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The impact of perioperative hypothermia on surgical site infection risk: a meta-analysis

Ruirong Chen^{1†}, Yingjie Du^{1†}, Lanyue Chen², Yafan Bai¹, Yue Zhang¹, Tiankuo Yu¹, He Li¹ and Guyan Wang^{1*}

Abstract

Objective The connection between perioperative hypothermia and the occurrence of surgical site infections (SSIs) is still not clearly established. This investigation aimed to clarify the potential link between these two factors using meta-analytical techniques.

Materials and methods This investigation examined the potential connection of perioperative hypothermia to the risk of SSI. A comprehensive literature review was conducted utilizing PubMed, Web of Science, and Embase. The primary endpoint was the incidence of SSI. Pooled risk ratios were estimated using fixed- or random-effects meta-analysis. Sensitivity analyses were performed to evaluate the impact of preoperative hypothermia on the pooled risk of SSI. Statistical analyses were performed using Review Manager software and R software.

Results Our meta-analysis encompassed 25 studies representing a total of 28,761 patients. The analysis revealed no statistically significant association between patients' intraoperative body temperature and their likelihood of developing post-surgical complications [odds ratio (OR), 1.39; 95% confidence interval (CI), 0.98–1.96; $I^2 = 89%$, $P = 0.06$]. However, two notable exceptions emerged from the subgroup analyses. Most importantly, patients undergoing breast surgery demonstrated a significantly higher risk of SSI when experiencing intraoperative hypothermia, with an odds ratio of 1.97 (95% CI: 1.21–3.21, $I^2 = 0%$, $P < 0.01$). Additionally, across all patient groups, a consistent trend was noted: when intraoperative body temperature fell to 35 °C or below, there was a substantial increase in SSI risk (OR: 2.12, 95% CI: 1.42–3.16, $I^2 = 89%$, $P < 0.01$).

Conclusions The findings suggest that the relationship between perioperative hypothermia and an increased incidence of SSI is not definitive; however, it is significantly associated with breast surgery and when body temperature falls below 35 °C. Future randomized controlled trials (RCTs) should focus on breast surgery and standardize temperature thresholds. Due to the high heterogeneity, the interpretation of this result should be approached with caution, and there is a call for future high-quality research.

Keywords Perioperative hypothermia, SSI, Meta-analysis

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Introduction

A core temperature under 36 °C during the perioperative period defines perioperative hypothermia [1]. Research indicates that the incidence of hypothermia during the perioperative period can be as high as 78.6% [2]. Various factors encountered during surgery contribute to perioperative hypothermia, including long surgical duration, low operating room temperature [3, 4], significant intraoperative blood loss [5], the anesthetic agents, and the infusion of cold fluids [6]. It may also be related to patient-specific factors, such as age [5], body mass index (BMI) [4], and nutritional status [3]. Hypothermia has been correlated with multiple adverse outcomes, including a heightened risk of surgical site infection (SSI) [7], myocardial ischemia [8], postoperative nausea and vomiting [9], thermal discomfort [10], and coagulopathies [11]. In addition to the complications, perioperative hypothermia is associated with prolonged recovery time and higher hospital expenses [4].

SSI is defined as an infection occurring within 30 days after surgery when no implants are involved, or within one year if implants are present [12]. The SSI is often considered the most prevalent postoperative complication, resulting in negative impacts on recovery, extended hospital stays, and higher healthcare costs [13, 14]. Perioperative hypothermia can promote the occurrence of SSI by suppressing the immune system [15, 16], promoting vascular constriction, reducing subcutaneous oxygen tension [17], impairing platelet function, and damaging the coagulation cascade [18]. The risk of SSI associated with perioperative hypothermia varies between 0.7% and 33% [19]. 3 randomized controlled trials (RCTs) have demonstrated that intraoperative warming can effectively lower the incidence of SSI [20]. Several studies have demonstrated that perioperative hypothermia increases the risk of developing SSI [21–28], whereas others have reported no significant association of hypothermia with the risk of SSI [29–45]. The variability in these findings has prompted continued discussion regarding the link between perioperative hypothermia and the risk of SSI development in surgical patients. Compared to previous meta-analyses, which mainly included retrospective studies and fewer than 10 studies, our analysis incorporates more recent data and includes comprehensive subgroup analyses by surgery type and temperature thresholds, providing a more detailed understanding of the hypothermia-SSI relationship. The objective was to investigate the relationship between perioperative hypothermia and SSI risk, evaluate its impact on SSI incidence.

Materials and methods

A comprehensive systematic review, including a meta-analysis, was performed. In developing the protocol and presenting the results, adherence was maintained

to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [46]. This approach ensured a thorough and transparent methodology throughout the review process.

Searching strategy

A systematic literature search was conducted across PubMed, Web of Science, Cochrane, and Embase databases using predefined search terms. In PubMed, both MeSH terms (e.g., "Hypothermia" and "Surgical Wound Infection") and free-text keywords (e.g., "intraoperative hypothermia" and "surgical site infection") were combined to enhance search sensitivity. For Web of Science and Embase, truncated terms (e.g., hypotherm for "hypothermia") were used to capture variations, and Boolean operators were applied to refine the search. The search strategy in Cochrane followed a similar approach. No language or publication filters were applied to ensure comprehensive retrieval. The search included all records from database inception through May 1, 2025. Additionally, reference lists were reviewed, and a manual search of related citations was performed to identify other relevant studies. Grey literature and unpublished studies were excluded from the analysis, as the focus was solely on peer-reviewed articles. Abstracts and citations were reviewed by two separate evaluators. The registration ID of PROSPERO is CRD42024592306. Articles that satisfied the inclusion criteria were then examined in full text. Figure 1 presents a comprehensive summary of the literature search process. Ethical approval was not necessary in this case.

Inclusion and exclusion criteria

Research that fulfilled the following criteria was deemed suitable for analysis: (a) documentation of SSI in the study population, regardless of surgical procedure; (b) comparison between at least one hypothermic group (core temperature < 36 °C) and one normothermic group; and (c) all clinical study designs, such as randomized controlled trials (RCTs), cohort studies, case-control studies, and both prospective and retrospective investigations. Studies were excluded from analysis according to these criteria: (a) lack of original data (e.g., reviews, meta-analyses, protocols, editorials, case reports); (b) non-human subjects or in vitro experiments; (c) inappropriate temperature grouping or inadequate reporting of perioperative temperature decline; (d) incomplete data for analysis (e.g., missing odds ratios); (e) duplicate publication; (f) grey literature or unpublished data; (g) insufficient data for pooling after two attempts to contact the authors; or (h) publications in languages that could not be translated using Google Translate. Studies were considered ineligible if they did not meet the inclusion criteria, such as: (a) lack of documented surgical site infection

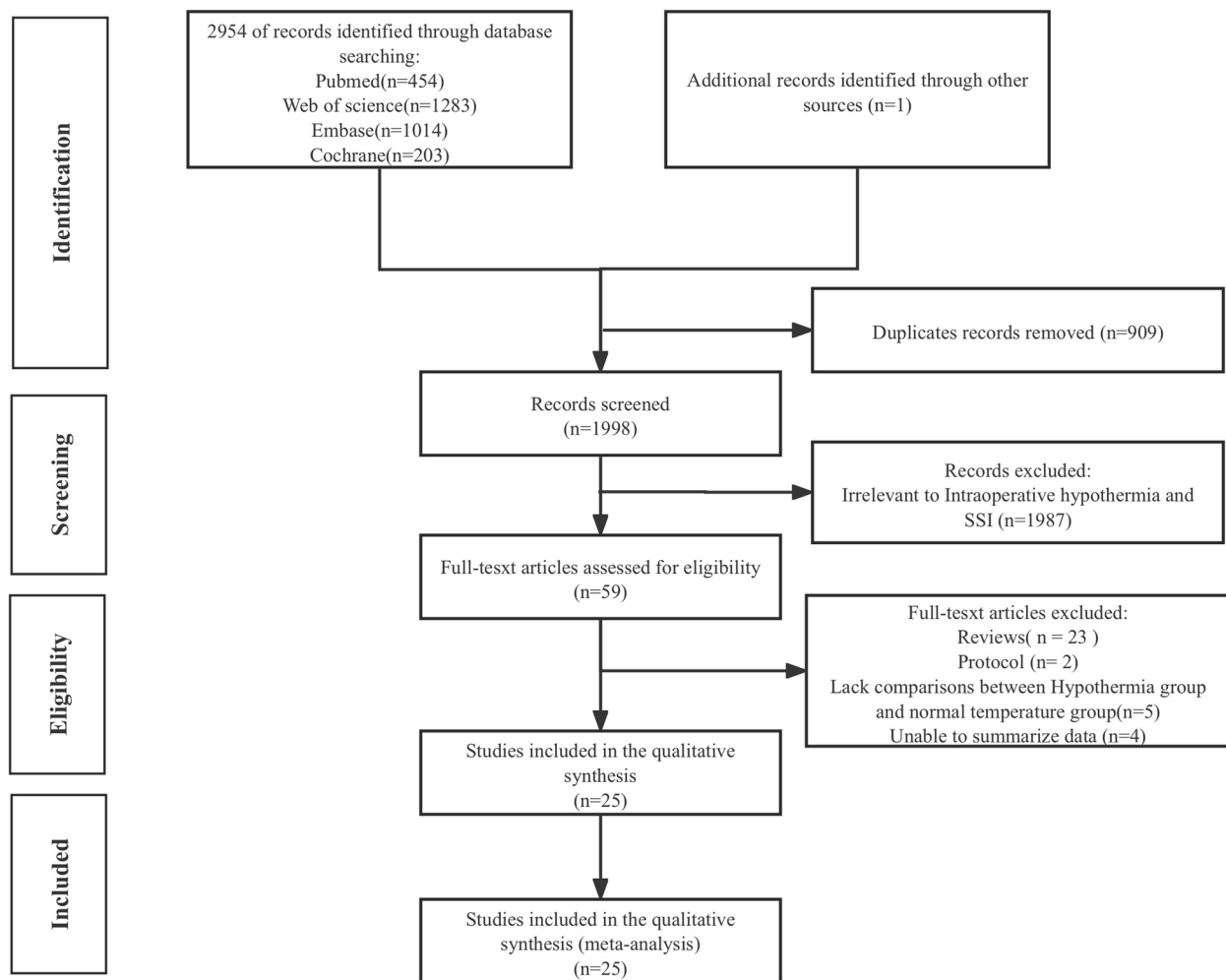


Fig. 1 Flowchart of the study selection process. From the initial 2,954 records identified through various databases and additional sources, duplicates were removed, and 1,987 records irrelevant to intraoperative hypothermia and SSI were excluded. Of the 59 full-text articles assessed for eligibility, 25 studies were included in the qualitative synthesis and meta-analysis after excluding 34 articles for various reasons

(SSI) outcomes; (b) absence of a comparison between hypothermic and normothermic groups; or (c) failure to report essential data needed for analysis (e.g., missing key variables or outcomes).

Data extraction

Information from each eligible paper was carefully examined and extracted using a standardized preparation form by two researchers independently (R. Chen and Y. Chen). In cases where discrepancies or uncertainties arose during the data extraction process, the two researchers first attempted to resolve the issues through in-depth discussions, ensuring that each decision was well-documented. If consensus could not be reached, a third author was consulted to review the conflicting data and provide an independent evaluation (Y. Wang). This adjudication process ensured that all discrepancies were resolved transparently and consistently. The collected data included the first author, countries of the authors, publication

year, study design, sample sizes for both case and control groups, age, and the type of procedure performed.

Quality assessment and risk of bias

The risk of bias was assessed using the Cochrane Risk of Bias tool for RCTs. The Newcastle–Ottawa Scale (NOS) was utilized to evaluate the methodological quality of both cohort and case–control studies [47]. This system assessed three main categories: selection of study participants, result comparability, and outcome quality. The NOS scale spans 0 to 9 stars, where scores under 5 reflect poor quality, scores between 5 and 7 represent fair quality, and scores exceeding 8 denote good quality [47]. To evaluate the impact of low-quality studies on the results of the meta-analysis and to assess the robustness of the findings, these studies will be included in the meta-analysis but excluded during the sensitivity analysis. As part of the outcome quality assessment, the adequacy of

follow-up time was evaluated based on the timing of SSI. SSI is typically defined as occurring within 30 days post-surgery without implants, or within one year with implants. Therefore, follow-ups of ≥ 30 days or ≥ 1 year, respectively, were considered sufficient to assess SSI occurrence [12]. The GRADE (Grading of Recommendations Assessment, Development and Evaluation) method was used to assess the quality of evidence for each outcome. The evaluation process considers the following five aspects: study limitations (risk of bias), consistency of results, directness, precision, and publication bias. Based on these factors, the quality of evidence is categorized into four levels: high, moderate, low, or very low. High-quality evidence means we are very confident in the effect estimate, while very low-quality evidence indicates minimal confidence in the effect estimate (Supplementary Table 1).

Data synthesis and analysis

The analysis evaluated the connection of hypothermia to the risk of SSI by calculating OR with 95% CIs. The chi-squared-based Q test and I^2 statistics were used to assess variability across the included studies. A random-effects model was applied when significant heterogeneity was detected ($I^2 > 50\%$) or when Cochran's Q test showed a P -value < 0.10 , indicating substantial variability. Otherwise, a fixed-effect model was used [48]. Heterogeneity was quantified using I^2 statistics, with $I^2 > 50\%$ indicating moderate to high heterogeneity [49]. Prior to performing subgroup or sensitivity analyses, potential sources of heterogeneity will be investigated by assessing study-level characteristics such as sample size, study design, and other relevant factors. The I^2 statistic and Cochran's Q test will be used to quantify heterogeneity, and if substantial heterogeneity is detected, sources will be explored using meta-regression or subgroup analyses. To address multiple comparisons in subgroup analysis, both Bonferroni and False Discovery Rate (FDR) were simultaneously applied. The Bonferroni correction adjusts the p -value threshold by dividing it by the number of comparisons. The FDR correction controls the expected proportion of false positives among all significant results. A sensitivity analysis was performed by sequentially removing each study to assess the stability of the pooled results. Additionally, Egger's test was employed to assess the likelihood of publication bias, with a P -value < 0.1 indicating significant statistical bias. Funnel plots and contour-enhanced funnel plots were also used to visually inspect the presence of publication bias. Statistical analyses were performed using Review Manager software (version 5.3) and R software (version 4.3.1; R Foundation for Statistical Computing,

Vienna, Austria), with a significance level established at $P < 0.05$.

Results

Search results

In total, 2,954 articles considered potentially relevant were retrieved from various online sources. Out of the retrieved articles, 909 duplicates and 1,987 articles unrelated to the topic were excluded. After a comprehensive review of the remaining articles, 23 review articles, 2 protocol articles, 5 articles lacked comparable data, and 4 articles lacked extractable data were excluded. In all, 25 eligible studies were included in the final meta-analysis [21–45]. Study selection is comprehensively illustrated in the flowchart presented in Fig. 1.

Characteristics of studies

The analyzed data encompassed 25 studies: 1 RCT [28], 5 case–control studies [23, 32, 33, 40, 44], and 19 cohort studies [21, 22, 24–27, 29–31, 34–39, 41–43, 45]. These investigations spanned from 1996 to 2025 and covered diverse geographical locations. The United States contributed the majority with 13 studies [24–26, 28, 29, 31, 37, 39, 40, 42–45], followed by Japan (3) [32, 34, 41] and China (2) [30, 38]. Single studies originated from Mexico [27], Brazil [22], India [36], France [33], Pakistan [35], Turkey [21], and the United Kingdom [23]. Table 1 presents a detailed overview of each study's essential characteristics. All the studies we included were non-cardiac surgeries. The risk of bias for the included RCT was assessed using the Cochrane Risk of Bias tool and was found to be low for random sequence generation and allocation concealment, but high for blinding of participants and personnel. The average Newcastle–Ottawa score for all nineteen retrospective studies and five case–control studies was equal to or greater than 7, indicating that all included observational studies were of moderate or high quality (Fig. 2) (Table 2).

Meta-analysis results

In total, 25 articles ($n = 28,761$) were finally included. Among them, 15 studies [21–29, 31, 33, 34, 36, 39] suggested that perioperative hypothermia increased the risk of postoperative incision infections, and 9 studies [30, 32, 35, 37, 40, 42–45] indicated that perioperative hypothermia may reduce the rate of postoperative incision infections, and 1 study [41] found no relationship between them. The meta-analysis indicated that perioperative hypothermia was associated with an increased risk of SSI; however, this link did not reach statistical significance. (OR, 1.39; 95% CI, 0.98–1.96; $I^2 = 89\%$, $P = 0.06$) (Fig. 3).

Subgroup analyses were conducted based on the type of study. There was no significant link between perioperative hypothermia and SSI in the case–control studies

Table 1 Characteristics of studies included in the meta-analysis

Study	Country	Design	Type of surgery	Definition of intraoperative hypothermia	Hypothermia events		Normothermia events		Age	Number of male patients	ASA	BMI	SSI definition	Anesthesia method
					total	total	total	total						
Abugri BO 2022 [32]	Japan	case-control study	orthopedic surgery	BT < 36.0°C	5	56	38	241	66.1 ± 17.1	61	I-IV	23.4 ± 4.1	a	NA
Akers JL 2019 [36]	India	cohort study	laparotomy	BT < 36.0°C	0	7	2	291	49.8 ± 14.9	38	NA	NA	b	GA/GA + RA
Andersen ES 2024 [25]	America	cohort study	colectomy	BT < 35.5°C	42	122	18	106	61.8 ± 13.1	0	I-IV	29.3 ± 6.5	c	GA
Baucom RB 2014 [44]	America	case-control study	ventral hernia repair	BT < 36.0°C	9	159	28	394	53.0 ± 13.0	153	I-IV	32.0 ± 8.0	a	NA
Baucom RB 2015 [43]	America	cohort study	Bariatric Surgery	BT < 36.0°C	2	21	34	275	NA	153	I-IV	28.9 ± 6.9	a	NA
Brown MJ 2017 [40]	America	case-control study	Shoulder Arthroplasty	BT < 36.0°C	667	2355	412	1273	69.0 ± 11.0	2546	I-IV	30 ± 7.2	a	NA
Chishom TA 2023 [24]	America	cohort study	abdominal surgery	BT < 35.0°C	7	55	9	99	54.4 ± 13.5	0	I-IV	31.3 ± 5.7	a	GA
Constantine RS 2015 [42]	America	cohort study	trauma laparotomies	BT < 36.0°C	204	820	69	242	31.2 ± 12.5	189	NA	27.8 ± 7.1	b	GA
Eker PY 2023 [21]	Turkey	cohort study	Autologous Breast Reconstruction	BT < 36.0°C	78	96	0	6	50.8 ± 9.1	38	II-IV	47.4 ± 4.4	a	GA
Flores-Maldonado A 2001 [27]	Mexico	cohort study	Implant-Based Breast Reconstruction	BT < 36.0°C	18	156	2	105	50.1 ± 12.2	40	I-II	NA	a	NA
Frisch NB 2016 [26]	America	cohort study	Plastic Surgery	BT < 36.0°C	17	260	66	1265	50.4 ± 13.4	549	I-V	24.1 ± 6.1	a	GA/RA
Jildeh TR 2018 [37]	America	cohort study	liver resection	BT < 36.0°C	5	346	9	311	58.6 ± 15.6	260	I-IV	30.5 ± 6.4	a	GA/GA + RA
Kurz A 1996 [28]	America	randomized controlled trial	hysterectomy, laparoscopic cholecystectomy, hernia repair, total knee arthroplasty, and total hip arthroplasty	BT < 35.0°C	18	96	6	104	59.1 ± 12.2	108	NA	NA	c	GA
Landisch RM 2017 [39]	America	cohort study	Breast Surgery Cancer	BT < 36.0°C	6	21	4	22	NA	25	NA	NA	a	GA
Liedl HJC 2024 [29]	America	cohort study	Closure of Gastroschisis	BT < 35.5°C	6	99	8	137	NA	98	NA	33 ± 7.5	c	GA
Long CK 2013 [45]	America	cohort study	Prolonged Gastroenterological Surgery	BT < 36.0°C	26	219	13	78	53.5 ± 13.8	0	I-IV	24.9 ± 24.1	a	GA

Table 1 (continued)

Study	Country	Design	Type of surgery	Definition of intraoperative hypothermia	Hypothermia events total	Normothermia events total	Age	Number of male patients	ASA	BMI	SSI definition	Anesthesia method
Motamed C 2021 [33]	France	case-control study	General surgery, Hepatobiliary surgery, Peripheral vascular surgery, Cardiovascular surgery, Thoracic surgery, Orthopedics surgery, Neurosurgery, Urology surgery, Plastic surgery, Obstetrics and gynecology surgery	BT < 36.5 °C	7	80	NA	35	III		b	GA
Nguyen AP 2022 [31]	America	cohort study	Spine surgery, Vascular surgery, General surgery, Neurosurgery, Orthopedic surgery	BT < 36.0 °C	3	230	61.2 ± 53.7	NA	NA		a	GA
Ribeiro JC 2021 [22]	Brazil	cohort study	cytoreductive surgery	BT < 36.0 °C	97	475	77.6 ± 14.2	221	III		a	GA/RA/ GA + RA
Seamon MJ 2012 [23]	Britain	case-control study	hip surgery	BT < 35.0 °C	40	86	63.9 ± 10.9	470	NA		a	GA
Siddiqi T 2020 [35]	Pakistan	cohort study	Hip or Knee Arthroplasty	BT < 36.0 °C	9	90	47 ± 10.8	66	IV	27.3 ± 5.8	a	NA
Tsuchida T 2016 [41]	Japan	cohort study		BT < 36.0 °C	101	528	64.0 ± 10.3	270	NA		a	GA
Yamada K 2020 [34]	Japan	cohort study	orthopaedic surgery	BT < 36.0 °C	88	1008	60.0 ± 14.5	3659	IV	23.4 ± 4.1	a	NA
Yi J 2017 [38]	China	cohort study	colorectal surgery	BT < 36.0 °C	33	1372	58.2 ± 16.2	1468	IV	23.6 ± 3.6	a	GA/GA + RA
Zhou YD 2023 [30]	China	cohort study	Thoracic Surgery	BT < 36.0 °C	150	2206	NA	2458	IV	23.7 ± 3.0	a	GA

BT body temperature, ASA american society of anesthesiologists, BMI body mass index, SSI surgical site infection, GA general anesthesia, RA regional anesthesia

* a, incision skin or subcutaneous tissue infection within 30 days postoperatively; b, infection of the surgical wound; c, incision skin or subcutaneous tissue infection occurring within 30 days postoperatively if there is no implant; or within 90 days if there is an implant

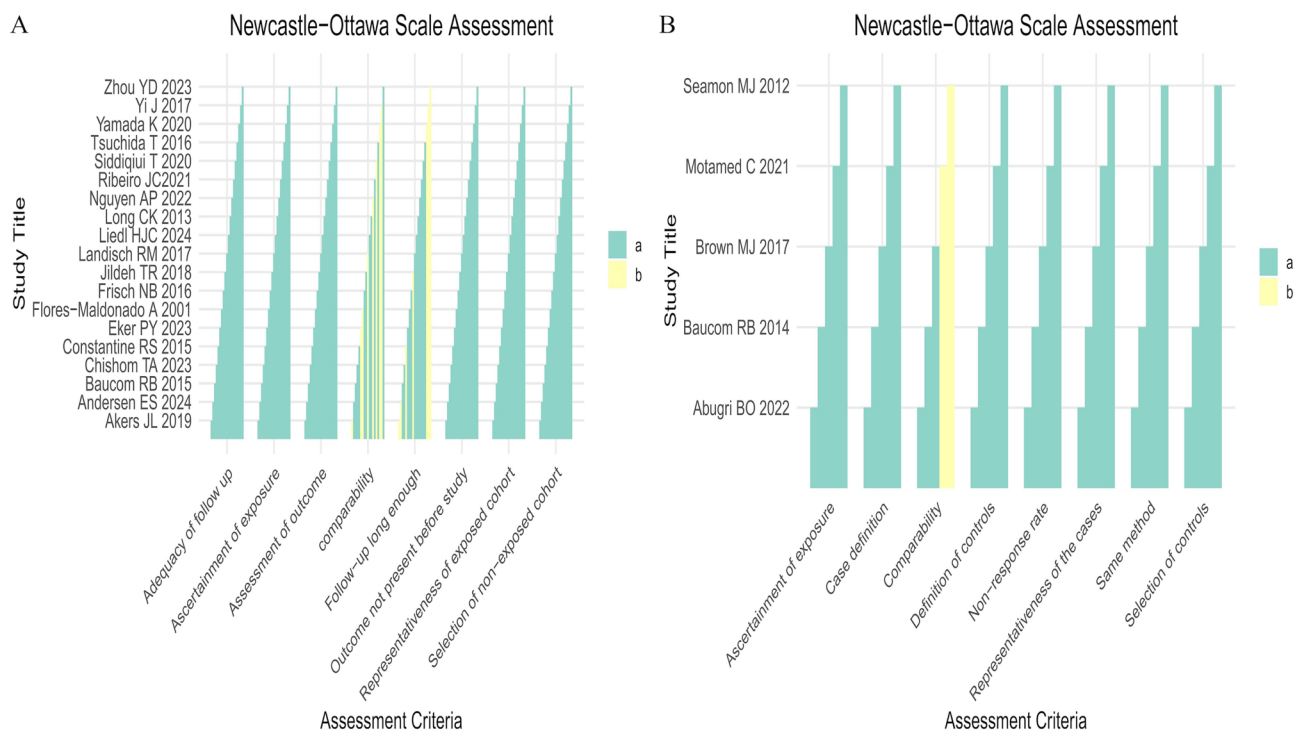


Fig. 2 Results of Newcastle–Ottawa Quality Assessment Scale. **A** Cohort studies. **B** Case–control studies. Most items receive a maximum of one star. However, for the comparability criterion, up to two stars can be awarded. Items that received full marks are labeled “a”, those that did not receive full marks are labeled “b”, and those that received no marks are labeled “c”

subgroup (OR, 1.00; 95% CI, 0.62–1.59; $I^2 = 70\%$, $P = 0.99$) (Fig. 3). In the cohort studies subgroup, perioperative hypothermia correlated with a 1.49-fold increase in the rate of SSI, although this association did not achieve statistical significance (OR, 1.49; 95% CI, 0.95–2.35; $I^2 = 70\%$, $P = 0.09$). In the RCT, perioperative hypothermia notably raised the incidence of postoperative SSI (OR, 3.77; 95%CI, 1.43– 9.95).

Subgroup analyses were performed based on the specific types of surgery. Among the included studies, 5 [26, 29, 32, 34, 37] were related to orthopedic surgery. Among them, 3 studies [26, 29, 34] suggested that perioperative hypothermia could elevate the risk of SSI, while the other 2 [32, 37] indicated it may lower the risk of SSI (Fig. 4). Patients undergoing orthopedic procedures with perioperative hypothermia faced a 1.28 times higher risk of SSI. However, this observed association lacked statistical significance in the study (OR, 1.28; 95% CI, 0.34–4.78; $I^2 = 95\%$, $p = 0.72$). Of the 25 studies included, 11 [21, 22, 27, 28, 30, 35, 39, 41, 43–45] focused on surgical procedures related to the abdomens. 4 [35, 43–45] suggested that perioperative hypothermia may reduce the risk of SSI, while 6 [21, 22, 27, 28, 30, 39] indicated it may increase the risk, and 1 [41] proposed there is little relationship between the two. For patients undergoing abdominal procedures, perioperative hypothermia potentially elevated infection risk at the surgical site. However,

this observed trend lacked statistical significance in the analysis (OR, 1.26; 95% CI, 0.88–1.80; $I^2 = 57\%$, $p = 0.20$). 3 articles [24, 25, 33] examined the relationship between perioperative hypothermia and SSI in breast procedures, with all three indicating a link between hypothermia and an increased incidence of SSI. The meta-analysis indicated a notable increase in the incidence of postoperative SSI in breast surgery associated with perioperative hypothermia (OR, 1.97; 95% CI, 1.21–3.21; $I^2 = 0\%$, $p < 0.01$). The breast surgery subgroup remained statistically significant after Bonferroni correction ($p = 0.018$) and FDR ($p = 0.018$). (Supplementary Fig. 1).

The analysis revealed diverse surgical wound classifications across the studies: 10 [24–26, 29, 32–34, 37, 42, 44] focused on Type I incisions, 11 [21, 22, 27, 28, 30, 31, 35, 39, 41, 43, 45] examined Type II incisions, and a single investigation [23] addressed Type III incisions. In studies with Type I surgical wounds, 6 studies [24–26, 29, 33, 34] suggested a potential increase in the risk of SSI associated with perioperative hypothermia, while 4 studies [32, 37, 42, 44] indicated a potential negative relationship between perioperative hypothermia and the incidence of SSI (Fig. 5). In studies involving Type I surgical wounds, perioperative hypothermia was linked to a higher risk of postoperative SSI; however, this finding was not statistically meaningful (OR, 1.45; 95% CI, 0.59–2.71; $I^2 = 93\%$, $p = 0.54$). Research on Type II surgical wounds showed

Table 2 Quality assessment of included studies

Study (cohort)	Representativeness of exposed cohort	Selection of non-exposed cohort	Ascertainment of exposure	Outcome not present before study	comparability	Assessment of outcome	Follow-up long enough	Adequacy of follow up	Quality score
Akers JL 2019 [36]	a	a	a	a	b	a	b	a	7
Andersen ES 2024 [25]	a	a	a	a	a	a	b	a	8
Baucom RB 2015 [43]	a	a	a	a	a	a	a	a	9
Chishom TA 2023 [24]	a	a	a	a	a	a	a	a	9
Constantine RS 2015 [42]	a	a	a	a	a	a	b	a	8
Eker PY 2023 [21]	a	a	a	a	b	a	a	a	8
Flores-Maldonado A 2001 [27]	a	a	a	a	b	a	a	a	8
Frisch NB 2016 [26]	a	a	a	a	a	a	a	a	9
Jildeh TR 2018 [37]	a	a	a	a	a	a	b	a	8
Landisch RM 2017 [39]	a	a	a	a	b	a	a	a	8
Liedl HJC 2024 [29]	a	a	a	a	a	a	a	a	9
Long CK 2013 [45]	a	a	a	a	a	a	a	a	9
Nguyen AP 2022 [31]	a	a	a	a	b	a	a	a	8
Ribeiro JC 2021 [22]	a	a	a	a	a	a	a	a	9
Siddiqiui T 2020 [35]	a	a	a	a	b	a	a	a	8
Tsuchida T 2016 [41]	a	a	a	a	a	a	a	a	9
Yamada K 2020 [34]	a	a	a	a	b	a	b	a	8
Yi J 2017 [38]	a	a	a	a	b	a	b	a	7
Zhou YD 2023 [30]	a	a	a	a	a	a	b	a	8
Study (case-control)	Case definition	Representativeness of the cases	Selection of controls	Definition of controls	Comparability	Ascertainment of exposure	Same method	Non-response rate	Quality score
Abugri BO 2022 [32]	a	a	a	a	a	a	a	a	9
Baucom RB 2014 [44]	a	a	a	a	a	a	a	a	9
Brown MJ 2017 [40]	a	a	a	a	a	a	a	a	9
Motamed C 2021 [33]	a	a	a	a	b	a	a	a	8
Seamon MJ 2012 [23]	a	a	a	a	b	a	a	a	8

mixed results. 7 studies [21, 22, 27, 28, 30, 31, 39] indicated perioperative hypothermia may elevate infection risk, while 3 [35, 43, 45] suggested a possible inverse relationship. 1 study [41] concluded there was no link between hypothermia and SSI. Meta-analysis suggested that in Type II surgical incisions, perioperative hypothermia was positively correlated with postoperative SSI (OR, 1.34; 95% CI, 0.92–1.94; $I^2 = 56\%$, $p = 0.13$).

As for the definition of perioperative hypothermia, 1 study [33] defined it as below 36.5°C, 19 studies [21, 22, 26, 27, 30–32, 34–40] defined it as below 36°C, 2 studies [25, 29] defined it as below 35.5°C, and 3 studies [23, 24, 28] defined it as below 35°C (Fig. 6). In studies defining hypothermia as below 36°C, 9 articles [21, 22, 26, 27, 30, 31, 34, 36, 39] suggested that hypothermia may reduce the risk of SSI, 9 articles [32, 35, 37, 38, 40, 42–45] indicated it may increase the risk, and 1 article [41] suggested there was no significant correlation. Meta-analysis suggested that in studies defining hypothermia as below 36°C, hypothermia may increase the risk of infection, however, this finding did not achieve statistically significant

(OR, 1.26, 95%CI, 0.83–1.90; $I^2 = 91\%$, $p = 0.27$). In studies defining hypothermia as below 35.5°C, both investigations indicated that perioperative hypothermia could elevate infection rates; a similar conclusion was reached in the meta-analysis (OR, 1.83, 95%CI, 0.78–4.31; $I^2 = 49\%$, $p = 0.17$). In studies where hypothermia was defined as below 35°C, all studies indicated that perioperative hypothermia may elevate the risk of infection (OR, 2.12, 95% CI, 1.42–3.16; $I^2 = 89\%$, $P < 0.01$). The subgroup with hypothermia was defined as below 35°C still had significant statistical significance after Bonferroni correction ($P = 0.0008$) and FDR ($P = 0.0008$) (Supplementary Fig. 2).

In the 25 studies included, 7 studies [21, 24, 25, 29, 37, 43, 44] had an average BMI ≥ 28 kg/m², and 8 studies [26, 30, 32, 34, 35, 38, 42, 45] had an average BMI < 28 kg/m². In the distribution of age, 3 studies [26, 34, 37] had an average age ≥ 65 years, while 17 studies [22–25, 27, 28, 31–33, 35, 36, 38, 42–45] had an average age ≥ 18 years and < 65 years. The meta-analysis showed that hypothermia might increase the risk of infection, but this finding was not statistically

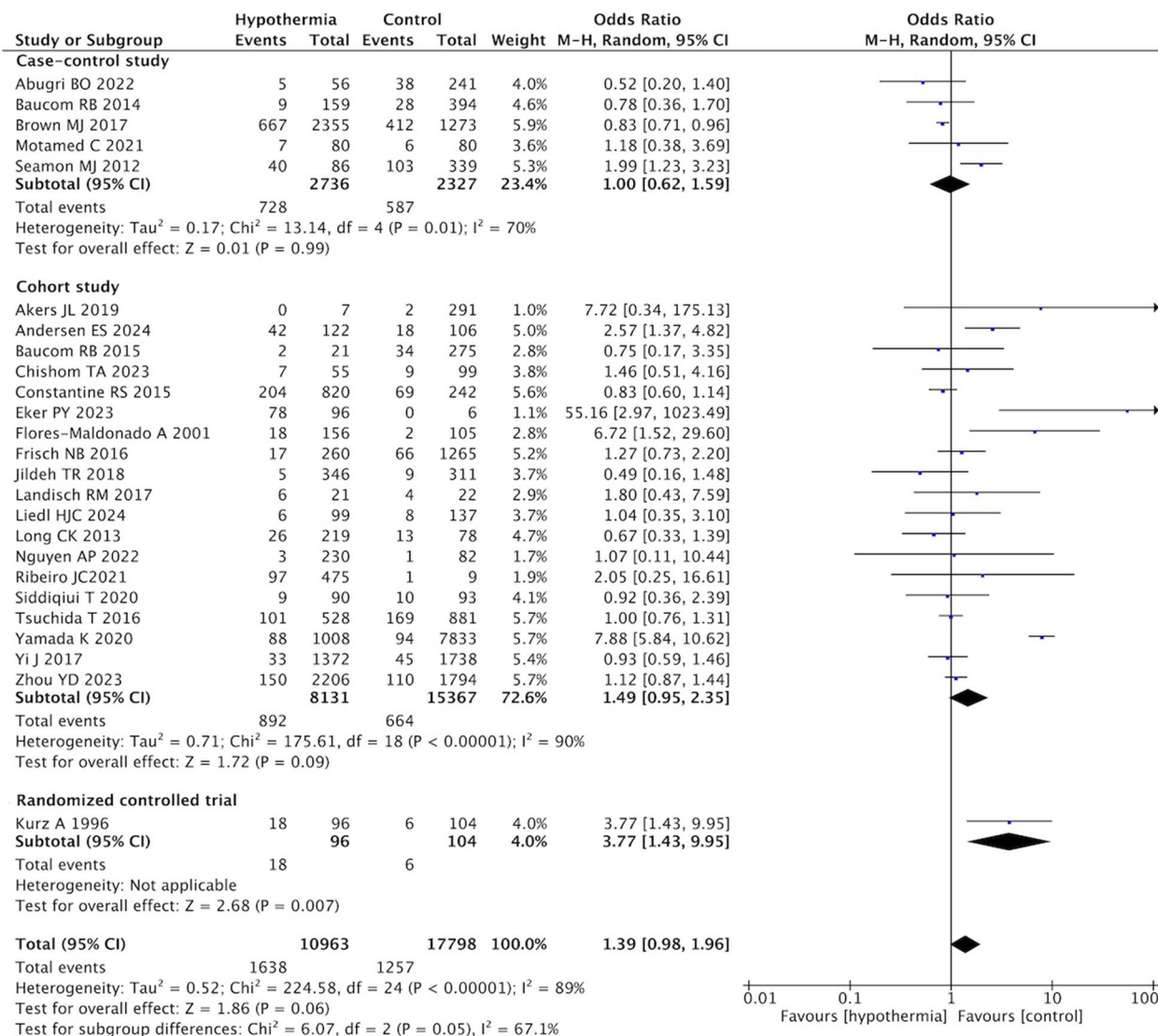


Fig. 3 Forest plots of the overall meta-analysis results and subgroup analysis by study design. CI, confidence interval

significant in the four subgroups of BMI ≥ 28 kg/m², BMI < 28 kg/m², age ≥ 65 years, and age < 65 years (Supplementary Fig. 3). Four studies [24, 25, 33, 45] included only female patients, and meta-analysis found similar result (Supplementary Fig. 4).

Sensitivity analysis

The sensitivity analysis revealed that effect sizes across most studies were relatively consistent, indicating overall homogeneity in the findings (Supplementary Fig. 5). However, the study by Yamada K [34] exhibited relatively high heterogeneity, and as an outlier, it was excluded from the subsequent meta-analysis. After excluding this study, the analysis suggested that hypothermia may increase the risk of SSI, although no statistical significance was observed (OR, 1.15, 95% CI, 0.94–1.41; I² = 58%, p = 0.18) (Supplementary Fig. 6).

Publication bias

The funnel plot (Supplementary Fig. 7) and a contour-enhanced funnel plot (Supplementary Fig. 8) results of this study display an overall symmetric distribution, indicating a possible lack of significant publication bias. Based on the Egger's test, no strong evidence was found to support the presence of publication bias (p = 0.1777).

Discussion

This meta-analysis assessed 25 studies to investigate how perioperative hypothermia influences the development of SSI. Our findings suggested a trend towards an elevated risk of SSI associated with perioperative hypothermia (OR, 1.39; 95% CI, 0.98–1.96; I² = 89%, p = 0.06), although this did not reach conventional statistical significance. Notably, significant associations were observed in specific subgroups, particularly in breast surgery (OR,

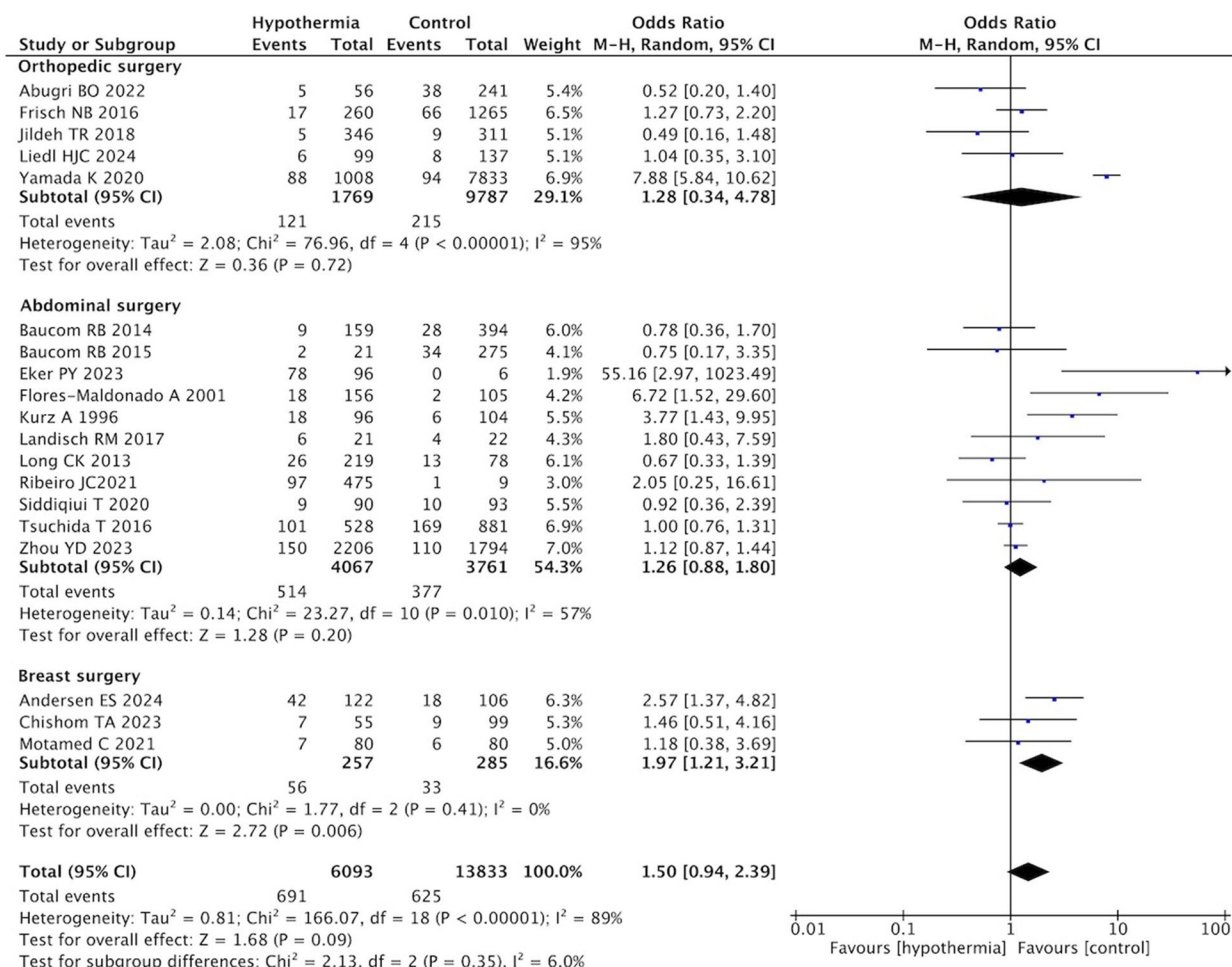


Fig. 4 Forest plots of the subgroup analysis by type of surgery. CI, confidence interval

1.97; 95% CI, 1.21–3.21; I² = 0%, P < 0.01) and when body temperature is below 35 °C (OR, 2.12; 95% CI, 1.42–3.16; I² = 89%, P < 0.01). Other comparable meta-analyses have demonstrated no significant association between perioperative hypothermia and SSI in surgical patients [50, 51], aligning with the conclusions drawn from our present study. However, our study offers several unique contributions. First, we conduct more granular subgroup analyses, examining factors such as surgery type, patient characteristics, and hypothermia severity, which have not been explored in previous studies. Second, our meta-analysis includes a larger number of studies, increasing the robustness and generalizability of the findings compared to prior analyses. These elements significantly enhance the depth of our analysis, providing additional insights into the relationship between perioperative hypothermia and SSI.

In the sensitivity analysis, Yamada K [34] exhibited high heterogeneity. The extreme effect size observed in the study by Yamada K [34] may be attributed to factors specific to the study design and patient population. This

study focused on bariatric surgery patients, who have unique high-risk factors for perioperative hypothermia and SSI, particularly those with a BMI greater than 45 kg/m², where the incidence of perioperative hypothermia and SSI was very high. Additionally, the small sample size (102 patients) can lead to greater fluctuations in effect sizes, especially when there are outliers or significant heterogeneity in the population. Importantly, the removal of the study by Yamada K [34] did not significantly alter the pooled estimates (OR changed from 1.39 to 1.15; 95% CI overlap), suggesting no substantial publication bias. This consistency across sensitivity analyses strengthens confidence in the robustness of the findings.

Perioperative hypothermia may increase the risk of wound infections through two mechanisms. Firstly, when core temperature drops sufficiently, it induces thermoregulatory vasoconstriction [52]. This physiological response significantly reduces oxygen levels in subcutaneous tissues, a factor closely linked to the occurrence of wound infections [17]. Secondly, even mild core hypothermia directly compromises immune function [53].

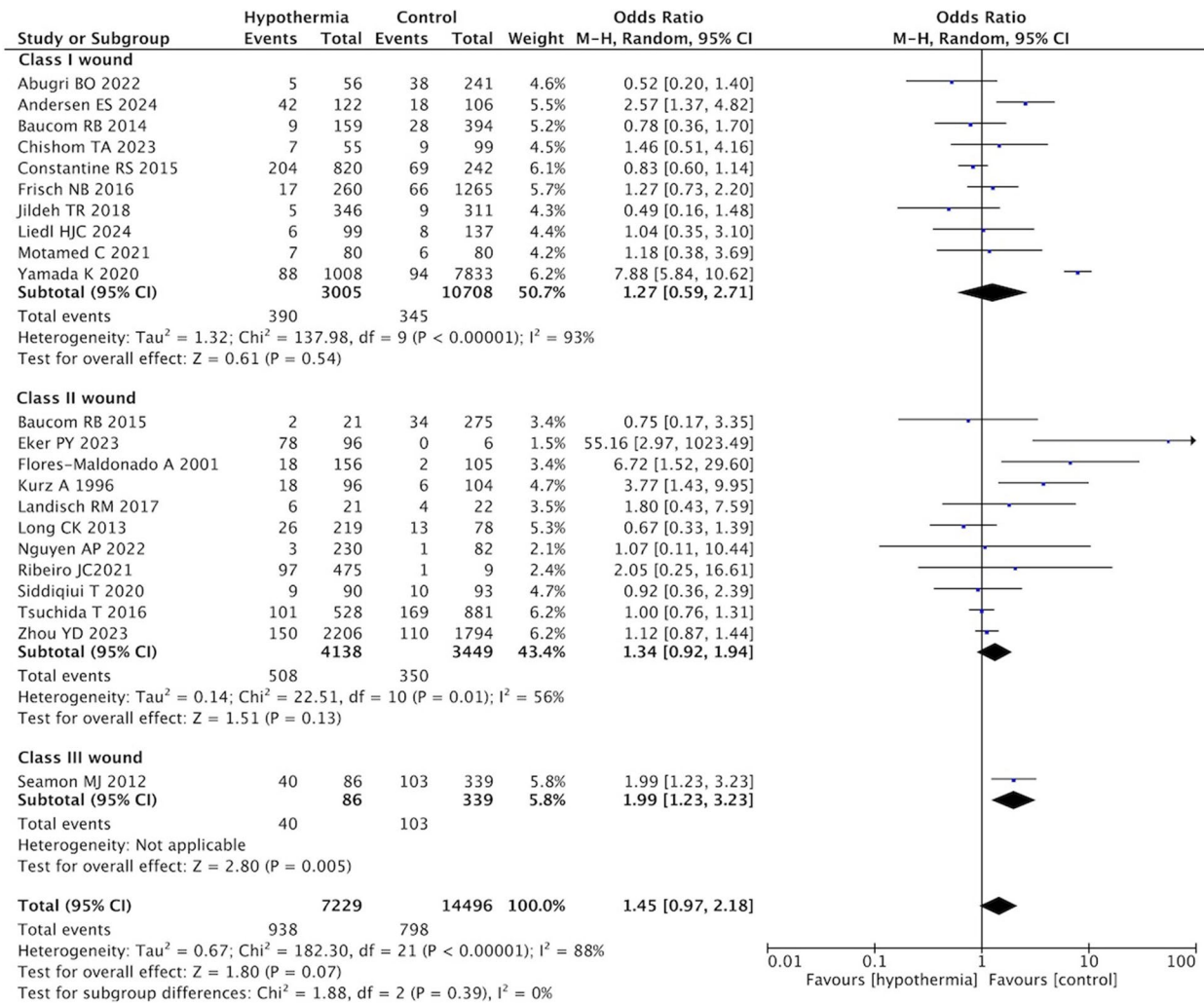


Fig. 5 Forest plots of the subgroup analysis by type of surgical incision. CI, confidence interval

Nonetheless, current studies regarding perioperative hypothermia and postoperative SSI show inconsistent findings. Our meta-analysis found no meaningful link between perioperative hypothermia and the risk of surgical site infections in surgical populations. Nevertheless, the findings of our review are limited by a degree of heterogeneity. To mitigate the effects of heterogeneity, subgroup analyses were performed based on study type, surgical procedure, incision site, the threshold for perioperative hypothermia, as well as average BMI and average age.

In terms of study type, no significant association was found between perioperative hypothermia and the occurrence of SSI in the case-control study subgroup. In cohort studies, perioperative hypothermia was associated with a higher incidence of SSIs, although this association did not reach statistical significance. In contrast, the single RCT included suggested that perioperative hypothermia may significantly increase the risk of post-operative

SSIs. Specifically, 1 RCT [28] found that when body temperature dropped 2 °C below normal, the incidence of wound infections was tripled. However, given that only one RCT was available, these findings should be interpreted with caution. The evidence from this single trial is limited, and further well-conducted RCTs are needed to confirm these results and better understand the potential impact of perioperative hypothermia on surgical outcomes.

In orthopedic and abdominal surgeries subgroups, perioperative hypothermia raises the risk of SSI, although no significant association was found. Several factors might contribute to this finding, including the relative avascularity of orthopedic surgical sites, the stable internal temperature of abdominal organs. Modern laparoscopic techniques used in many abdominal procedures involve less exposure of internal organs to the external environment, potentially mitigating the effects of hypothermia. Additionally, the peritoneum's natural defense

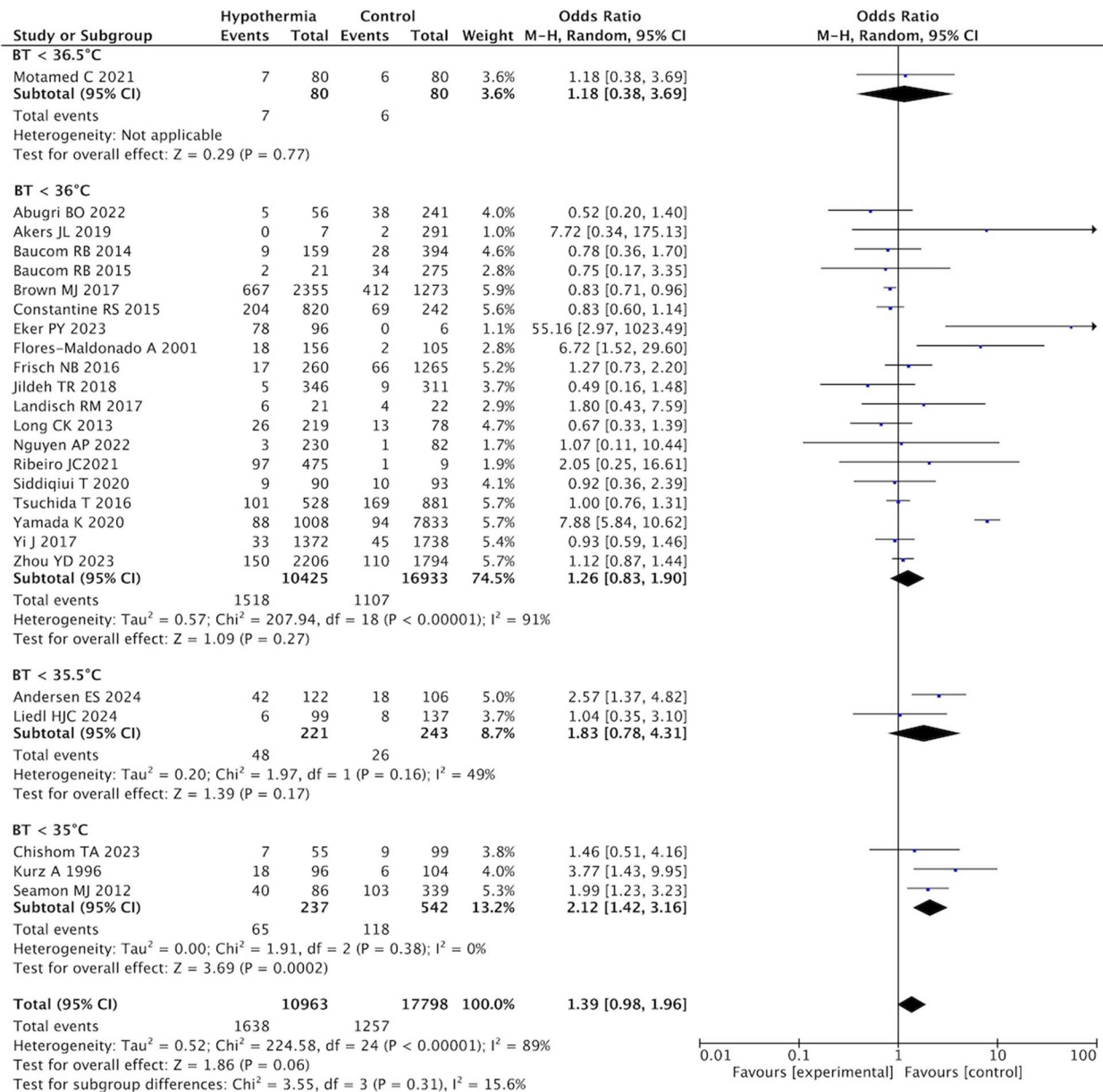


Fig. 6 Forest plots of the subgroup analysis by different definitions of hypothermia. BT, body temperature; CI, confidence interval

mechanisms [54] may help counteract any increased infection risk due to hypothermia. However, in breast surgeries, perioperative hypothermia was associated with SSI. This could be attributed to the extensive body surface exposure required during breast surgeries, and the longer duration of combined procedures involving flap transplantation, such as breast reconstruction [25]. Moreover, flap transplantation in breast surgeries is particularly sensitive to local blood perfusion [55]. Perioperative hypothermia may lead to vasoconstriction, further reducing local blood and oxygen supply [17]. This could potentially increase the risk of ischemic necrosis and infection in these patients' postoperative wounds [56]. Therefore, it is

essential to develop personalized temperature management strategies tailored to different types of surgeries. When designing these strategies, it is important to not only consider the specific nature of the procedure but also to take into account patient characteristics, underlying health conditions, and the unique risks associated with each surgical environment. For instance, active warming should be prioritized in breast surgery when temperatures fall below 35 °C to prevent hypothermia-related complications. This approach will help ensure that temperature management protocols are optimized to minimize the risk of postoperative infections.

The meta-analysis did not find a statistically significant association between mild perioperative hypothermia (with body temperature no lower than 35 °C) and postoperative SSI. While mild drops in body temperature don't seem to be a problem, things change when patients get really cold. Specifically, when a patient's temperature dips below 35 °C during the operation, we start to see a higher risk of surgical site infections. During surgery, under anesthesia, a body temperature below 36 °C might actually be protective due to decreased metabolic rate [57]. When body temperature drops below 35 °C, multiple physiological systems are affected, including cardiovascular, hematological, neurological, respiratory, renal, gastrointestinal, and endocrine systems [58]. The immune system is particularly vulnerable to hypothermia. This low body temperature can lead to a decrease in white blood cell count, impaired neutrophil migration, and reduced bacterial phagocytosis. Additionally, complement activation may be weakened. As a result, when body temperature falls below 35 °C, patients are more susceptible to developing SSI. Therefore, it's crucial to accurately manage the patient's intraoperative temperature and determine the optimal timing for active warming to minimize waste of healthcare resources. Additionally, future research should focus on the standardization of temperature thresholds, as variations in these thresholds contribute to inconsistencies across studies. Key areas for investigation include determining the lowest temperature patients can safely tolerate, the duration of time they can remain at this temperature without adverse effects, and the clinical implications of different temperature thresholds.

The subgroup analyses based on BMI and age both suggest a potential increase in SSI risk with hypothermia, but these findings lack statistical significance and are marked by high heterogeneity. The consistency in odds ratios across BMI subgroups (OR 1.17 for both ≥ 28 kg/m² and < 28 kg/m²) indicates that BMI may not substantially modify the hypothermia-SSI relationship. Age subgroup analysis hints at a possibly stronger effect in older patients (OR 1.80 for ≥ 65 years vs. 1.22 for < 65 years), but wide confidence intervals and high heterogeneity limit the reliability of this observation. While these results support the importance of perioperative temperature management across patient groups, they also highlight the need for more standardized, larger-scale studies to clarify the relationships between hypothermia, patient characteristics, and SSI risk. Future research should focus on reducing heterogeneity, increasing sample size, and conducting studies targeting specific populations (e.g., elderly patients, those with cardiovascular disease, pregnant women, obese patients, diabetic patients, etc.)

There are a number of limitations in our study that must be considered when analyzing the results. Firstly, RCTs

requiring temperature manipulation in patients are ethically challenging due to the potential induction of preventable pathological states that may lead to adverse outcomes. Consequently, such studies are relatively scarce in the literature and the majority of studies included in this meta-analysis are observational studies, which led to a "low quality" rating in the GRADE assessment. While observational studies can offer important insights, they are inherently vulnerable to numerous biases and confounding variables, which restrict their capacity to determine causal links between perioperative hypothermia and SSI. And the exclusion of grey literature and unpublished studies may introduce selection bias. Additionally, the breast surgery subgroup analysis is based on only three studies ($n = 542$). Although the large effect size (OR = 1.79, 95% CI: 1.21–3.21) and low subgroup heterogeneity ($I^2 = 0\%$) suggest robustness, these findings require validation in larger cohorts. In addition to the limitations of study design, the heterogeneity observed in our meta-analysis also warrants consideration. This heterogeneity can be attributed to several factors. One key factor is the variability in the study populations, which differed in terms of demographics, comorbidities, and risk factors for SSIs. For example, some studies focused on specific patient groups, such as neonates or women, while others included more general surgical populations. Another important factor is the variability in average BMI and age across studies. These characteristics were reported as averages for the entire study population in most studies, representing rough estimates of these factors. However, due to substantial missing data and inconsistent reporting across studies, it was difficult to integrate these variables meaningfully into the analysis. Furthermore, the types of surgeries investigated were diverse, ranging from orthopedic and abdominal surgeries to breast surgeries, each with its own inherent SSI risk. The complexity and duration of these surgeries also varied, which could influence the likelihood of hypothermia and the associated SSI risk. While we conducted subgroup analyses for major categories like abdominal, orthopedic, and breast surgeries, many studies reported on mixed surgical populations without granular details. This constraint limits our ability to provide a comprehensive breakdown of all surgery types and may impact the comparability of SSI and thermoregulation dynamics across different procedures. Another source of heterogeneity lies in the inconsistency in how hypothermia was defined and measured across studies. Although we attempted to address this by performing subgroup analyses based on temperature thresholds, variations in the timing, duration, and methods of temperature measurement may have contributed to the observed differences. Some studies measured core temperature, while others relied on peripheral temperature, which may not accurately reflect core body temperature. It is important to recognize that the accuracy of different body temperature measurement methods can vary, potentially impacting the detection of

hypothermia. For instance, techniques like peripheral thermometers and axillary chemical dots tend to be less reliable compared to more accurate methods such as esophageal temperature measurement [59–61]. While these concerns are especially relevant in specific clinical settings, precise temperature monitoring remains crucial. Further research is needed to evaluate and compare the effectiveness of various methods across different clinical environments. Lastly, variations in perioperative care protocols—such as the selection, dosage, and duration of prophylactic antibiotics, as well as the use of warming devices and other infection prevention measures—may have further influenced the relationship between hypothermia and SSIs. Regarding the exploratory nature of the subgroup analyses, although we applied statistical corrections for multiple comparisons, the possibility of Type I errors cannot be entirely ruled out. Future studies should pre-specify subgroup analyses to validate our findings. These factors were not consistently reported or controlled across all the studies included in the analysis.

Conclusion

While the overall association between perioperative hypothermia and SSI risk was not statistically significant, significant relationships were observed in breast surgery and at temperatures below 35 °C. Future RCTs should focus on breast surgery and standardize temperature thresholds. High heterogeneity ($I^2 = 89\%$) limits generalizability and calls for further research.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12871-025-03277-7>.

Supplementary Material 1: Supplementary Figure 1. Bar charts comparing the original p -values and adjusted p -values of different surgical types. Comparison of raw and adjusted p -values (Bonferroni and False Discovery Rate (FDR)) across three surgical groups: Abdominal, Breast, and Orthopedic Surgery. The bars show how adjustment methods affect statistical significance.

Supplementary Material 2: Supplementary Figure 2. Bar chart comparing the original p -value and the adjusted p -value at different temperature thresholds. Comparison of raw and adjusted p -values (Bonferroni and False Discovery Rate (FDR)) across three surgical groups: BT < 35.5°C, BT < 35°C, BT < 36.5°C, BT < 36°C. The bars show how adjustment methods affect statistical significance.

Supplementary Material 3: Supplementary Figure 3. Forest plots of the subgroup meta-analysis results. (a) Subgroup analysis by mean BMI. (b) Subgroup analysis by mean age. CI, confidence interval, BMI, body mass index.

Supplementary Material 4: Supplementary Figure 4. Subgroup analysis of studies including only female participants. CI, confidence interval.

Supplementary Material 5: Supplementary Figure 5. Sensitivity analysis results. The plot shows the odds ratios (OR) with 95% confidence intervals for each study included in the sensitivity analysis. The consistency of the results across different studies indicates the robustness of the overall findings.

Supplementary Material 6: Supplementary Figure 6. Meta-analysis results

after excluding a study with relatively high heterogeneity.

Supplementary Material 7: Supplementary Figure 7. Funnel plot of publication bias. The funnel plot displays study effects on a coordinate system with the log odds ratio on the horizontal axis and standard error on the vertical axis. This plot is used to detect publication bias. Grey areas indicate the dispersion range of effect sizes. With smaller standard errors, the variability of effect sizes is smaller, hence the funnel narrows towards the top.

Supplementary Material 8: Supplementary Figure 8. Contour-enhanced funnel plot of publication bias. The plot displays the relationship between study size (represented by standard error) and effect size (risk ratio on a log scale). The shaded areas represent different levels of statistical significance (p -values), with darker areas indicating higher significance. The distribution of the points is used to assess potential publication bias among the included studies.

Supplementary Material 9.

Supplementary Material 10.

Supplementary Material 11.

Authors' contributions

WGY conceived and designed the study. CRR, DYJ conducted a literature search and drafted the manuscript. Figure 1–4 are prepared by CLY, BYF and ZY. Supplementary figures are prepared by YTK and LH. All authors critically revised the manuscript and approved the final version for submission.

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Data availability

The corresponding author can provide the datasets used and analyzed in this study upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Consent for publication is not applicable.

Competing interests

The authors declare no competing interests.

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