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Research

Warm Weather and Surgical Site Infections: A Meta-analysis

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Background: Seasonal variability, in terms of warm weather, has been demonstrated to be a significant risk factor for surgical site infections (SSIs). However, this remains an underexposed risk factor for SSIs, and many clinicians are not aware of this. Therefore, a systematic review and meta-analysis has been conducted to investigate and quantify this matter.

Methods: Articles were searched in Embase, Medline Ovid, Web of Science, Cochrane Central, and Google Scholar, and data were extracted from relevant studies. Meta-analysis used random effects models to estimate and compare the pooled odds ratios (OR) and corresponding confidence intervals (CIs) of surgery performed during the warmest period of the year and the colder period of the year.

Results: The systematic review included 20 studies (58,599,475 patients), of which 14 studies (58,441,420 patients) were included for meta-analysis. Various types of surgical procedures across different geographic regions were included. The warmest period of the year was associated with a statistically significant increase in the risk of SSIs (OR 1.39, 95%CI: [1.34–1.45], $P < 0.0001$). Selection of specific types of surgical procedures (eg, orthopedic or spinal surgery) significantly altered this increased risk.

Conclusions: The current meta-analysis showed that warm weather seasons are associated with a statistically significant risk increasement of 39% in developing SSIs. This significant risk factor might aid clinicians in preoperative patient information, possible surgical planning adjustment for high risk patients, and potentially specific antibiotic treatments during the warmer weather seasons that could result in decrease of SSIs. *(Plast Reconstr Surg Glob Open 2021;9:e3705; doi: 10.1097/GOX.0000000000003705; Published online 27 July 2021.)*

INTRODUCTION

Surgical site infections (SSIs) are a common complication of surgery and hospitalization, occurring in 2%–5% of patients undergoing surgical procedures in the United States, and representing 160,000 to 300,000 SSIs each year.[1–4] The definition of SSIs are infections located at or near the area of incision and/or deeper underlying tissue spaces and organs which present within 30 days, or when prosthetics are implanted, 90 days postoperatively.[5] SSIs are becoming more common and more challenging to treat due to the number of surgical procedures being performed worldwide, more complex comorbidities of our patients, and the rise of antimicrobial resistance in pathogens.[6] Consequently, the growing incidence of SSIs leads to a substantial increase in healthcare costs, accounting for the third most costly healthcare-associated infection, with estimated mean attributable costs ranging from $10,443 to $25,546 per infection in the United States.[7–12] Costs can exceed up to $90,000 per infection when SSIs involve prosthetic joint implants or antimicrobial resistance.[13–16]

Seasonal variability, in terms of warm weather, has been shown to be a significant risk factor for SSIs with an odds ratio (OR) of up to 2.16.[17,18] When compared with other well-known risk factors like preoperative weight loss more than 4.5 kg (OR 2.12), diabetes mellitus (OR 1.53), emergency operations (OR 2.05), and blood loss (EBL)

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more than 600 ml (OR 2.23), seasonal variability remains a major contributor.[19–21] A recent cohort study that investigated the seasonal impact on surgical-site infections in body contouring surgery showed that seasonal variability had a more significant impact on SSIs than age, duration of surgery, hospitalization time, BMI, and smoking.[22] Proposed theories explaining the association between warmer weather conditions and SSIs are increased colonization of pathogens like *Staphylococcus aureus*, increased skin-to-skin contact with a higher transmission chance, and skin disruptions (ulcers and sores), which are more common in the summer.[22–24]

Despite the multitude[17,25–27] of proposed studies that show the significance of seasonal variability as a risk factor for SSIs, many clinicians are not aware of this association. Consequently, patients are not informed of this increased risk especially for the elective planned surgical cases. Therefore, our main goal was to first conduct a systematic review and investigate how significant the impact of seasonal variability on SSIs is and subsequently perform a meta-analysis to quantify this association. Second, we investigated if a specific type of surgery was more prone to SSIs during the warmer weather conditions. Third, we described the relationship between warmer weather conditions and type of microbial pathogen causing SSIs. By understanding the magnitude of the effect and the specific microbial pathogens involved, we aimed to create more awareness among clinicians, possibly producing additional preoperative patient information, adjusted surgical planning of high-risk patients, and administration of potentially specific antibiotic treatments during the warmer months. Through this, we aim to achieve a decrease in SSIs.

METHODS

Data Sources and Searches

A medical librarian (Dr. W.M. Bramer) of the Erasmus Medical Centre, Rotterdam, developed search strategies and conducted a systematic literature search within five databases (Embase, Medline Ovid, Web of Science, Cochrane Central, and Google Scholar), to identify all articles concerning the association between seasonality and SSIs. The search was performed in April 2020. The search strings that were used are listed in Supplemental Digital Content 1. (**See appendices, Supplemental Digital Content 1,** which displays (a) the search results from five databases in April 2020, (b) PRISMA 2009 Checklist, (c) PICOS, (d) Variables of interest and data extraction, and (e) bias assessment using the Newcastle-Ottowa scale for assessing the quality of nonrandomized studies in meta-analyses. **http://links.lww.com/PRSGO/B713**.)

The Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines were followed, and the checklist is available in the online supplements of this article. (**See SDC1B**. **http://links.lww.com/PRSGO/B713**.)[28]

Study Eligibility and Selection

Two reviewers (APHS and LSD) performed a manual secondary selection based on the following inclusion criteria for our primary and secondary outcome measures. The reviewers screened titles, abstracts, and full-text articles reporting potentially eligible studies. Differences between reviewers were resolved by consensus. Eligibility criteria were formulated to select articles with comparable, preferably standardized, measures of seasonality (Table 1).

Data Extraction

The two reviewers independently extracted the following data from each article using a standardized study form: (1) study information; (2) patient characteristics; (3) climate information according to geographic location; (4) primary outcomes, including data for calculating risk of SSIs during the warmest period of the year compared with the colder period of the year; (5) secondary outcomes, including data on types of microbial pathogen cultured from SSIs during the warmest period of the year compared with the colder period of the year (Table 2).

Quality Assessment

Bias was assessed using the Newcastle-Ottawa scale for assessing the quality of nonrandomized studies in meta-analyses.[43]

Statistical Analysis

Our primary aim was to analyze the risk of SSIs during the warmest period of the year compared with the colder

Table 1. Eligibility Criteria

Only original clinical articles (no reviews) were included.
Articles had to be written in English.
Conference abstracts were excluded.
SSIs had to be confirmed either by clinical diagnosis meeting the criteria for SSI according to the CDC guidelines or National Healthcare Safety Network criteria in the United States, or the need for antibiotic treatment, reoperation, or revision for wound problems or SSIs.

	Level	Strength of Evidence	Type of Study Design
Articles with a design classification of Levels I–V, according to the Jovell and Navarro-Rubio classification system.‡	I	Good	Meta-analysis of randomized controlled trials
	II		Large-sample randomized controlled trials (N > 25 for each group)
	III	Good to fair	Small-sample randomized controlled trials (N < 25 for each group)
	IV		Nonrandomized controlled prospective trials
	V		Nonrandomized controlled retrospective trials
	VI	Fair	Cohort studies
	VII		Case-control studies
	VIII	Poor	Noncontrolled clinical series; descriptive studies
	IX		Anecdotes or case reports

CDC, Centers for Disease Control and Prevention; SSI, surgical site infections.

Table 2. Details on Seasonality, Tested Modalities, Outcome of All Included Articles, and Microorganism

Reference and Study Classification	Female, n (%); Age, mean (SD) / Age Group with Most Patients (% Patients)	Country	Inclusion Period	Type of Surgical Procedure	Total Surgical Procedures	Results (OR: SSIs Warm Period versus SSIs Colder Period)	Total SSIs Cultured	Microorganism	Total SSIs per Microorganism	PRR / OR (Warm Period versus Colder Period)
Malik et al[29]* Level 3	563 (77.7); 62.4 [52.7–72.1]	Pakistan	01/2006–2/2015	Orthopedic surgery (total knee arthroplasty)	725	0.93 [0.25–3.49]			NA	
Huntley et al[30]* Level 3	9615 (53.6); 51.9 [NA]	USA	2011–2015	Orthopedic surgery (foot and ankle surgery)	17939	1.23 [1.18–1.27]			NA	
Anthony et al[17]* Level 3	44,9327 (59.1); ≥65 (58)	USA	01/2013–2/2014	Orthopedic surgery (total knee arthroplasty)†	424104	1.30 [0.49–3.47]			NA	
				Orthopedic surgery (total hip arthroplasty)†	336179	1.19 [1.09–1.30]			NA	
Parkinson et al[31]* Level 3	NA	Australia	01/2011–2/2015	Orthopedic surgery (total knee arthroplasty)	8244	1.88 [1.12–3.16]			NA	
Rosas et al[32]* Level 3	802743 (61.2); 65–69 (24.3)	USA	2005–2014	Orthopedic surgery (total hip arthroplasty)	1311672	1.01 [1.01–1.01]			NA	
Ng et al.[33] Level 3	56475 (55); 65 [18–89]	USA	2011–2015	Orthopedic surgery (total hip arthroplasty)	102682	NA			NA	
Kane et al.[34] Level 3	NA	USA	01/2011–2/2011	Orthopedic surgery (total hip or knee arthroplasty)	750	NA			NA	
Gu et al[18]* Level 3	831 (47.1); 51.9 [18–86]	Xinjiang Province of China	01/2015–2/2016	Spinal surgery	1764	2.16 [1.17–3.99]			NA	
Ohya et al[35]* Level 3	23578 (49.9); 65.4 [20–101]	Japan	07/2010–3/2013	Spinal surgery	47252	2.02 [1.75–2.32]			NA	

(*Continued*)

Table 2. (*Continued*)

Reference and Study Classification	Female, n (%); Age, mean (SD) / Age Group with Most Patients (% Patients)	Country	Inclusion Period	Type of Surgical Procedure	Total Surgical Procedures	Results (OR: SSIs Warm Period versus SSIs Colder Period)	Total SSIs Cultured	Microorganism	Total SSIs per Microorganism	PRR / OR (Warm Period versus Colder Period)
Durkin et al[25*] Level 3	29355 (51); 54 [NA]	USA	2007–2012	Spinal surgery	57559	1.24 [1.23–1.26]	642	Gram pos. cocci	502 (78%)	PRR 1.27 (95% CI: [1.06–1.52], $P = 0.008$)‡‡
								S. Aureus	380 (59%)	PRR 1.06 (95% CI: [1.06–1.60], $P = 0.01$)‡‡
								MSSA	213 (33%)	PRR 1.52 (95% CI: [1.16–1.99], $P = 0.002$)‡‡
								MRSA	167 (26%)	PRR 1.06 (95% CI: [0.77–1.46], $P = 0.74$)‡‡
								Gram neg. rods	119 (19%)	PRR 0.92 (95% CI: [0.62–1.35], $P = 0.47$)‡‡
Gruskay et al[36*] Level 3	NA	USA	2005–2009	Spinal surgery	8122	1.49 [1.40–1.58]	NA			
Fortaleza et al.[37] Level 3	NA	Brazil	2011–2016	Different types of surgery‡	36429	NA	NA			
Anthony et al[27*] Level 3	32954170 (59.2); 56.67 [NA]	USA	01/1998–1/2011	Different types of surgery§	55665828	1.21 [1.16–1.25]	NA			
Durkin et al[26*] Level 3	NA	USA	2007–2012	Different types of surgery¶	441428	1.11 [1.11–1.11]	4543	Gram pos. cocci	2654 (58%)	PRR 1.08 (95% CI: [1.00–1.19], $P = 0.04$)‡‡
								S. Aureus	1666 (37%)	
								MSSA	805 (18%)	
								MRSA	867 (19%)	
								Gram neg. rods	1268 (28%)	PRR 1.26 (95% CI: [1.10–1.40], $P < 0.001$)‡‡
Nwankwo et al.[38] Level 3	NA	Nigeria	2010–2011	Different types of surgery‖	5800	NA	NA			
Duscher et al[22*] Level 2	563 (93.5); 40 [28.8–51.2]	Austria	2009–2015	Plastic surgery**	602	2.52 [1.94–3.28]	NA			
Ng et al.[39] Level 3	NA	Canada	01/01/2003–01/01/2013	Plastic surgery and different types of surgery††	12183	NA	NA			

(*Continued*)

Table 2. (*Continued*)

Reference and Study Classification	Female, n (%); Age, mean (SD) / Age Group with Most Patients (% Patients)	Country	Inclusion Period	Type of Surgical Procedure	Total Surgical Procedures	Results (OR: SSIs Warm Period versus SSIs Colder Period)	Total SSIs Cultured	Microorganism	Total SSIs per Microorganism	PRR / OR (Warm Period versus Colder Period)
Gross et al.[40] Level 3	NA	Sao Paulo, Brazil and Buenos Aires, Argentina	2001–2016	Penile protheses surgery	211	NA	213	Gram pos. cocci	87 (41%)	OR = 2.27 (95% CI: [1.04–4.93], $P = 0.039$)§§; OR = 3.14 (95% CI: 1.44–6.83], $P = 0.004$)¶¶; OR = 1.99 (95% CI: [0.86–4.632], $P = 0.11$)‖
Turan et al[41]* Level 3	1489 (51); 52.5 [NA]	USA	06/2010–3/2012	Colorectal surgery	2919	1.21 [1.14–1.28]	NA			
Li et al[42]* Level 3	67908 (58); ≥ 80 (28.2)	Australia (West)	1980–2000	Cataract surgery	117083	1.27 [0.83–1.94]	NA			

*Articles included in meta-analysis.

†Concerning one article by Anthony et al, the results were divided according to the type of arthroplasty, namely total hip arthroplasty and total knee arthroplasty.[17]

‡Different types of surgery included open reduction of fractures, caesarean delivery, hernia repair, craniectomy, laparotomy, breast surgery, and spinal surgery, among other surgical procedures.

§Different types of surgery included knee and hip arthroplasty, spinal fusion, treatment of fracture or dislocation of lower extremity, bowel resection, caesarean delivery, inguinal, femoral and other hernia repair, and exploratory laparotomy.

¶Different types of surgery included abdominal hysterectomy, laparoscopic appendectomy, breast surgery, caesarean delivery, laparoscopic cholecystectomy, colon surgery, coronary artery bypass graft, gastric surgery, herniorrhaphy, hip prosthesis, knee prosthesis, laminectomy, open reduction of fracture, spinal fusion, and vaginal hysterectomy.

‖Different types of surgery included mastectomy, cystectomy, colostomy, appendectomy, herniorrhaphy, urethrotomy, fistulectomy, prostatectomy, abdominal surgery, excisional biopsy, urethroplasty, debridement, deep laceration, hydrocelectomy, cystostomy, cholecystectomy, thyroidectomy, and excisional biopsy.

**Plastic surgery included body lift 98 (82 women, 16 men), abdominoplasty 180 (162 women and 18 men), breast reduction 194 (189 women and 5 men), thigh lift 64 (64 women), brachioplasty 15 (15 women), and mastopexy 51 (51 women).

††Plastic surgery (7326 of which 821 implant-based procedures) and different types of surgery (4857) included breast augmentation, insertion of tissue expanders, exchange of tissue expanders for implants, open reduction and internal fixation of hand or facial fractures, and finger arthroplasty, laparoscopic cholecystectomy, caesarean delivery, abdominal hysterectomy, cataract surgery, hip arthroplasty, knee arthroplasty, open reduction and internal fixation of long bone fracture, and thoracotomy.

‡‡The PRR of different types of bacteria cultured from SSIs during the warmest period of the year compared with the remainder of the year could be extracted from two articles by Durkin et al[25,26]; 1 article by Gross et al reported the OR of gram positive cocci cultured from SSIs during

§§summer, ¶¶fall and ‖‖winter, all individually compared with spring.[40]

period of the year within the concerning geographic area. For meta-analysis, only studies describing an OR, standard error, and corresponding confidence intervals (CIs) or studies providing enough data to calculate this, were included. For data on SSIs during the colder period of the year, data during winter was preferred. When this could not be isolated, data during the remainder of the year (eg, spring, autumn, and winter combined) were used. A random-effects model, without Hartung and Knapp correction, was used to pool the ORs and 95% CIs. All study analyses were performed using R, version 3.6.0 (R Core Team, 2014) and figures were produced using the package ggplot (Wickham and Chang, 2009).

For subgroup analysis, we also used a random-effects model, without Hartung and Knapp correction, to test if the OR for SSIs during the warmest period of the year is dependent on the type of surgery performed. We tested this for two subgroups:

- Orthopedic surgery procedures versus nonorthopedic surgery procedures.
- Spinal surgery procedures versus non-spinal surgery procedures.

Thirdly, we analyzed the incidence of different types of microbial pathogen cultured from SSIs during the warmest period of the year compared with the remainder of the year. Therefore, the corresponding OR or prevalence rate ratio (PRR) was extracted when available.

RESULTS

A systematic literature search in databases (such as Embase.com, Medline Ovid, Web of Science, and Cochrane Central) and Google revealed a total of 1733 articles. After automated removal of 510 duplicate articles, 1223 articles remained. After screening the article abstracts, a total of 1191 records were excluded, with the following reasons: no research regarding the association between change in weather conditions and incidence of SSIs, change in weather conditions did not demonstrate a seasonal pattern, the language was other than English, the title referred to a conference abstract. The remaining 32 full-text articles were then reviewed. After exclusion of 12 full-text articles (with reasons of no data regarding the influence of seasonality on the incidence of SSIs was found, and the term "seasonality" did not refer to factors regarding climate), a total of 14 articles remained to be included in quantitative synthesis. (**See figure, Supplemental Digital Content 2,** which displays the flowchart regarding the selection of included articles according to the PRISMA standards. A systematic literature search including Embase.com, Medline Ovid, Web of Science, Cochrane Central and Google revealed a total of 1733 articles. After automated duplicate removal of 510 duplicate articles, 1223 articles remained. After screening the article abstracts, a total of 1191 records were excluded. The remaining 32 full-text articles were then reviewed and 12 full-text articles were excluded. A total of 14 articles remained to be included in quantative synthesis. **http://links.lww.com/PRSGO/B714**.)

There was a low risk of bias in the individual articles. (**See SDC 1**, **Appendix 5**. **http://links.lww.com/PRSGO/B713**.) Six articles were excluded from meta-analysis, because of insufficient data regarding calculation of risk of SSIs during the warmest period of the year compared with the colder period of the year.[33,34,37–40]

Only 14 studies described an OR or provided sufficient data to include in the meta-analysis.[17,18,22,25–27,29–32,35,36,41,42] (Table 2). Most studies were conducted in the Northern Hemisphere, mainly in North America, with climate conditions divided into four distinct seasons (summer, fall, winter, and spring). The number of included patients varied greatly across studies, ranging from 602 to 55,665,828 patients. Several surgical procedures were described, namely orthopedic surgery procedures, spinal surgery procedures, plastic surgery procedures, colorectal surgery procedures, and cataract surgery procedures. The most common type of surgical procedure was orthopedic arthroplasty surgery. Two articles (by Duscher et al and Ng et al) described plastic surgery procedures. Plastic surgery procedures described by Duscher et al included body lift, abdominoplasty, breast reduction, thigh lift, brachioplasty, and mastopexy. Ng et al described a total of 7326 plastic surgery procedures, including, a total of 821 implant-based procedures. Plastic surgery procedures included breast augmentation, insertion of tissue expanders, exchange of tissue expanders for implants, open reduction and internal fixation of hand or facial fractures, and finger arthroplasty.

Of the articles included for meta-analysis, four articles regarding orthopedic surgery procedures reported arthroplasties only.[17,29,31,32] Another article reported orthopedic foot and ankle surgery, but the specific type of surgical procedure was not mentioned.[30] Concerning one article by Anthony et al, the results were divided according to the type of arthroplasty, namely total hip arthroplasty and total knee arthroplasty.[17]

Primary Outcomes

The risk of SSIs during the warmest period of the year was compared with the coldest period of the year in nine studies and the remainder of the year in five studies. For meta-analysis, the coldest period of the year (nine studies) and the remainder of the year (five studies) were both included in the category named "the colder period of the year." Meta-analysis using a random-effects model, without Hartung and Knapp correction, showed that SSIs are more common during the warmest period of the year, when compared with the colder period of the year (OR 1.39, 95% CI: [1.34–1.45], $P < 0.0001$) (Fig. 1).

Subgroup Analysis

Subgroup analysis focusing on the comparison between patients receiving orthopedic surgery (which mainly regarded arthroplasties) versus patients receiving other types of surgery showed that the association between warmer weather conditions and a higher incidence of SSIs was significantly less common among 2,098,863 patients receiving orthopedic surgery ($P = 0.029$) (Fig. 2). Adversely, subgroup analysis, focusing on the comparison

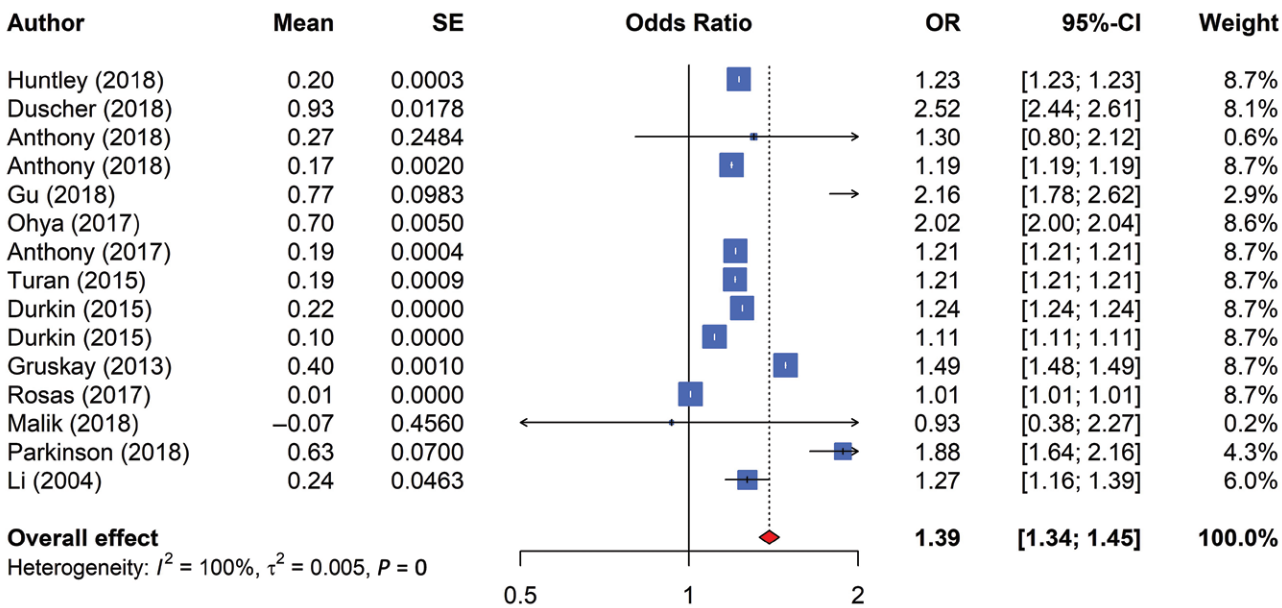

Fig. 1. OR of SSIs among all patients. Forest plot of a random-effects model, without Hartung and Knapp correction, including all 14 studies describing OR and corresponding CI of SSIs among patients who underwent surgery during the warmest period of the year compared with those who underwent surgery during the colder period of the year. The lowest diamond represents the pooled OR and CI, demonstrating that SSIs are more common during the warmest period of the year, when compared with the colder period of the year (OR = 1.39, 95% CI: 1.34–1.45, $P < 0.0001$).

between patients receiving spinal surgery versus patients receiving other types of surgery, showed that the association between warmer weather conditions and a higher incidence of SSIs was significantly more common among 114,697 patients receiving spinal surgery (P = 0.003) (Fig. 3).

Microbial Pathogen

The PRR of different types of bacteria, namely gram positive cocci and gram negative rods, cultured from SSIs during the warmest period of the year compared with the remainder of the year could be extracted from two articles by Durkin et al.[25,26] One article by Gross et al[40] reported the ORs of gram positive cocci cultured from SSIs during summer, fall, and winter, all compared with the same reported during spring. The low number of articles reporting on microbial pathogen cultured from SSIs precluded statistical analyses of pooled data. Therefore, no meta-analysis was performed.

Gram Positive Cocci

Of a total of 5398 SSIs among the three aforementioned articles, gram positive cocci were isolated from 3243 SSIs (60%).[25,26,40] Gross et al reported gram positive cocci to be cultured from 40.8% of all infections. Concerning the overall incidence of SSIs, the article reported inflatable penile prosthesis (IPP) infections to be more common in IPPs placed during spring (29%) and summer (27%) months when temperature tends to be higher than 55°C, when compared with those during fall (26%) and winter (18%). Infected implants performed in the fall and summer were over three and 2.3 times, respectively, more likely to grow gram positive cocci compared with implants performed in spring (P = 0.004; P = 0.039). The study reported an OR of 3.14 (95% CI: 1.44–6.83, P = 0.004) for gram positive cocci cultured from infections of IPP during fall (52.7%) and an OR of 2.27 (95% CI: 1.04– 4.93, P = 0.039) for gram positive cocci cultured from infections of IPPs during summer (44.6%), when compared with during spring (26.2%). The incidence of gram positive cocci cultured from these SSIs during winter (41.5%) was also higher when compared with during spring, with an OR of 1.99 (95% CI: 0.86–4.63, P = 0.11).[40] Furthermore, one article by Durkin et al regarding spinal surgery compared the PRR for gram positive cocci cultured from SSIs during summer to the PRR for gram positive cocci cultured from SSIs during the remainder of the year. The article reported a PRR of 1.27 (95% CI: 1.06–1.52, P = 0.008) for gram positive cocci cultured from SSIs and, more specifically, a PRR of 1.06 (95% CI: 1.06–1.60, P = 0.01) for *S. aureus* cultured from SSIs, both comparing summer with the remainder of the year.[25] The other article by Durkin et al, regarding different types of surgery, reported a PRR of 1.08 (95% CI: 1.00–1.19, P = 0.04) for gram positive cocci cultured from SSIs during summer, when compared with the remainder of the year.[26]

Gram Negative Rods

Of a total of 5185 SSIs among both articles by Durkin et al, gram negative rods were isolated from 1387 SSIs (27%).[25,26] Gross et al did not report on gram negative rods.[40] The two articles by Durkin et al reported a PRR of 0.92 (95% CI: 0.62–1.35, P = 0.47) among patients receiving spinal surgery and 1.26 (95% CI: 1.10–1.40, $P < 0.001$) among patients undergoing different types of surgery, regarding gram negative rods cultured from SSIs during

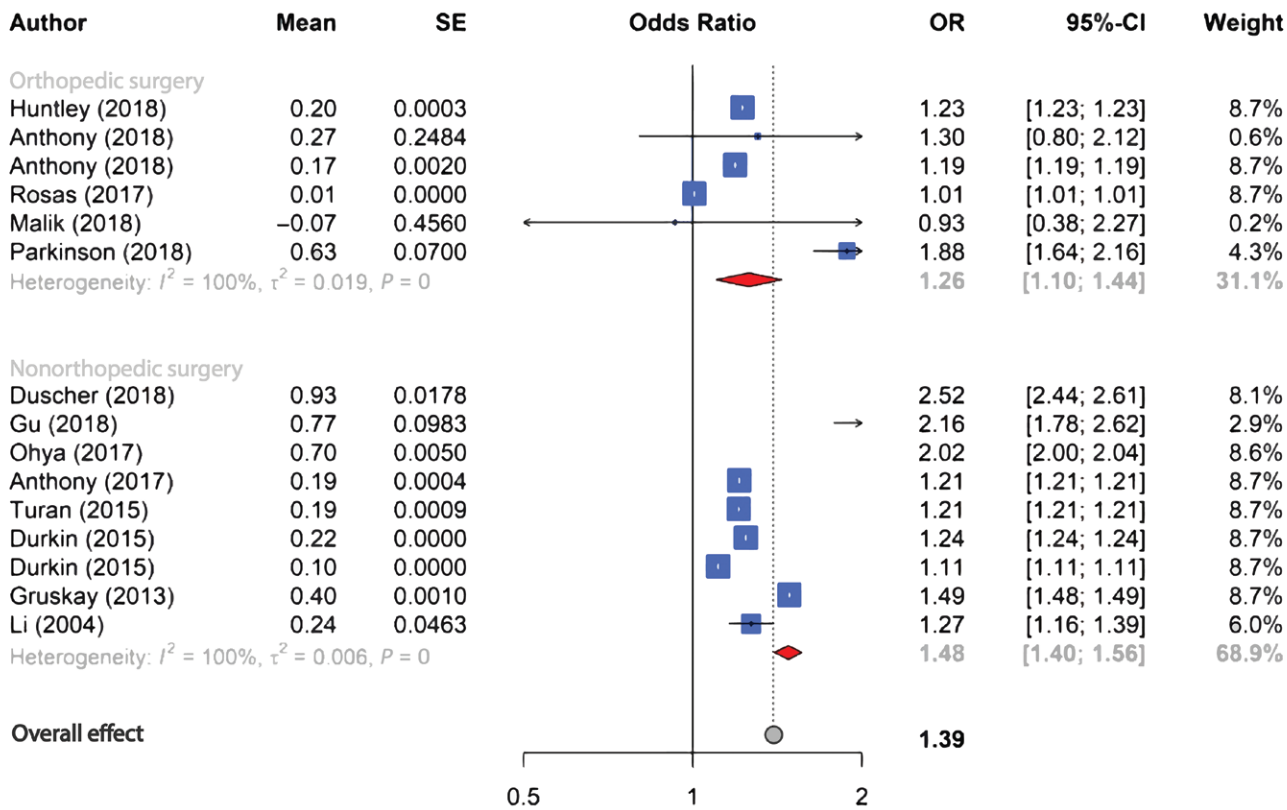

Fig. 2. OR of SSIs among orthopedic surgery procedures versus nonorthopedic surgery procedures. Forest plot of a random-effects model, without Hartung and Knapp correction, comparing the OR and corresponding CI of SSIs among patients who underwent surgery during the warmest period of the year compared with those who underwent surgery during the colder period of the year. In this forest plot, five articles (six ORs) regarding orthopedic surgery procedures are compared with nine articles (nine ORs) regarding nonorthopedic surgery procedures. The diamonds following both orthopedic and nonorthopedic studies represent the pooled ORs and CIs of both all orthopedic studies and all nonorthopedic studies (OR = 1.26, 95% CI: 1.10–1.44 and OR = 1.48, 95% CI: 1.40–1.56, respectively). Both display a positive association between the risk of developing SSIs and the warmest period of the year. The lowest diamond represents the comparison between both pooled ORs and CIs, demonstrating that the positive association between the risk of developing SSIs and the warmest period of the year is less common after orthopedic surgery procedures when compared with nonorthopedic surgery procedures as a significant *P* value is found (OR = 1.39, 95% CI: 1.34–1.45, *P* = 0.029).

summer, when compared with those during the remainder of the year.[25,26]

DISCUSSION

We performed a meta-analysis of 58,441,420 patients undergoing different types of surgical procedures during different periods of the year. Summer is a risk factor for developing SSIs. Patients are 39% more likely to develop an infection during the warmest period of the year, when compared with the colder period of the year.

While seasonality of many infections (eg, respiratory infections, tick- and mosquito-borne infections) is considered common knowledge, little attention has been focused on seasonality of healthcare-related infections.[44] Although, some surgical fields extensively studied seasonality of SSIs and different types of microbial pathogen cultured from SSIs, this area remains underexposed, and very little action has been taken to apply this knowledge in the prevention of SSIs.[17,25–27] Unlike prior studies, we included a large and more generalized population of patients, undergoing various types of surgery, across different geographic regions, including different climate conditions. Our results demonstrate both statistical and potential clinical significance of this seasonality. As absolute reduction of the amount of surgical procedures performed during warm summer months cannot be expected, healthcare staff should be aware of the increased risk of developing SSIs during this period. We advise this factor to be taken into account regarding surveillance systems and precautionary measures in the prevention and control of SSIs and the timing of elective surgical procedures. Regarding prevention, we suggest extra attention for current measures (ie, preoperative control of comorbidities such as obesity and diabetes mellitus, preoperative antibiotic prophylaxis and screening, and utilizing nasopharyngeal and oropharyngeal swabs in patients at risk for developing SSIs). We also suggest intraoperative strict surveillance, control of patient homeostasis, and postoperative strict compliance to methods ensuring optimal wound hygiene.[45,46] Also, we recommend that further research on seasonal variations in bacterial colonization of skin and soft tissue, as well as further analyses of the patient population exhibiting this seasonal increase in SSIs, should be performed.

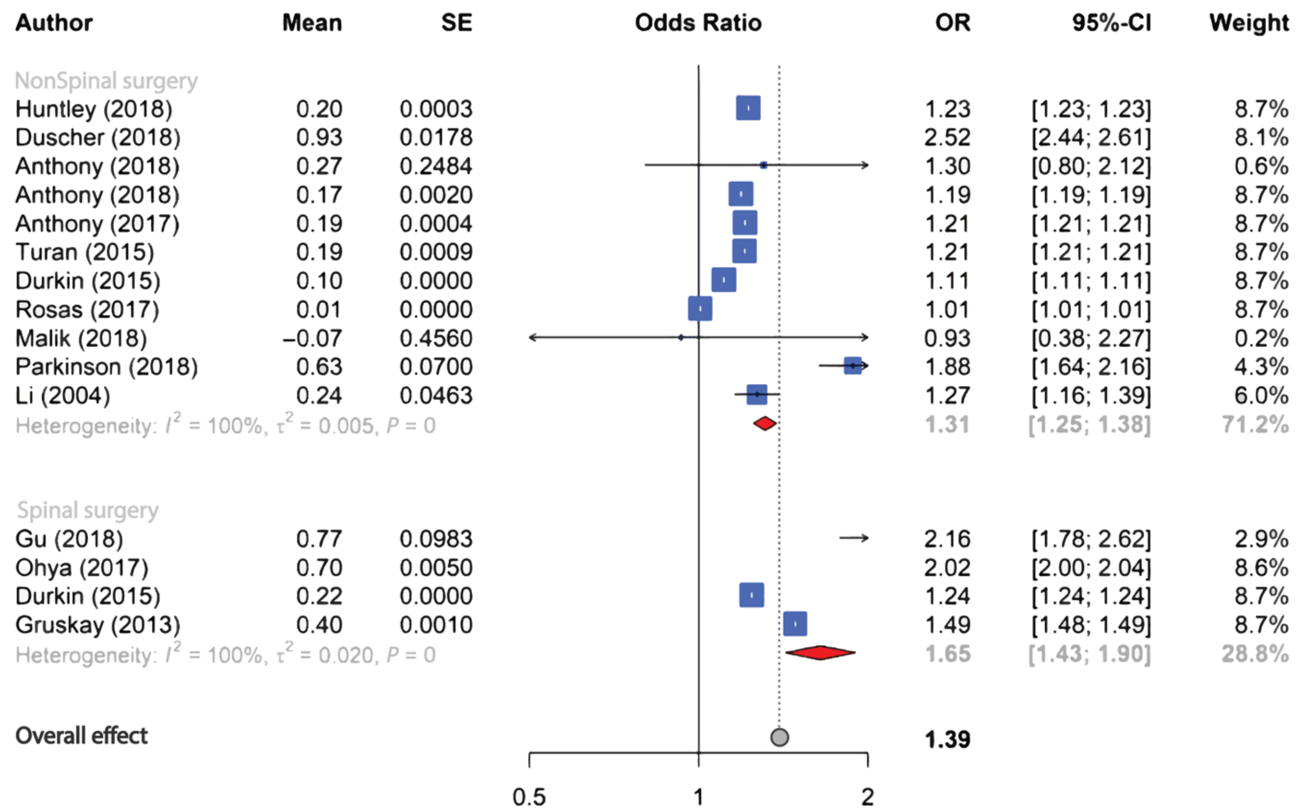

Fig. 3. OR of SSIs among spinal surgery procedures versus nonspinal surgery procedures. Forest plot of a random-effects model, without Hartung and Knapp correction, comparing the OR and CI+ of SSIs among patients who underwent surgery during the warmest period of the year compared with the colder period of the year. In this forest plot, 10 articles (11 ORs) regarding nonspinal surgery procedures are compared with four articles (four ORs) regarding spinal surgery procedures. The diamonds following both nonspinal and spinal studies represent the pooled ORs and CIs of both all nonspinal studies and all spinal studies (OR = 1.31, 95% CI: 1.25–1.38 and OR = 1.65, 95% CI: 1.43–1.90, respectively). Both display a positive association between the risk of developing SSIs and the warmest period of the year. The lowest diamond represents the comparison between both pooled OR and CIs, demonstrating that the positive association between the risk of developing SSIs and the warmest period of the year is more common after spinal surgery procedures when compared to nonspinal surgery procedures as a significant *P* value is found (OR = 1.39, 95% CI: 1.34–1.45, *P* = 0.003).

We argue that a better understanding of the association between warm weather conditions and the increased risk of developing SSIs would not only allow prevention of this seasonal increase, but also significantly reduce the corresponding healthcare costs.

Several theories explaining the increase of SSIs during warm summer months have been suggested. These include increased skin-to-skin contact during summer, causing an increase in bacterial transmission and colonization, and the increase in possible portals of entry for bacteria as sores and ulcers have been shown to be more prevalent during summer.[22–24] One often mentioned theory suggest a higher bacterial colonization rate of skin and soft tissue due to increase in environmental temperature and humidity.[47,48] Supporting this, Leekha et al performed a systematic review on seasonal variations of *S. aureus* skin and soft-tissue infections, confirming an association of warm summer months with a higher incidence of infections.[49] One article by Gross et al, and two articles by Durkin et al reported an increased incidence of gram positive cocci cultured from SSIs during the warmer periods of the year.[25,26,40] While Gross et al reported an increased OR of SSIs during all seasons of the year when compared with winter, gram positive cocci were prominently found in SSIs of IPPs placed during fall, followed by SSIs of IPPs placed during summer. Although Gross et al also reported gram positive cocci to display a higher OR during winter when compared with that during spring, this finding was not significant.[40] Also, both articles by Durkin et al reported an increased PRR for SSIs during summer, when compared with the remainder of the year.[25,26] Furthermore, one article by Durkin et al, regarding different types of surgery, also reported an increased PRR of gram negative rods during the warmest period of the year.[26] Adversely, the other article by Durkin et al, regarding spinal surgery, reported the opposite, but this finding was not significant.[25] We also point out that this article reported on patients undergoing spinal surgery, among whom gram positive cocci, namely *S. aureus*, is known to be the principal causal agent of SSIs.[50] Our findings suggest the incidence of SSIs increases considerably as soon as winter ends and environmental temperatures start to rise. Concerning the incidence of gram positive cocci found in SSIs, our findings suggest a delayed increase in incidence persisting throughout fall.

We found that the seasonal increase in SSIs differs between surgical specialties. In orthopedic surgery more is done to prevent postoperative infection, especially when foreign material is implanted. These surveillance systems and precautionary measures include surgical hand preparation, antibiotic perioperative prophylaxis, use of glycopeptide antibiotics in routine prophylaxis, antibiotic-containing cement for prophylaxis, prophylaxis before dental interventions, screening for *S. aureus* carriage with subsequent decolonization and preoperative bathing or showering, among others.[51] Our findings show that the increased risk for developing SSIs during warm summer months is significantly lower in patients undergoing orthopedic surgery when compared with patients undergoing nonorthopedic surgery. While this difference may be due to the aforementioned systems and measures, the exact determining factors remain unclear. Adversely, the increased risk for developing SSIs during warm summer months is significantly higher in patients undergoing spinal surgery, when compared with patients undergoing nonspinal surgery. While the continuous expanding complexity and the increasing number of invasive procedures instead of conservative treatment in spinal surgery has been proved to play an important role in the increase of SSIs in general, the exact determining factors of our finding remain unclear and possibly involve an amplification of the aforementioned.[52]

Furthermore, when studying current literature, we noticed that the term "seasonality" does not only refer to change in weather conditions, but is also used to describe the "July Effect." This phenomenon refers to the academic year-end changeover and suggests that seasonal increase in SSIs is caused by trainee changeover, due to arrival of inexperienced staff which have higher surgical complication rates.[36,53–55] However, studies have shown this to be a false assumption.[25,32] To substantiate this, studies focused on the difference between teaching and nonteaching hospitals. In teaching hospitals, trainee changeovers take place during specific periods of the year. However, in nonteaching hospitals, arrival of inexperienced staff is not concentrated during specific periods of the year. Durkin et al reported the rate of SSIs following spinal surgery to be higher during summer, while only nonteaching hospitals were included.[25] Rosas et al argued that their finding of periprosthetic joint infections being more common during winter suggests that incoming residents may not be at fault.[32] We also argue that the "July Effect" does not fully explain the seasonal increase in SSIs because studies included in this meta-analysis regard both teaching and nonteaching hospitals, as well as countries where trainee changeover does not take place during warm summer months, thus refuting the "July Effect" as the only cause of seasonal increase in SSIs.

While the individual studies included in this systematic review and meta-analysis do not solely focus on plastic surgery procedures, the importance of our finding to the field of plastic surgery is evident and unavoidable. In addition to plastic surgery procedures, studies included report on surgical procedures regarding bone fractures, prosthetic devices, debridement and deep laceration, all of which are important in the field of plastic surgery. Also, we feel that multiple factors are of importance concerning the cause of the seasonal increase in SSIs found. While operative factors influencing the risk of SSIs in plastic surgery procedures might somewhat differ from other surgical procedures, there is much overlap. Overlapping factors include duration of the surgical scrub, skin antiseptic preparation, length of the operation, antimicrobial prophylaxis, proper ventilation of the operating room, usage of surgical drains, quality of surgical technique, and exposure to hemoglobin.[19] Also, factors such as patient characteristics and physiological states influencing the risk of SSIs are of importance in all surgical procedures.

One of the limitations of this study is the inclusion of surveillance data with limited patient information available. Therefore, we were unable to address multiple known patient-related risk factors, which play a significant role in the development of SSIs. Also, we included surgical procedures with limited information on surgery-related and physiological risk factors for developing SSIs. However, we argue that the variation of studies included for meta-analysis (eg, describing large populations, different types of surgical procedures, and procedures performed in different countries) generate a decreased influence of these factors on the results of this study.

Secondly, the diagnosis of SSIs was not standardized among included articles. SSIs were confirmed either by clinical diagnosis meeting criteria for SSIs according to the CDC guidelines or National Healthcare Safety Network criteria in the United States, or the need for antibiotic treatment, reoperation or revision after wound problems or SSIs. We argue that SSIs were possibly missed or remained undiagnosed, especially when diagnosis of SSIs was based solely on the need for antibiotic treatment, reoperation, or revision after wound problems.

Also, concerning the incidence of SSIs and microbial pathogens cultured from SSIs, there was a variability in the definition of the coldest period of the year. When data on the coldest period of the year were unavailable, data regarding the remainder of the year were used. We argue that this variable definition distorts the outcome, as an exact comparison between the warmest and coldest period of the year would provide a better representation of the association between seasonality and the incidence of SSIs. We recommend further research on this matter, including different factors regarding seasonality (eg, temperature and humidity), comparing all seasons within the concerning geographic area and in search of a threshold temperature regarding the risk of SSIs.

CONCLUSIONS

Summer is a risk factor for SSIs. Patients are 39% more likely to develop an infection during warm summer months, compared with the remainder of the year, although the general incidence of 1.9% remains low. This finding differs after selection of orthopedic and spinal surgery procedures and might be caused by gram positive cocci in particular. Due to the absence of trainee changeover during warm summer months in various articles included, we deny the "July Effect" as the only cause of the seasonal increase in SSIs. Instead, our data support the hypothesis of warm weather conditions contributing to a higher rate of SSIs during summer. Based on our analysis, we recommend this factor to be taken into account regarding surveillance systems and precautionary measures in the prevention and control of SSIs and the timing of elective surgical procedures. We also suggest further research should be done on seasonal variations in bacterial colonization of skin and soft tissue, as well as the exact determining factors of the seasonal increase in SSIs.

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