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**Systematic Review**

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# Effect of the number of door openings in the operating room on surgical site infections: individual-patient data meta-analysis

Hannah Groenen[1,2,3], Hasti Jalalzadeh[1,2,3], Nathan Bontekoning[1,2,3], Antoinette A. A. Bediako-Bowan[4,5], Dennis R. Buis[3,6], Yasmine E. M. Dreissen[3,6], Anne M. Eskes[1,7], Jon H. M. Goosen[3,8], Mingyang L. Gray[9], Mitchel Griekspoor[3,10], Brian L. Hollenbeck[11], Frank F. A. IJpma[3,12], Maarten J. van der Laan[3,13], Appiah-Korang Labi[14], Nina M. C. Mathijssen[15,16], Brett A. Miles[17], Kåre Mølbak[18,19], Ricardo G. Orsini[20], Frederik J. Prakken[21], Roald R. Schaad[3,22,23], Patrique Segers[3,24], Marius A. Stauning[25,26], Wil C. van der Zwet[3,27], Stijn W. de Jonge[1,2], Niels Wolfhagen[1,2,3], Gerjon Hannink[28,†] and Marja A. Boermeester[1,2,3,*†]

[1]Department of Surgery, Amsterdam UMC location University of Amsterdam, Amsterdam, the Netherlands
[2]Amsterdam Gastroenterology Endocrinology and Metabolism, Amsterdam, the Netherlands
[3]Dutch National Guideline Group for Prevention of Postoperative Surgical Site Infections, the Netherlands
[4]Department of Surgery, University of Ghana Medical School, University of Ghana, Accra, Ghana
[5]Department of Surgery, Korle Bu Teaching Hospital, Accra, Ghana
[6]Department of Neurosurgery, Amsterdam UMC location University of Amsterdam, Amsterdam, the Netherlands
[7]Amsterdam Public Health, Amsterdam, the Netherlands
[8]Department of Orthopedic Surgery, Sint Maartenskliniek, Ubbergen, the Netherlands
[9]Department of Otolaryngology, Icahn School of Medicine at Mount Sinai, New York, New York, USA
[10]Dutch Association of Medical Specialists, Utrecht, the Netherlands
[11]New England Baptist Hospital, Boston, Massachusetts, USA
[12]Department of Surgery, Division of Trauma Surgery, University Medical Centre Groningen, Groningen, the Netherlands
[13]Department of Surgery, Division of Vascular Surgery, University Medical Centre Groningen, Groningen, the Netherlands
[14]Department of Medical Microbiology, University of Ghana Medical School, Accra, Ghana
[15]Reinier Haga Orthopedisch Centrum, Zoetermeer, the Netherlands
[16]Department of Orthopaedics, Reinier de Graaf Groep, Delft, the Netherlands
[17]Department of Otolaryngology Head and Neck Surgery, Northwell Cancer Institute, Northwell Health, New York, New York, USA
[18]Department of Veterinary and Animal Science, University of Copenhagen, Copenhagen, Denmark
[19]Division of Infectious Disease Preparedness, Statens Serum Institut, Copenhagen, Denmark
[20]Department of Surgery, Maastricht University Medical Centre+, Maastricht, the Netherlands

**Correspondence to:* Marja A. Boermeester, Department of Surgery, Amsterdam UMC location University of Amsterdam, Meibergdreef 9, 1105 AZ Amsterdam, the Netherlands (e-mail: m.a.boermeester@amsterdamumc.nl)

[†]Joint senior authors; these authors contributed equally to this article

## Abstract

**Background:** The effect of door openings in the operating room on surgical site infections remains a controversial topic and has led to strict door-opening policies. The aim of this individual-patient data meta-analysis was to evaluate the effect of the number of door openings in the operating room on surgical site infection.

**Methods:** MEDLINE (PubMed) and Embase (Ovid) were searched up to 2 December 2024. Authors with individual-patient data on surgical site infections and door openings were invited to collaborate. A one-stage individual-patient data meta-analysis accounting for heterogeneity was performed to examine effects overall and in subgroup analyses (wound class, implant surgery, and income level). The primary outcome was surgical site infection. The risk of bias and Grading of Recommendations, Assessment, Development, and Evaluation framework were used to determine the certainty of evidence.

**Results:** Individual-patient data from 8 observational studies, encompassing 4412 patients, revealed a 6.0% incidence of surgical site infection. Each extra door opening per hour was associated with increased risk of surgical site infection (odds ratio 1.012, 95% c.i. 1.005 to 1.019; $\tau^2 = 0.095$; very low certainty of evidence). This means that, for example, at a baseline infection risk of 2%, approximately 35 additional door openings per hour per surgery would be needed to cause one additional surgical site infection per 100 patients. In subgroup analyses, no differences in effect were found. The cumulative effect was more pronounced in patients with a high baseline risk of surgical site infection.

**Conclusion:** Very low certainty of evidence suggests a marginal increase in the risk of surgical site infection for each additional door opening per hour. Although the relative effect is minimal, the cumulative effect has an impact on patients with a higher baseline surgical site infection risk more than others. However, the certainty of the available evidence is too low and the relative effect on clinical outcomes too small to support a rigorous zero door-openings policy to reduce rates of surgical site infections.

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[21]Department of Surgery, Gelre Hospital, Apeldoorn, the Netherlands
[22]Department of Anaesthesiology, Leiden University Medical Centre, Leiden, the Netherlands
[23]Dutch Association of Anaesthesiology (NVA), the Netherlands
[24]Department of Cardiothoracic Surgery, Maastricht University Medical Centre+, Maastricht, the Netherlands
[25]Department of Clinical Microbiology, Copenhagen University Hospital, Rigshospitalet, Copenhagen, Denmark
[26]Centre for Translational Medicine and Parasitology, Department of Immunology and Microbiology, University of Copenhagen, Denmark
[27]Department of Medical Microbiology, Infectious Diseases and Infection Prevention, Maastricht University Medical Centre+, Maastricht, the Netherlands
[28]Department of Medical Imaging, Radboud University Medical Centre, Nijmegen, the Netherlands

# Introduction

Surgical site infections (SSIs) are frequent healthcare-associated infections, significantly contributing to postoperative morbidity, mortality, and increased healthcare costs[1,2]. Minimizing door openings during surgery to prevent SSI is broadly recommended in clinical guidelines and SSI prevention care bundles[3–8]. Among others, the National Institute for Health and Care Excellence[6], the Healthcare Infection Society[7], the European Society of Clinical Microbiology and Infectious Diseases[7], and the Centers for Disease Control and Prevention (CDC)[8] all recommend limiting door openings during surgery. This recommendation arises from the observed association between door openings and increased intraoperative microbial air contamination, as well as that between intraoperative microbial air contamination and SSI[6–9]. However, conclusive clinical data examining the direct effect of door openings during surgery on SSI rates is scarce, and existing studies are predominantly retrospective or observational in nature. Notably, the World Health Organization (WHO)[10,11] and the updated CDC guideline do not address this topic[12]. Some studies[13–16] have shown that laminar airflow reduces air contamination compared with turbulent ventilation. However, a recent systematic review and meta-analysis[17] did not find that laminar airflow reduced SSI rates compared with turbulent ventilation.

With the lack of randomized clinical trials (RCTs) and substantial heterogeneity between studies found by previous reviews, an individual-patient data (IPD) meta-analysis (IPDMA) enables the use of all available data. An IPDMA uses raw individual-study participant-level data from the included studies, standardizes analysis to account for possible confounders for maximum statistical power, and enables detailed subgroup analyses. It seems particularly relevant to examine the potential effect of door openings in clean surgeries and implant operations, for which the association between door openings and SSI is a frequent subject of debate. This has led to a rigorous zero door-openings policy in some settings. Although exogenous contamination is believed to play a significant role in clean surgeries and operations of long duration, studies in these specialties mostly show associations with surrogates of SSI (such as increased wound contamination), rather than direct evidence of an increase in clinically relevant SSI rates[18,19]. In implant surgeries, SSI poses additional concerns owing to the severe consequences of prosthetic infections, particularly those caused by biofilm formation on the implant[20].

This study presents a systematic review, IPDMA, and Grading of Recommendations Assessment Development and Evaluation (GRADE) assessment of the available evidence. The aim of the study was to investigate the potential effect of door openings in the operating room on the incidence of SSI.

# Methods

## Study registration

This study adhered to the PRISMA statement. The study protocol was registered with PROSPERO (CRD42022309958).

## Search strategy

A systematic review and IPDMA were conducted to evaluate the effect of the number of door openings in the operating room on SSI in any type of surgery. MEDLINE (PubMed) and Embase (Ovid) databases were searched for eligible studies from inception to 2 December 2024. Additional papers were identified by backward and forward citation tracking. Moreover, all collaborators were asked whether they were aware of any other eligible studies. The complete search strategy is presented in the *supplementary methods*.

## Selection criteria

Prospective, retrospective, and randomized studies with available IPD on SSI, the number of door openings in the operating room, and procedure duration were included. In the case of studies with a before–after cohort design that investigated the number of door openings as part of a bundle of SSI prevention measures, the cohorts in the different phases were included as separate studies. Cohorts were excluded if a significant proportion of the standard SSI prevention measures, such as appropriate systemic antibiotic prophylaxis, hair removal, skin preparation, or surgical hand preparation, were not applied. These decisions were made in consultation with a senior author (M.A.B.). The analysis included only patients for whom data regarding IPD on SSI, the number of door openings in the operating room, and procedure duration were available. Unpublished and non-human studies, and studies performed outside the operating room were excluded. Furthermore, studies were excluded if the authors were unwilling or unable to contribute. There were no restrictions on the year or language of publication.

Two researchers (H.G., H.J.) individually performed title, abstract, and full-text screening, with disagreements resolved by consulting the senior author (M.A.B.).

## Data extraction and validation

Corresponding authors from eligible studies were contacted. If no response was received, the co-authors were contacted. When the study met the inclusion criteria and IPD were available, the principal investigators were subsequently invited to participate in the IPDMA study group. An online collaborative meeting was organized to discuss the study protocol and the set of data items with definitions. All parties were asked to sign a data transfer agreement and to anonymize the IPD before data transfer. To guarantee data integrity, all IPD were examined for missing values or invalidities and compared with published data. In the event of potential discrepancies, the principal investigators were contacted.

## Quality assessment

The risk of bias for the outcome SSI was assessed by two reviewers (H.G. and H.J.) independently using the Risk of Bias in Non-randomized Studies—of Interventions (ROBINS-I) tool for non-randomized studies[21]. The domain 'bias due to deviations from intended interventions' was not scored for studies that did not compare interventions. Disagreements were resolved by discussion or by consulting the senior authors (M.A.B. and G.H.).

## Specification of outcomes and effect measures

The primary outcome was the incidence of SSI, as defined by the authors of the original publication. No secondary outcome was analysed.

## Missing data

Multilevel imputation of missing data was performed at the participant level using multiple imputation by chained equations for all studies simultaneously[22,23]. A detailed description of the handling of missing data can be found in *supplementary methods*, with an overview of missing data presented in *Table S1*.

## Data analysis

A one-stage meta-analysis of IPD using a random-effects framework was undertaken to determine the effect of the number of door openings per hour on SSI. Between-study differences were accounted for with mixed-effects models, with a term for random intercept and random slope for the effect of door openings per study. In addition, the relationship between the number of door openings per hour and SSI was evaluated by comparing a simple linear model with a model using restricted cubic splines.

The number of door openings was examined as a continuous variable. All analyses were adjusted for age, sex, body mass index (BMI), smoking, diabetes, the use of appropriate systemic antibiotic prophylaxis, American Society of Anesthesiologists (ASA) physical status classification, the level of wound contamination according to the CDC criteria[8], emergency surgery, procedure duration, income level of the country where the study was conducted, and implantation of a foreign body. Confounders to be controlled for were identified using directed acyclic graphs, as shown in *Fig. S1*[24,25]. Results are presented as an odds ratio (OR) with corresponding 95% confidence interval (c.i.). A two-sided $P < 0.050$ was considered statistically significant, and the results of all statistical tests are interpreted in context[26]. Heterogeneity was assessed by the $\tau^2$ statistic. Trial-level co-variates were accounted for in the one-step meta-analysis. An unadjusted two-step meta-analysis was also carried out.

To explore heterogeneity and test for potential effect modification, a prespecified subgroup analysis was performed based on the level of wound contamination[8], and a non-planned subgroup analysis was conducted based on implantation of a foreign body. There may be challenges in low- and lower–middle-income countries in maintaining optimal adherence to key measures for the prevention of SSI that are considered standard in perioperative clinical care in high-income countries. Therefore, a non-planned subgroup analysis was done based on income level of the country where the study was conducted (high and upper–middle *versus* lower–middle and low), based on World Bank data[27]. Furthermore, a planned sensitivity analysis was conducted after exclusion of studies with serious or critical risk of bias based on the ROBINS-I tool[21].

## Evidence appraisal

The GRADE methodology was used to evaluate the certainty of evidence using a minimally contextualized approach on the following domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias[28]. Inconsistency was assessed using $\tau^2$ statistics. Imprecision was evaluated taking the minimally important difference into account and, when the relative effect was large, the optimal information size approach was used by calculating the ratio of the upper to the lower boundary of the c.i. with a threshold for downgrading of 2.5[29,30]. A more detailed description of the GRADE methodology can be found in the *supplementary material*.

All analyses were done using R version 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria).

# Results

## Study selection

The initial search yielded 302 records after duplicates had been removed. Five articles were identified from citation tracking. After screening 81 full-text reports, the authors of 18 studies were contacted for IPD. Two studies[31,32], with 72 and 50 participants, respectively, that were identified during an update of the literature search on 2 December 2024 were not contacted for IPD retrieval because they were identified (and published) after the IPD meta-analysis had been completed. As a result, these two additional but small studies were included only in the systematic review and not in the IPDMA: the two studies would have increased the total number of patients by only 1.0% (from 4412 to 4534) and the number of SSI events also by 1.0% (from 265 to 268). Attempts to contact the authors of four studies were unsuccessful; three of these studies[33–35] did not mention SSI data in their papers, and the fourth[36] dated back to 1994. The authors of five studies responded, but lacked data on SSI[18,37–39] or were not able to share IPD (688 participants)[40]. Finally, the principal investigator of one study[41] responded initially, but later withdrew from collaboration without further explanation (3060 participants). Thus, the authors of 8 eligible studies[42–49] with a potential total of 8230 patients were willing to participate in this IPDMA and provided IPD. *Figure 1* shows the flow chart of study and participant inclusion in the IPDMA; *Table S2* provides reasons for exclusion after full-text review.

## Study characteristics

The characteristics of the eight studies included in the IPDMA are presented in *Table S3*. Seven prospective comparative cohort studies[42,44–49] and one prospective cohort study[43] were identified. One before–after cohort study[42] was incorporated, implementing or strengthening multiple SSI preventive measures, involving three phases: baseline, follow-up, and sustainability. The baseline phase in that study was excluded because the authors did not adhere to the most recent standards for perioperative clinical care in a significant number of patients. The follow-up and sustainability phases were included as two separate studies. Another study was published in two separate articles[9,49], with one article describing surgical environment and the other SSI follow-up. Data from these studies[9,49] were compiled into a single data set and included in the analysis and risk-of-bias assessment as a single study. One study[45] did not provide information on the number of door openings in the article; however, IPD were available for a significant proportion of patients. In addition, two studies[46,47] did not include SSI data in the published articles, but the authors were able to share IPD on SSI outcomes. Three studies[9,42,44] were conducted in lower–middle- or low-income countries. Primary outcomes of the original articles varied, encompassing SSI (4), colony-forming units in the air (3), and operative workflow and efficiency (1) (*Table S3*). Furthermore, the median number of door openings per

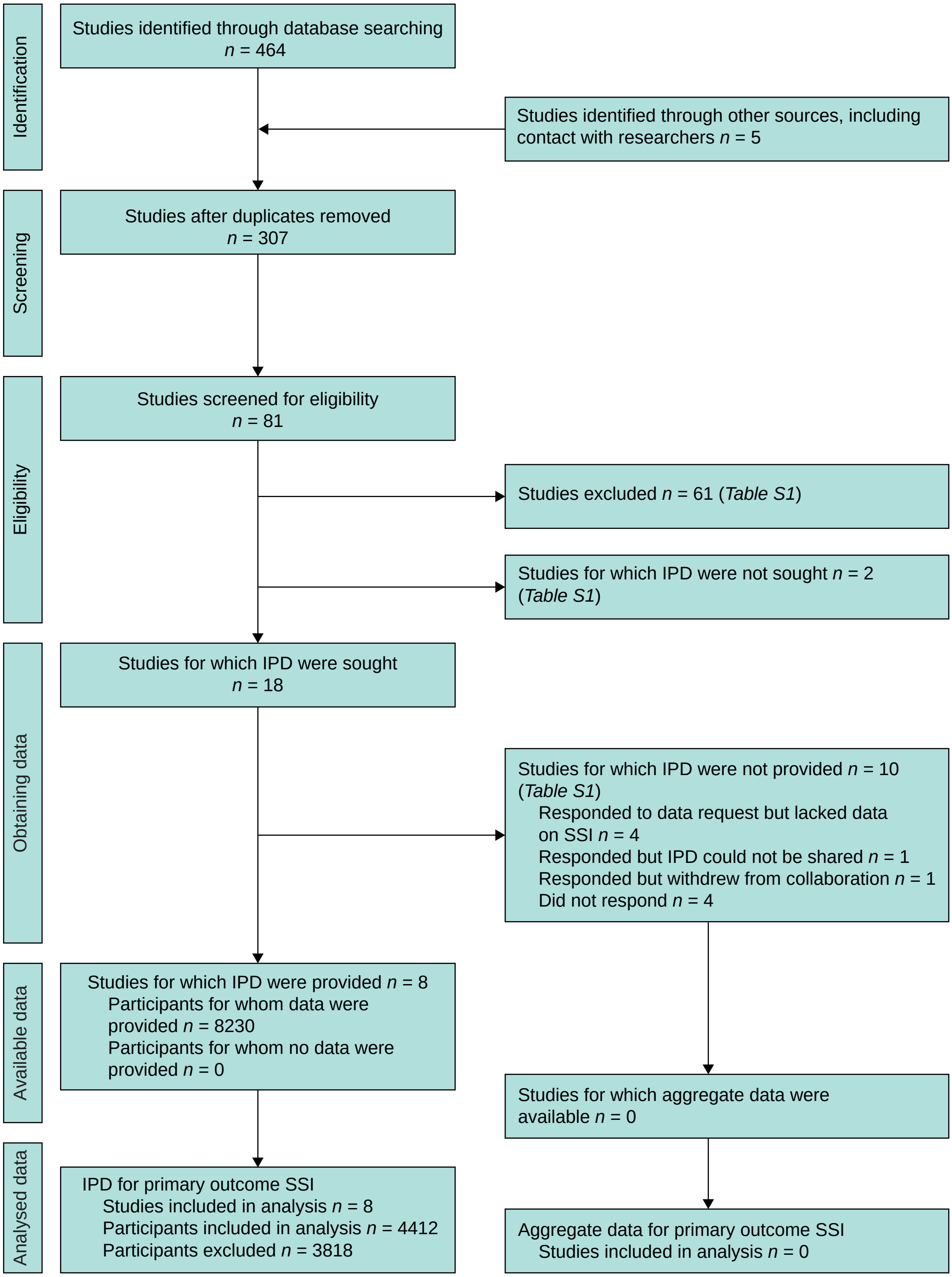


**Fig. 1 PRISMA-IPD flow diagram**

PRISMA-IPD, Preferred Reporting Items for Systematic Reviews and Meta-Analysis of Individual Patient Data; IPD, individual-patient data; SSI, surgical site infection.


hour (measured between incision to closure), type of surgery, and the level of wound contamination differed between studies (*Table S3*). The characteristics of the four studies that could not be included in the IPDMA because of challenges in IPD retrieval are presented in *Table S4*.

## Quality assessment

The risk-of-bias assessment of the individual studies for the outcome SSI is presented in *Table S5*. Using the ROBINS-I tool[21], four studies[45,46,48,49] were scored as having a moderate risk of bias. Another four studies were rated as having a serious risk of

**Table 1 Baseline and surgical characteristics of participants included in the primary individual-patient data analysis**

| | Total (n = 4412) | SSI (n = 265) | No SSI (n = 4147) |
|---|---|---|---|
| **Age (years), median (i.q.r.)** | 43.0 (30.0–60.0) | 50.5 (35.0–64.0) | 43.0 (30.0–60.0) |
| Missing | 76 (1.7) | 1 (0.4) | 75 (1.8) |
| **Sex** | | | |
| Male | 1549 (35.1) | 114 (43.0) | 1435 (34.6) |
| Female | 2790 (63.2) | 150 (56.6) | 2640 (63.7) |
| Missing | 73 (1.7) | 1 (0.4) | 72 (1.7) |
| **ASA grade** | | | |
| I | 1830 (41.5) | 75 (28.3) | 1755 (42.3) |
| II | 1815 (41.1) | 125 (47.2) | 1690 (40.8) |
| III | 557 (12.6) | 54 (20.4) | 503 (12.1) |
| IV–V | 70 (1.6) | 7 (2.6) | 63 (1.5) |
| Missing | 140 (3.2) | 4 (1.5) | 136 (3.3) |
| **BMI (kg/m$^2$), median (i.q.r.)** | 25.1 (22.5–28.3) | 26.3 (22.7–29.8) | 24.9 (22.5–28.1) |
| Missing | 3197 (72.5) | 140 (52.8) | 3057 (73.7) |
| **Smoking status** | | | |
| Active smoking | 363 (8.2) | 32 (12.1) | 331 (8.0) |
| Not smoking | 852 (19.3) | 98 (37.0) | 754 (18.2) |
| Missing | 3197 (72.5) | 135 (50.9) | 3062 (73.8) |
| **Diabetes** | | | |
| Yes | 117 (2.7) | 23 (8.7) | 94 (2.3) |
| No | 1201 (27.2) | 113 (42.6) | 1088 (26.2) |
| Missing | 3094 (70.1) | 129 (48.7) | 2965 (71.5) |
| **Appropriate systemic antibiotic prophylaxis** | | | |
| Yes | 3858 (87.4) | 240 (90.6) | 3618 (87.2) |
| No | 89 (2.0) | 7 (2.6) | 82 (2.0) |
| Not indicated | 280 (6.3) | 13 (4.9) | 267 (6.4) |
| Missing | 185 (4.2) | 5 (1.9) | 180 (4.3) |
| **Implantation of a foreign body** | | | |
| Yes | 693 (15.7) | 39 (14.7) | 654 (15.8) |
| No | 3373 (76.5) | 203 (76.6) | 3170 (76.4) |
| Missing | 346 (7.8) | 23 (8.7) | 323 (7.8) |
| **Procedure category** | | | |
| Abdominal | 2351 (54.4) | 183 (69.1) | 2168 (53.4) |
| Vascular | 164 (3.8) | 12 (4.5) | 152 (3.8) |
| Trauma and/or orthopaedic | 691 (16.0) | 28 (10.6) | 663 (16.3) |
| Head and neck | 274 (6.3) | 7 (2.6) | 267 (6.6) |
| Breast | 366 (8.5) | 15 (5.7) | 351 (8.7) |
| Gynaecology | 215 (5.0) | 7 (2.6) | 208 (5.1) |
| Hernia repair | 226 (5.2) | 10 (3.8) | 216 (5.3) |
| Other | 36 (0.8) | 3 (1.1) | 33 (0.8) |
| Missing data | 89 (2.1) | 0 (0.0) | 89 (2.1) |
| **Emergency surgery** | | | |
| Yes | 1222 (27.7) | 82 (30.9) | 1140 (27.5) |
| No | 3133 (71.0) | 183 (69.1) | 2950 (71.1) |
| Missing | 57 (1.3) | 0 (0.0) | 57 (1.4) |
| **Contamination level*** | | | |
| Clean | 1828 (41.4) | 64 (24.2) | 1764 (42.5) |
| Non-clean | 2525 (57.2) | 201 (75.8) | 2324 (56.0) |
| Missing | 59 (1.3) | 0 (0.0) | 59 (1.4) |
| **No. of door openings per hour, median (i.q.r.)** | 13.9 (3.4–31.7) | 22.4 (6.1–46.7) | 13.1 (3.3–31.0) |
| Missing | 0 (0) | 0 (0) | 0 (0) |
| **Procedure duration (min), median (i.q.r.)** | 75 (49–120) | 107 (65–164) | 73 (48–119) |
| Missing | 0 (0) | 0 (0) | 0 (0) |

Values are n (%) unless otherwise stated. *According to the Centers for Disease Control and Prevention wound classification. SSI, surgical site infection; i.q.r., interquartile range; ASA, American Association of Anesthesiologists; BMI, body mass index.

bias, owing to missing data[42], confounding[43,47], or selection of reported results[44]. The IPD provided additional insights into confounding and selection of the reported results, resulting in the risk of bias being reduced from serious to moderate for three studies[43,44,47].

## Participant selection

All 1605 patients from the baseline phase of the before–after cohort study[42] were excluded because a significant proportion of the standard SSI prevention measures, such as systemic antibiotic prophylaxis, were not achieved. Furthermore, an additional 2213 patients were excluded because IPD on SSI, procedure duration, or door openings were missing, resulting in the inclusion of 4412 patients in the IPDMA.

## Results of syntheses

The overall incidence of SSI was 6.0% and the median number of door openings per hour was 13.9 (interquartile range 3.4–31.7) (*Table 1*). In addition, there was an increased duration of surgery and a higher number of door openings per hour in the SSI group compared with the non-SSI group (*Table 1*).

**Table 2 Effect sizes of door openings and door openings–variable interactions (unadjusted and adjusted results) on surgical site infections**

| | Unadjusted analysis | | Adjusted analysis* | |
|---|---|---|---|---|
| | Odds ratio | P | Odds ratio | P |
| Per one additional door opening per hour | 1.009 (1.002, 1.015) | 0.010 | 1.012 (1.005, 1.019) | < 0.001 |

Values in parentheses are 95% confidence intervals. Results are for a one-step meta-analysis of individual-patient data using a random-effects framework to test the effect of the number of door openings per hour on surgical site infections. *Variables included in the model were: age, sex, body mass index, smoking, diabetes, the use of appropriate systemic antibiotic prophylaxis, American Association of Anesthesiologists grade, level of wound contamination according to Centers for Disease Control and Prevention criteria, emergency surgery, procedure duration, income level of the country where the study was conducted, implantation of a foreign body, and study as a random effect.

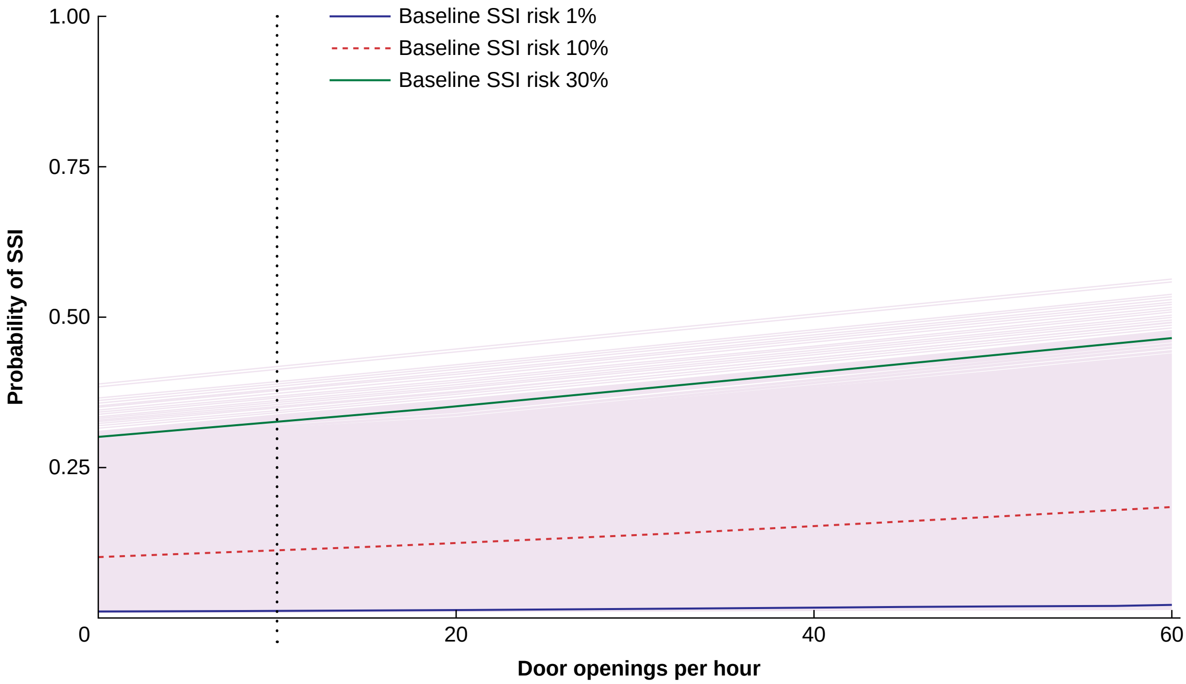


**Fig. 2 Effect of door openings on the rate of surgical site infections**

The plot shows the effect of the number of door openings per hour on the rate of surgical site infections (SSIs) from a one-step meta-analysis of individual-patient data using a random-effects framework, and corrected for confounders. The pink lines show the absolute increase in SSI risk for every extra door opening per hour (odds ratio 1.012, 95% c.i. 1.005 to 1.019) for every possible scenario in the model. The absolute increase in SSI risk is shown for three baseline SSI risks: 1, 10, and 30%. Variables included in the model were: age, sex, body mass index, smoking, diabetes, the use of appropriate systemic antibiotic prophylaxis, American Association of Anesthesiologists grade, level of wound contamination according to the Centers for Disease Control and Prevention criteria, emergency surgery, procedure duration, income level of the country where the study was conducted, implantation of a foreign body, and study as a random effect. The vertical dotted line represents the commonly recommended threshold of 10 door openings per hour, as often suggested in guidelines[6–8].

Restricted cubic splines did not benefit model fit. Therefore, the non-spline approach was used. Effect estimates with corresponding 95% confidence intervals for the primary outcome are presented in *Table 2*. After adjustment for confounding, a difference in SSI risk was found for every extra door opening per hour (OR 1.012, 95% c.i. 1.005 to 1.019). This means that, for example, at a baseline infection risk of 2%, approximately 35 additional door openings per hour per surgery would be needed to cause one additional surgical site infection per 100 patients. The cumulative effect of door openings was more pronounced in patients with a high baseline risk of SSI than in patients with a low baseline risk of SSI (*Fig. 2*). Unadjusted two-step meta-analysis is presented in *Fig. S2* (OR 1.007, 0.994 to 1.019). Low between-study heterogeneity was found ($\tau^2 = 0.095$).

## Subgroup and sensitivity analyses

The SSI incidence was 3.5% in clean surgeries (64 of 1828 patients) and 8.0% in non-clean operations (201 of 2525 patients). The association between the number of door openings per hour and SSI did not differ between non-clean and clean surgeries (OR interaction term 0.996, 95% c.i. 0.982 to 1.009). For implant surgeries, which consisted of 298 clean (43.0%) and 395 non-clean (57.0%) operations, the SSI incidence was 5.6% (39 of 693 patients), compared with an incidence of 6.0% for non-implant surgery (203 of 3373 patients). Within clean implant surgeries, the types of procedure varied, and included 188 abdominal operations (27.1%), 27 vascular procedures (3.9%), 205 trauma and/or orthopaedic surgeries (29.6%), two head and neck operations (0.3%), 183 gynaecological procedures (26.4%), 78 hernia repairs (11.3%), and six surgeries classified as other (0.9%). Consequently, associations between the number of door openings per hour and SSI were comparable for implant and non-implant surgeries (OR interaction term 0.980, 0.952 to 1.008). Regarding income levels, the incidence of SSI was 8.1% in high-income countries (101 of 1251 patients) and 5.2% in low-income countries (164 of 3161 patients). The association between the number of door openings and SSI also did not vary between high- and low-income countries (OR interaction term 0.991, 0.979 to 1.004).

**Table 3 GRADE assessment for outcome surgical site infections**

| Certainty assessment | | | | | | | Certainty |
|---|---|---|---|---|---|---|---|
| No. of studies | Study design | Risk of bias | Inconsistency | Indirectness | Imprecision | Other considerations | |
| 8 | Observational studies | Not serious | None | None | None | Publication bias suspected | ⨁◯◯◯ Very low |

GRADE, Grading of Recommendations Assessment, Development, and Evaluation.

A sensitivity analysis excluding studies at serious or critical risk of bias, comprising 1726 patients *versus* 4412 patients in the main analysis, revealed comparable results to the main analysis (OR 1.012, 1.002 to 1.022).

## Certainty of evidence

The starting certainty of evidence was low, because all included studies had an observational design. One study had a serious risk of bias, but sensitivity analysis excluding this study revealed comparable results to those of the main analysis, so downgrading for risk of bias was not necessary. Furthermore, no downgrade for inconsistency was needed ($\tau^2 = 0.095$). All studies provided IPD on the primary outcome SSI, so indirectness was not serious[50,51]. There was no imprecision, because the confidence intervals did not overlap thresholds of interest, and the ratio of the upper and the lower boundary of the confidence intervals was < 2.5[30]. Previous research has indicated that publication bias is potentially more significant in observational studies than in RCTs[52,53]. Therefore, the risk of publication bias was considered substantial because of the observational design of the included studies and the fact that data were often collected for previous study. Overall, the certainty of evidence for the primary outcome was downgraded by one level, resulting in a very low overall certainty of evidence for SSI (*Table 3* and *Table S6*).

# Discussion

This systematic review and IPDMA examined the effect of the number of door openings in the operating room on SSI in any type of surgery. The findings indicate, with very low certainty of evidence, that each additional door opening per hour is associated with an increase in the risk of SSI. Although the relative effect is minimal, the cumulative impact may be clinically more noteworthy in patients with a higher baseline risk of SSI owing to patient- or surgery-related factors.

A restriction on the maximum number of door openings in the operating room to reduce SSI risk has been a controversial topic for many decades[54]. Restricting the maximum number of door openings is incorporated into guidelines and care bundles on the prevention of SSI, even though the clinical evidence to support this recommendation is limited[3–8,19,55]. The underlying assumption about the impact of door openings on SSI risk is grounded in the theory that door openings disrupt airflow in the operating room, potentially introducing contaminants into the operating field and wounds. To date, available studies have presented low-quality clinical evidence with inconclusive results.

The IPDMA approach is necessary because of the substantial heterogeneity of earlier studies on this topic and the lack of clinical data. All the available evidence was aggregated by using raw individual-level data from original studies, which allowed the inclusion of individual patients and unpublished data, the performance of detailed subgroup analyses, and standardization of the analysis for maximum statistical power.

Conducting subgroup analysis based on wound contamination levels is crucial, because wound contamination is an important predictive factor for SSI. Clean and implant surgeries, in particular, have been key topics of ongoing debate because of the association between the number of door openings in the operating room and surrogates of SSI[18,19,47]. Moreover, SSI presents additional concerns in implant surgeries due to the potential for the formation of implant biofilm[20]. This has prompted the implementation of strict zero door-openings policies in some settings. Although previous studies have frequently demonstrated a significant association between door openings and increased bacterial air or wound contamination[19], it is important to emphasize that the present study focused specifically on the clinical outcome of SSI. Consequently, associations between the number of door openings per hour and SSI were comparable among wound contamination levels or implant status.

The limitations of this study stem primarily from the nature of the individual studies and their inherent clinical heterogeneity. Although IPDMA allows more detailed adjustment for confounders, the possibility remains of residual confounding owing to unmeasured or imperfectly measured variables, which may not be consistently available across all studies. Multiple imputation was used to increase precision and avoid bias during the analysis[22]. Still, the high rate of unavailable data may have limited the accuracy of the imputed values, possibly affecting the findings to some extent. However, even with a high percentage of missing data, multiple imputation has been shown to result in unbiased estimates if the missing data are missing at random and the imputation model is well specified[22,56].

It is worth noting that studies conducted in lower-income countries may not strictly adhere to the most recent standards for perioperative clinical care. Therefore, a subgroup analysis was performed based on country income level, which revealed no differences in the association between the number of door openings per hour and SSI for high-income countries compared with low-income countries. Furthermore, several studies did not report a definition for SSI or used definitions other than the diagnostic criteria outlined by the CDC[8].

After obtaining IPD, the risk of bias for most studies initially assessed as having a serious risk of bias was fortunately reduced to a moderate risk, thereby enhancing the robustness of the findings. However, one study remained at serious risk of bias[42]. Notably, a sensitivity analysis excluding that study yielded results comparable to those of the main analysis, further supporting the reliability of the conclusions.

Finally, IPD was not retrieved from four eligible studies, resulting in their inclusion in the systematic review only, and not in the IPDMA. These studies reported conflicting results. One of these[41] was a two-phase neurosurgery study including 3060 patients, whose authors unexpectedly withdrew from the collaboration without providing a clear reason. The authors of that study concluded that the potential benefit of restricting operating room traffic in reducing SSI rates is minimal at best, and possibly non-existent. Another study[40] in cardiac surgery, which included 688 patients, was unable to share IPD. That study reported an association between an increased mean door opening frequency and a higher risk of SSI in both univariable and multivariable analyses; however, some methodological weaknesses, such as the possibility of unmeasured confounders, may have influenced these results[40]. Two studies identified in the updated search were not contacted for IPD retrieval because they were identified (and published) after the IPD meta-analysis had been completed. One orthopaedic study[31] with 72 patients demonstrated that implementing an informational sign reduced the number of door openings. The study suggested that this reduction also influenced SSI rates, because fewer SSIs occurred with the sign in place. However, it did not present data on the number of door openings per SSI patient, making it impossible to draw conclusions about the relationship between door openings and SSI[31]. The other study[32], a paediatric neurosurgery investigation involving 50 patients, quantified foot traffic but found no cases of SSI.

Interestingly, door openings in the operating room may also have a potential non-infectious impact[19]. Some studies have suggested that a decrease in door openings increases attention in the operating room[38]. In addition, door openings are believed to be a surrogate marker for operating room discipline and hygiene. Given that lapses in operating room discipline have been strongly associated with the occurrence of SSI[57], decreasing the number of door openings could possibly be of value[38,58].

This IPDMA presents the first cumulative clinical data on the effect of the number of door openings in the operating room on SSI in any type of surgery. A marginal increase in SSI risk for each additional door opening per hour was found, which may affect patients with a higher baseline SSI risk more than others. However, the certainty of the available evidence is too low and the relative effect on clinical outcomes too small to support a rigorous zero door-openings policy to reduce SSI rates.

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## Author contributions

Hannah Groenen (Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing—original draft), Hasti Jalalzadeh (Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Writing—review & editing), Nathan Bontekoning (Writing—review & editing), Antoinette Bediako-Bowan (Resources, Writing—review & editing), Dennis Buis (Writing—review & editing), Yasmine Dreissen (Writing—review & editing), Anne Eskes (Writing—review & editing), Jon Goosen (Writing—review & editing), Mingyang Gray (Resources, Writing—review & editing), Mitchel Griekspoor (Writing—review & editing), Brian Hollenbeck (Resources, Writing—review & editing), Frank IJpma (Writing—review & editing), Maarten van der Laan (Writing—review & editing), Appiah-Korang Labi (Resources, Writing—review & editing), Nina Mathijssen (Resources, Writing—review & editing), Brett Miles (Resources, Writing—review & editing), Kåre Mølbak (Writing—review & editing), Ricardo Orsini (Writing—review & editing), Frederik Prakken (Resources, Writing—review & editing), Roald Schaad (Writing—review & editing), Patrique Segers (Writing—review & editing), Marius Stauning (Resources, Writing—review & editing), Wil van der Zwet (Writing—review & editing), Stijn de Jonge (Resources, Writing—review & editing), Niels Wolfhagen (Methodology, Writing—review & editing), Gerjon Hannink (Conceptualization, Formal analysis, Methodology, Resources, Supervision, Writing—review & editing), and Marja Boermeester (Conceptualization, Funding acquisition, Methodology, Supervision, Writing—review & editing)

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## Supplementary material

Supplementary material is available at *BJS Open* online.

## Data availability

Deidentified individual participant data obtained via data sharing agreements were used in this analysis. The decision to share data with third parties is that of the authors of the original studies.

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