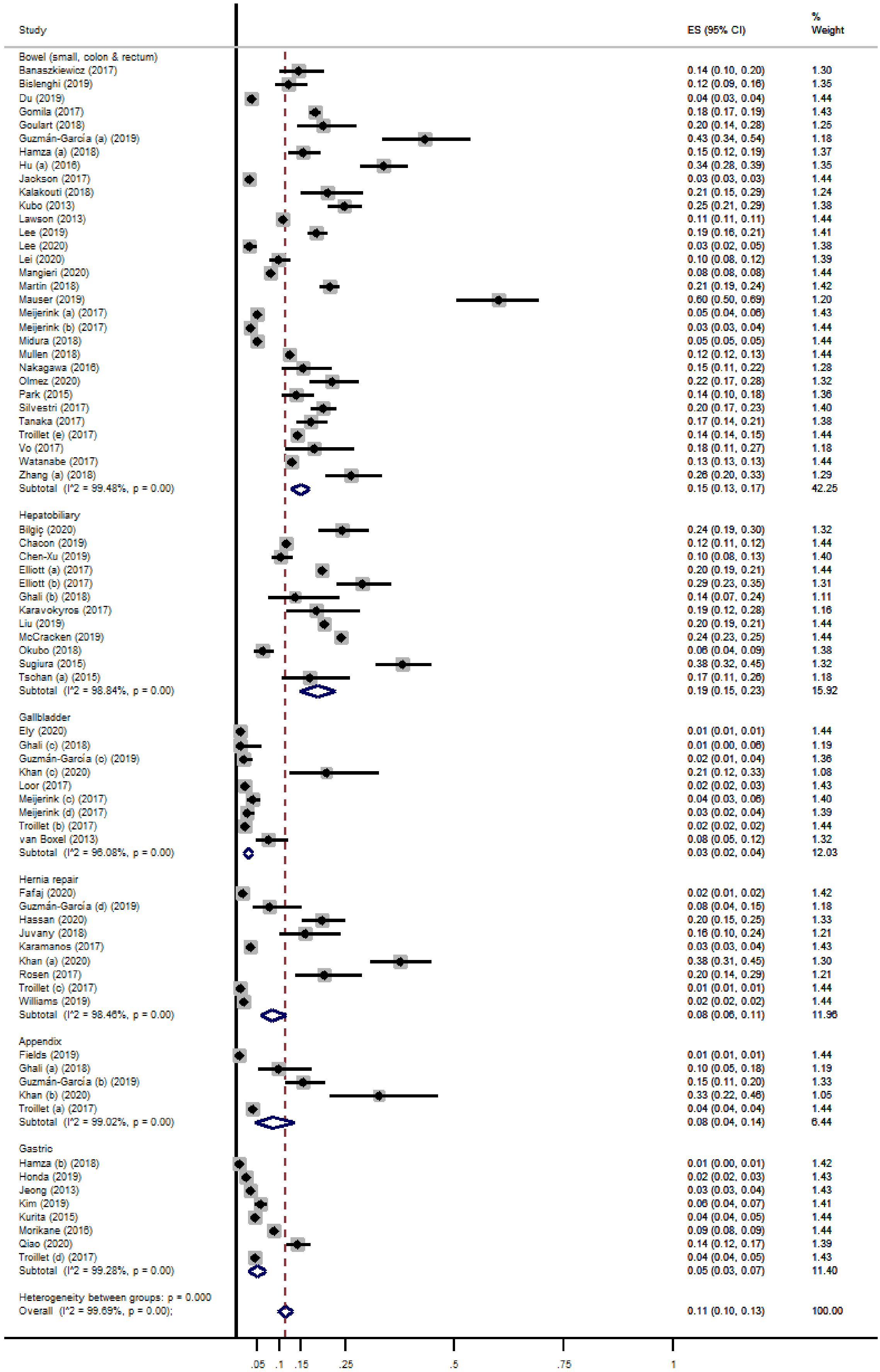

Figure 2. Forest plot for 30-day Cumulative incidence of SSI by surgical site