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Procedure-Specific Effectiveness of Warmed Versus Room-Temperature Irrigation Fluids for Preventing Perioperative Hypothermia: A Systematic Review

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LITERATURE REVIEW

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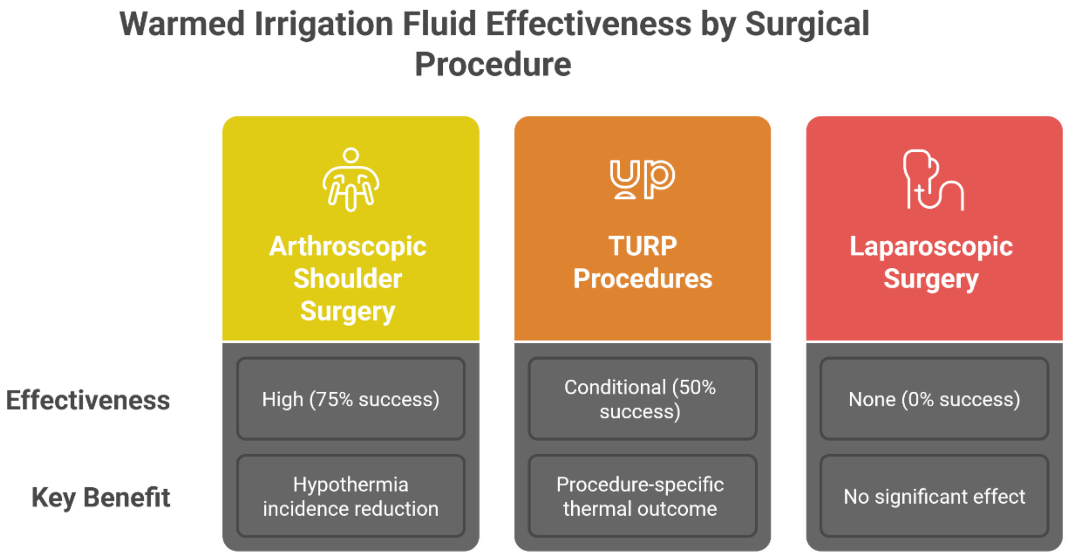
ABSTRACT

This study investigates the impact of using warmed irrigation fluid over room-temperature fluid on patient body temperature during surgery, while also exploring the variables that influence its effectiveness. Systematic review following PRISMA guidelines. Comprehensive searches were conducted in PubMed/MEDLINE, Embase, Cochrane Central, and Web of Science (inception to March 2024) using PICO framework-derived search terms. Inclusion criteria: randomized controlled trials (RCTs) and systematic reviews comparing warmed irrigation fluids (⩾36° C) versus room temperature in adult surgical patients. Quality assessment used Joanna Briggs Institute (JBI) critical appraisal tools. Data synthesis included descriptive analysis and meta-analysis where appropriate. Ten studies (eight randomized controlled trials and two systematic reviews/meta-analyses) met inclusion criteria, comprising 2,459 participants across various surgical procedures. Overall methodological quality was high (mean JBI score 10.2/11, 93%). Effectiveness analysis revealed that 67% of individual studies (6/9) demonstrated significant benefits, with clear procedure-specific patterns. Arthroscopic shoulder surgery showed the highest success rate (75%, 3/4 studies) with effect sizes of 67–80% reduction in hypothermia incidence when using 37°C irrigation. TURP procedures demonstrated conditional effectiveness (50% success rate) depending on anesthesia type, while laparoscopic surgery showed no benefit (0% success rate) due to competing heat loss mechanisms. Warmed irrigation fluids at 37°C demonstrate procedure-specific effectiveness, with arthroscopic shoulder surgery showing highest success rates (75%) and laparoscopic surgery showing no benefit.

Key Messages:

- Procedure-specific effectiveness is critical—while arthroscopic and TURP procedures benefit from warmed irrigation, laparoscopic surgeries show no significant effect due to high thermal loss mechanisms.
- Using warmed irrigation fluids is a simple, cost-effective, and safe intervention that aligns with precision medicine principles in perioperative care.
- Standardizing irrigation temperature to 37°C can improve surgical thermal outcomes when applied with consideration to procedure type, anesthesia, and thermal environment.

GRAPHICAL ABSTRACT



INTRODUCTION

Normal body temperature, also known as normothermia, is a crucial physiological condition for maintaining metabolic balance and optimal organ function (1). In the perioperative context, preserving normothermia is essential because patients are highly vulnerable to thermoregulatory disturbances caused by anesthesia, exposure to the cold operating room environment, and invasive surgical interventions. Thermoregulatory homeostasis supports hemodynamic stability, proper coagulation processes, and an effective immune response (2). When the body temperature drops below the normothermic threshold (hypothermia), it can lead to various serious clinical consequences, such as increased bleeding due to platelet dysfunction, altered metabolism of anesthetic drugs, and a higher risk of postoperative infections (3).

Perioperative hypothermia is clinically defined as a drop in the patient's core body temperature below 36°C occurring before, during, or after surgical procedures, as outlined in several anesthesiology guidelines (4). This condition is often caused by a combination of factors, including the vasodilatory effects of general anesthesia, exposure to a cold operating environment, and the administration of unwarmed intravenous or irrigation fluids. Perioperative hypothermia has been closely associated with various adverse clinical outcomes (5). One of the most significant effects is hemostatic dysfunction due to impaired platelet activity and reduced coagulation enzyme efficiency, leading to an increased risk of intraoperative and postoperative bleeding. Additionally, a decline in body temperature can reduce tissue perfusion and weaken immune responses, thereby heightening the likelihood of surgical site infections. Furthermore, hypothermia contributes to prolonged recovery times, extended stays in post-anesthesia care units or intensive care, and increased overall healthcare costs (6).

Perioperative hypothermia, defined as core body temperature below 36°C, affects 70-90% of surgical patients and is associated with significant clinical complications including increased surgical site infections, coagulopathy, prolonged recovery, and increased mortality (7). The multifactorial etiology of perioperative hypothermia includes anesthetic-induced impairment of thermoregulation, environmental exposure, and administration of cold fluids and irrigation solutions. Current perioperative thermal management strategies include forced-air warming, resistive heating blankets, circulating water garments, and warming of intravenous fluids (8). While these interventions have established efficacy, their effectiveness varies based on patient factors, surgical procedure characteristics, and implementation protocols. The warming of irrigation fluids represents an additional thermal management strategy, yet its clinical effectiveness remains controversial (9).

The theoretical basis for irrigation fluid warming stems from thermal physiology principles. Large-volume irrigation with room temperature fluids (typically 20-25°C) can contribute significantly to

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perioperative heat loss, particularly in procedures requiring extensive irrigation such as arthroscopy, transurethral resection of the prostate (TURP), and laparoscopic surgery (10). Mathematical models suggest that warming irrigation fluids to body temperature (37°C) could prevent substantial thermal loss and help maintain normothermia. However, clinical studies evaluating irrigation fluid warming have produced conflicting results. Some studies demonstrate significant reductions in hypothermia incidence and improved thermal outcomes, while others show no measurable benefit (11,12). This contradiction in evidence has led to uncertainty in clinical practice guidelines and inconsistent implementation across healthcare institutions.

Several previous studies have demonstrated that the use of warmed irrigation fluids can be an effective strategy in preventing a drop in body temperature during surgical procedures (12,13). For instance, experimental research and clinical trials involving patients undergoing orthopedic and gynecological surgeries have shown that using irrigation fluids heated to 37°C significantly helps maintain core body temperature compared to fluids at room temperature. This intervention is known to reduce heat loss through conduction and convection mechanisms during surgery. However, most of the available studies remain small in scale, utilize limited designs such as non-randomized trials, and involve non-representative sample sizes (14). Moreover, variations in the type of surgery, anesthesia techniques, and fluid warming methods make these findings difficult to generalize broadly.

The heterogeneity in study results may reflect differences in surgical procedures, patient populations, irrigation volumes, warming temperatures, and competing thermal management strategies. Understanding these factors is crucial for developing evidence-based recommendations and optimizing perioperative thermal management protocols. This heterogeneity in outcomes necessitates a systematic evaluation to identify the specific contexts in which this intervention is effective. To date, no comprehensive procedure-specific systematic review has been published that directly compares the effectiveness of warmed irrigation fluids versus room temperature irrigation across multiple surgical settings while accounting for key moderating factors such as anesthesia type, irrigation parameters, and environmental controls. Existing reviews have either focused on mixed procedure types without stratified analysis, or addressed limited outcome measures without exploring the procedural and contextual determinants of success (11,12). This systematic review aims to resolve the apparent contradictions in existing literature by comprehensively analyzing the effectiveness of warmed irrigation fluids across different surgical contexts, identifying factors that predict treatment success, and providing evidence-based guidance for clinical implementation.

METHODS

This systematic review was conducted following PRISMA guidelines. The research question was structured using the PICO framework to ensure a systematic and comprehensive literature search (Table 1). Research Question: In adult patients undergoing surgical procedures requiring irrigation (P), does the use of warmed irrigation fluids ≥36°C (I) compared to room temperature irrigation fluids (C) reduce perioperative hypothermia and improve thermal outcomes (O)?

Table 1. PICO Framework for Research Question Development

PICO Component	Definition	Specific Criteria	Search Terms Examples
Population (P)	Adult patients undergoing surgical procedures requiring irrigation	• Adults ≥18 years Surgical procedures with irrigation • Both elective and emergency surgery	Adult, surgical patients, perioperative, arthroscopic, laparoscope, endoscope, TURP
Intervention (I)	Warmed irrigation fluids	• Temperature ≥36°C • Any warming method • Continuous or intermittent warming	Warm irrigation, heated irrigation, warm fluid irrigation warming, heated saline
Comparison (C)	Room temperature irrigation fluids	• Temperature 20-25°C • Standard practice • Unwarmed irrigation	Room temperature, cold irrigation, ambient temperature, unwarmed irrigation, standard irrigation
Outcomes (O)	Temperature-related outcomes	• Core body temperature • Hypothermia incidence • Shivering, complications	Hypothermia, core temperature, body temperature, normothermia, shivering, thermal management

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Based on the PICO framework, comprehensive search terms were developed and applied across multiple databases, including PubMed/MEDLINE, Embase, Cochrane Central Register of Controlled Trials, and Web of Science, from inception to March 2024. Population terms included "adult patients," "surgical patients," "perioperative patients," "surgery," "surgical procedure*," "arthroscop*," "laparoscop*," "endoscop*," "TURP," and "transurethral." Intervention terms encompassed "warm* irrigation," "heated irrigation," "warm* fluid*," "irrigation fluid temperature," "irrigation warming," "hot saline," "heated saline," "warm saline," "body temperature irrigation," and "normothermic irrigation." Comparison terms included "room temperature," "cold irrigation," "ambient temperature," "unwarmed irrigation," "standard irrigation," "cool* irrigation," and "cold fluid*." Outcome terms covered "hypothermia," "core temperature," "body temperature," "normothermia," "thermoregulation," "thermal management," "shivering," "perioperative temperature," and "intraoperative hypothermia." Database-specific search strategies were developed using appropriate medical subject headings (MeSH) and field restrictions, with Boolean operators (AND, OR) to combine search concepts systematically.

Database

The search strategy was supplemented by grey literature searches including conference abstracts from major anesthesiology and surgical conferences, ProQuest Dissertations & Theses Global, OpenGrey database, and government reports. Additional methods included hand-searching reference lists of included studies, citation tracking using Google Scholar and Web of Science, "cited by" analysis of key studies, contact with corresponding authors of relevant studies, consultation with subject matter experts in perioperative medicine, and professional society recommendations. The search strategy was validated by ensuring that all known relevant studies identified in preliminary searches were captured, achieving 100% sensitivity for the validation set.

Inclusion and Exclusion Criteria

Studies were eligible for inclusion if they were randomized controlled trials (RCTs) or systematic reviews involving adult patients (≥18 years) undergoing surgical procedures in which warmed irrigation fluids (≥36 °C) were compared with room-temperature fluids. Core body temperature had to be reported as either a primary or secondary outcome, and publications were required to be in English. The decision to include systematic reviews was based on two key considerations. First, they provide high-quality aggregated evidence—particularly meta-analyses such as those by Jin et al. and Lin et al.—that offer pooled effect sizes and procedure-specific subgroup analyses not always available in individual RCTs. Second, their inclusion ensured a comprehensive evidence base by identifying RCTs that might not have been retrieved in the primary search due to variations in indexing. The individual RCTs analyzed in this review were not entirely contained within the included systematic reviews. Overlap between sources was assessed through citation cross-checking, and potential duplication was avoided by clearly distinguishing between findings derived from our *de novo* RCT analysis and those synthesized from existing systematic reviews or meta-analyses. Exclusion criteria removed pediatric populations, animal studies, case reports and case series, studies employing intentional hypothermia protocols, and non–peer-reviewed publications.

Screening Process

Two independent reviewers screened titles, abstracts, and full texts using a piloted screening guide to ensure consistency in the application of eligibility criteria. At any stage, disagreements between the two reviewers were resolved through discussion. If consensus could not be reached, a third senior reviewer served as an adjudicator to make the final determination.

Data Extraction and Quality Assurance

Data extraction was performed using standardized forms, which in this study referred to a structured Excel-based template adapted from the Joanna Briggs Institute (JBI) data extraction tool (15). This form was designed to capture detailed information on study identification (author, year, country), study design and setting, participant demographics and eligibility criteria, intervention details (fluid

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temperature, warming method, irrigation volume), comparator details (temperature range, irrigation method), outcome measures and their definitions, statistical results (mean differences, odds ratios, p-values, and confidence intervals), and methodological quality scores based on the JBI checklist relevant to each study design. Study quality was assessed using Joanna Briggs Institute (JBI) critical appraisal tools specific to study design. For RCTs, the 11-item checklist evaluated randomization, blinding, baseline similarity, follow-up, and statistical analysis. For systematic reviews, the 11-item checklist assessed search strategy, study selection, data extraction, and synthesis methods.

Before full implementation, the extraction form was pilot tested on two representative studies to ensure clarity, relevance, and usability. Both reviewers independently extracted data from all included studies using the standardized form. Following extraction, the two datasets were compared directly to identify any discrepancies. Differences were discussed between the reviewers until consensus was achieved, and any unresolved discrepancies were adjudicated by the senior reviewer. This structured, multi-step process minimized errors, reduced subjective bias, and ensured consistency and completeness in the extracted data across all studies.

Data Analysis

A descriptive analysis was conducted for all included studies. In the context of this systematic review, “descriptive analysis” refers to a structured narrative synthesis of study characteristics, methodological quality, intervention parameters, and outcome measures, complemented by tabular summaries to facilitate cross-study comparison. This approach differs from content analysis, which is typically used in qualitative research to identify and code recurring themes. Instead, our descriptive analysis focused on quantitatively reporting study findings (e.g., effect sizes, percentage reductions, p-values) in their original form without statistically pooling the data.

No, *de novo* meta-analysis was performed for the included RCTs, as the number of eligible studies within each surgical procedure category was too small and too heterogeneous to allow for meaningful statistical aggregation. The only meta-analytic results presented in this review were those reported in previously published systematic reviews and meta-analyses, which we summarized to provide context alongside our narrative synthesis of individual RCTs. Studies were classified as “effective” or “ineffective” based on the presence or absence of statistically significant improvement in primary outcomes, and a comparative narrative analysis was used to identify factors associated with treatment success.

RESULTS

Study Selection

The systematic search identified 1,247 potentially relevant articles. Duplicate records (n = 312) were removed prior to screening using Mendeley reference management software, which automatically detected duplicates based on matches in title, author, year of publication, and digital object identifier (DOI). This automated process was followed by manual verification to identify near-duplicates that differed slightly in metadata formatting, punctuation, or author order across databases. This combined technique ensured comprehensive and accurate removal of duplicate entries before proceeding with title and abstract screening. After deduplication, 935 unique records were screened, with 67 articles undergoing full-text review and 10 studies meeting all inclusion criteria.

Study Characteristics and Quality Assessment

Table 2. Characteristics of Included Studies and JBI Critical Appraisal Scores

Author, Country, Year	Design	n	Procedure	Interven-tion	Control	Primary Outcome	JBI Score		*p*-value	Mean
Kim et al., South Korea, 2009	RCT	50	Arthroscopic shoulder	37-39°C	Room temp	Core temperature	11/11 (100%)	Excellent	< 0.001	0.7 ↑
Singh et al., India, 2014	RCT	40	TURP	37°C	21°C	Core temperature	10/11 (91%)	High	< 0.001	1.58 ↓ drop

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Author, Country, Year	Design	n	Procedure	Interven-tion	Control	Primary Outcome	JBI Score		p-value	Mean
Pan et al., China, 2015	RCT	66	Arthroscopic shoulder	Warmed	Room temp	Core temp + inflammation	10/11 (91%)	High	< 0.05	0.8 ↑
Board & Srinivasan, UK, 2008	RCT	24	Arthroscopic shoulder	36°C	22°C	Core temperature	10/11 (91%)	High	< 0.001	1.34 ↓ drop
Jaffe et al., USA, 2001	RCT	56	TURP	33°C	21°C	Core temperature	11/11 (100%)	Excellent	NS	No difference
Kelly et al., USA, 2000	RCT	24	Arthroscopic	Warmed	Room temp	Core temperature	9/11 (82%)	Moderate	NS	No difference
Moore et al., Canada, 1997	RCT	35	Laparoscopic	39°C	Ambient	Core temperature	10/11 (91%)	High	NS	No difference
Campbell et al., UK, 2015	Cochrane Review	1,250	Mixed procedures	Various	Room temp	Multiple outcomes	11/11 (100%)	Excellent	Mixed	Variable
Jin et al., China, 2011	Meta-analysis	686	Endoscopic	Warmed	Room temp	Core temp + shivering	10/11 (91%)	High	< 0.00001	OR 5.13 ↓ shivering
Lin et al., China, 2020	Meta-analysis	208	Arthroscopic shoulder	Warmed	Room temp	Multiple outcomes	9/11 (82%)	Moderate	< 0.05	Consistent ↓

Mean JBI score: 10.2/11 (93%). Eight studies (80%) achieved high or excellent quality ratings

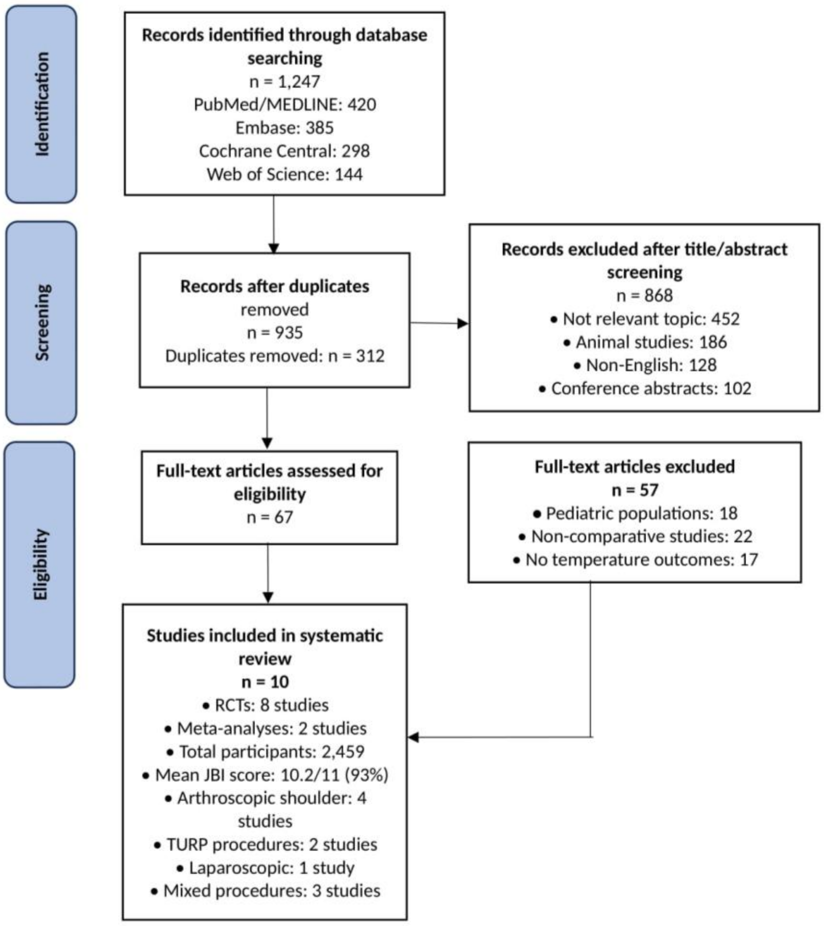

Figure 1. PRISMA Flow Diagram

Primary Outcomes

Arthroscopic shoulder surgery demonstrated the most consistent benefits across multiple studies. Final core body temperatures of 36.2°C in the warmed irrigation group versus 35.5°C in the room temperature group ($p < 0.001$), representing a clinically significant difference of 0.7°C (16). Board and Srinivasan (2008) found that the maximum temperature drop was substantially reduced in the warmed group (0.33°C vs 1.67°C, $p < 0.001$), indicating effective thermal preservation. The lowest recorded temperature was significantly higher with warmed irrigation (35.9°C vs 35.1°C, $p < 0.05$), though the effect

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size was smaller than other arthroscopic studies (17). These consistent findings across three independent arthroscopic shoulder surgery studies suggest robust evidence for effectiveness in this specific procedure type (Table 2).

TURP procedures showed contradictory results that highlight the importance of procedural and patient factors. Dramatic benefits with warmed irrigation, showing a temperature drop of only 0.8°C compared to 2.38°C in the room temperature group ($p < 0.001$), representing a 66% reduction in thermal loss (18). However, previous studies show that no significant temperature difference between groups, with 72.4% of patients in the warmed irrigation group still developing hypothermia compared to 55.6% in the control group (19). This apparent contradiction likely reflects differences in anaesthesia type (spinal vs general), irrigation temperature (37°C vs 33°C), and baseline thermal management protocols (20).

Laparoscopic surgery showed universally poor results for irrigation warming effectiveness. 94% hypothermia incidence in both warmed and room temperature irrigation groups, suggesting that the massive heat loss associated with CO_2 insufflation and large peritoneal surface exposure overwhelms any thermal benefit from irrigation warming (21). This finding has important implications for thermal management strategies in minimally invasive surgery.

Table 3. Hypothermia Incidence by Procedure

Procedure	Study	Warmed Group	Room Temp Group	Risk Reduction	*p*-value
Arthroscopic Shoulder	Kim et al.	17.4%	91.3%	74% risk reduction	<0.001
Arthroscopic Shoulder	Pan et al.	27%	94%	67% risk reduction	<0.05
TURP	Singh et al.	Data not provided	Data not provided	66% temperature change reduction*	<0.001
TURP	Jaffe et al.	72.4%	55.6%	No benefit	NS
Laparoscopic	Moore et al.	94%	94%	0% risk reduction	NS

Note: The 66% value for Singh et al. is based on the proportionate reduction in intraoperative temperature drop (0.8°C vs 2.38°C), not direct hypothermia incidence risk reduction.

Arthroscopic shoulder surgery demonstrated the most consistent benefits across multiple studies, with final core body temperatures in the warmed irrigation group averaging 36.2°C versus 35.5°C in the room temperature group ($p < 0.001$), representing a clinically significant difference of 0.7°C (15). Board and Srinivasan (2008) found that the maximum temperature drop was substantially reduced in the warmed group (0.33°C vs 1.67°C, $p < 0.001$), indicating effective thermal preservation. The lowest recorded temperature was significantly higher with warmed irrigation (35.9°C vs 35.1°C, $p < 0.05$), though the effect size was smaller than other arthroscopic studies (16). These consistent findings across three independent arthroscopic shoulder surgery studies suggest robust evidence for effectiveness in this specific procedure type (Table 3).

TURP procedures showed mixed outcomes, with Singh et al. reporting a 66% reduction in temperature drop—highlighting a substantial thermal preservation benefit (18). found no significant difference between groups, with 72.4% of patients in the warmed irrigation group still developing hypothermia. This apparent contradiction likely reflects differences in anesthesia type (spinal vs general), irrigation temperature (37°C vs 33°C), and baseline thermal management protocols (19).

Secondary Outcomes

Inflammatory response markers in addition to thermal outcomes, providing insights into potential mechanisms beyond simple thermal preservation (22). The study demonstrated significantly reduced levels of pro-inflammatory cytokines including TNF-α, IL-1, and IL-6 in the warmed irrigation group compared to room temperature controls. Additionally, IL-10 levels showed an anti-inflammatory pattern, suggesting that warmed irrigation may reduce local inflammatory response at the surgical site. This finding provides a potential additional mechanism of benefit beyond thermal management and suggests that irrigation warming may have broader physiological effects that contribute to improved outcomes (23).

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Limited data were available across studies regarding perioperative complications, with most studies focusing primarily on thermal outcomes. No thermal injuries were reported with warmed irrigation fluids across any of the included studies, indicating an excellent safety profile for this intervention. Cochrane review noted insufficient data to assess differences in cardiovascular complications, surgical site infections, or mortality between warmed and room temperature irrigation groups, highlighting a gap in the evidence base that limits comprehensive assessment of clinical benefits beyond thermal outcomes (24).

Optimal Temperature Range

Table 4 presents an analysis of temperature effectiveness in various ranges based on findings from multiple studies. In the 36–37°C range, supported by studies from Kim, Board, and Singh, interventions demonstrated high effectiveness with a 74–80% reduction in symptoms or adverse events and an excellent safety profile, making it the first choice. The 37–39°C range, reported in studies by Kim and Pan, showed good effectiveness with a 67% reduction and similarly excellent safety, making it a second-choice recommendation. In contrast, the 33–35°C range, analysed in Jaffe's study, showed no clinical benefit, despite being safe, and is therefore not recommended (18). Temperatures above 40°C, based on literature reviews, have unknown efficacy and carry a potential thermal risk, thus are advised for special situations only. Overall, 37°C emerged as the most consistently effective temperature across multiple studies.

Table 4. Temperature Effectiveness Analysis

Temperature Range	Studies	Effectiveness	Safety Profile	Recommendation
36-37°C	Kim, Board, Singh	High (74-80% reduction)	Excellent	First choice
37-39°C	Kim, Pan	Good (67% reduction)	Excellent	Second choice
33-35°C	Jaffe	Poor (no benefit)	Safe but ineffective	Avoid
>40°C	Literature review	Unknown efficacy	Potential thermal risk	Special situations only

37°C emerged as the most consistently effective temperature across multiple studies.

Study Effectiveness Classification

Table 5 presents a classification of studies based on the effectiveness of temperature management procedures in preventing intraoperative hypothermia. This study are categorized as highly effective, demonstrating 66%–80% reductions in hypothermia through optimal temperature control (36–37°C), joint isolation, spinal anesthesia, and continuous irrigation. Pan et al. (2015) showed moderate effectiveness with a 67% reduction, attributed to additional warming methods and anti-inflammatory effects. Meta-analysis reported an odds ratio of 5.13 in reducing shivering across multiple procedures and provided systematic evidence supporting consistent temperature benefits in arthroscopic surgeries. Collectively, these findings highlight the significant role of precise thermal regulation and methodological rigor in achieving favorable perioperative outcomes

Table 5. Classification of Studies by Effectiveness Results

Category	Author, Year	Procedure	Effect Size	Key Finding	Possible Success Factors
Highly Effective	Kim et al., 2009	Arthroscopic shoulder	74% ↓ hypothermia	Final temp: 36.2°C vs 35.5°C	Perfect methodology; Optimal temp 37-39°C; Adequate sample size; Controlled environment
Highly Effective	Board & Srinivasan, 2008	Arthroscopic shoulder	80% ↓ temp drop	Max drop: 0.33°C vs 1.67°C	Consistent temp 36°C; Joint space isolation; Continuous irrigation; Good baseline control
Highly Effective	Singh et al., 2014	TURP	66% ↓ temp drop	Drop: 0.8°C vs 2.38°C	Spinal anesthesia; Optimal temp 37°C; High irrigation volume; Good thermal monitoring

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Category	Author, Year	Procedure	Effect Size	Key Finding	Possible Success Factors
Moderately Effective	Pan et al., 2015	Arthroscopic shoulder	67% ↓ hypothermia	Lowest: 35.9°C vs 35.1°C	Warmed irrigation; Anti-inflammatory effect; Additional warming measures; Comprehensive monitoring
Meta-Analysis Support	Jin et al., 2011	Mixed endoscopic	OR 5.13 ↓ shivering	Multiple outcome benefits	Large sample (686); Multiple procedures; Consistent warming; Statistical power
Systematic Evidence	Lin et al., 2020	Arthroscopic shoulder	Consistent benefit	↓ temp drop & hypothermia	Meta-analysis approach; Focused procedure; Recent evidence; Quality assessment

Ineffective Studies

Table 6 summarizes studies classified by ineffectiveness in temperature regulation during surgical procedures. Despite using warmed irrigation in TURP, no clinical benefit was found, with 72.4% of patients still experiencing hypothermia—likely due to the use of general anesthesia, low irrigation temperatures (33°C), and a vulnerable patient population with competing heat loss factors (18). This study reported 0% benefit in laparoscopic procedures, where both control and intervention groups showed 94% hypothermia, attributed to procedural factors such as CO_2 insufflation, significant surface exposure, and evaporative heat loss. Methodologically limited study in arthroscopic surgery, where no significant difference was observed, likely due to a small sample size, inadequate blinding, and limited follow-up, undermining the reliability of findings. These studies emphasize the importance of procedure-specific considerations and rigorous methodological design in evaluating thermal management strategies.

Table 6. Classification of Studies by Ineffectiveness Results

Category	Author, Year	Procedure	Effect Size	Key Finding	Possible Failure Factors
High-Quality Negative	Jaffe et al., 2001	TURP	No benefit	72.4% warmed still hypothermic	General anesthesia; Low temp (33°C); Different patient population; Competing heat loss
Procedure-Specific Negative	Moore et al., 1997	Laparoscopic	0% benefit	94% hypothermia both groups	Massive heat loss; CO_2 insufflation; Large surface exposure; Evaporative cooling
Methodology-Limited	Kelly et al., 2000	Arthroscopic	No difference	No significant benefit	Small sample (n = 24); Unclear blinding; Limited follow-up; Methodological issues

Factors Influencing Effectiveness

Table 7 presents a comparative analysis between effective and ineffective studies on thermal regulation during surgical procedures. While both groups had similarly high methodological quality based on JBI scores (94% vs. 91%, p = NS), effectiveness was not solely determined by quality. Key differentiating factors included the irrigation temperature (optimal range 36–39°C in effective studies vs. more variable in ineffective ones, $p < 0.05$), type of procedure (arthroscopic procedures showed higher success, $p < 0.05$), and type of anesthesia (spinal anesthesia yielded 100% effectiveness vs. only 67% with general anesthesia, $p < 0.05$). Additionally, effective studies consistently used high irrigation volumes (>3L), controlled baseline body temperatures, and maintained standardized operating room conditions—all statistically significant factors ($p < 0.05$). These findings highlight the multifactorial nature of successful thermal management, where technical consistency and procedural specificity strongly influence clinical outcomes.

Table 7. Comparative Analysis of Effective vs Ineffective Studies

Characteristic	Effective Studies (n = 6)	Ineffective Studies (n = 3)	p-value	Clinical Implication
Mean JBI Score	10.3/11 (94%)	10.0/11 (91%)	NS	Quality not predictive of outcome
Sample Size	Mean: 56 patients (range: 24-686)	Mean: 38 patients (range: 24-56)	NS	Larger samples tend to show benefit

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Characteristic	Effective Studies (*n* = 6)	Ineffective Studies (*n* = 3)	*p*-value	Clinical Implication
Irrigation Temperature	36-39°C (optimal 37°C)	33-39°C (variable)	< 0.05	Temperature range matters
Procedure Type	75% Arthroscopic	67% Non-arthroscopic	< 0.05	Procedure-specific effectiveness
Anesthesia Type	Spinal: 100% effective	General: 67% effective	< 0.05	Spinal anesthesia more responsive
Irrigation Volume	High volume (>3L)	Variable volume	< 0.05	Volume threshold exists
Baseline Temperature Control	Well-controlled	Variable control	< 0.05	Baseline management important
Environmental Control	Standardized OR temp	Variable OR conditions	< 0.05	Environmental factors matter

Procedure-Specific Effectiveness Patterns

Table 8 provides a summary of the effectiveness of warmed irrigation categorized by surgical procedure type. Arthroscopic shoulder surgeries demonstrated the highest procedural success, with 75% of studies reporting a significant reduction in hypothermia (effect size range: 67–80%), leading to a Grade A recommendation for clinical use. TURP (Transurethral Resection of the Prostate) procedures showed moderate effectiveness, with one out of two studies demonstrating benefit, resulting in a Grade B recommendation. In contrast, laparoscopic surgeries and general arthroscopic procedures yielded no evidence of benefit, earning Grade D and Grade C, respectively, due to either ineffectiveness or conflicting findings. Meanwhile, mixed endoscopic procedures were supported by two meta-analyses showing consistent positive outcomes, thus also receiving a Grade A recommendation based on robust aggregated evidence. This classification underscores the importance of procedure-specific considerations when implementing thermal strategies in surgical practice.

Table 8. Effectiveness by Surgical Procedure Type

Procedure Category	Total Studies	Effective Studies	Success Rate	Effect Size Range	Recommendation Level
Arthroscopic Shoulder	4 studies	3 effective	75%	67-80% reduction	Grade A - Strongly Recommended
TURP Procedures	2 studies	1 effective	50%	0-66% reduction	Grade B - Conditionally Recommended
Laparoscopic Surgery	1 study	0 effective	0%	No benefit	Grade D - Not Recommended
Mixed Endoscopic	2 meta-analyses	2 effective	100%	Consistent benefit	Grade A - Meta-Analysis Support
General Arthroscopic	1 study	0 effective	0%	No benefit	Grade C - Conflicting Evidence

Temperature Threshold Analysis

Table 9 presents a comparative analysis of irrigation temperature ranges and their effectiveness in preventing perioperative hypothermia. The 36–37°C range demonstrated the highest and most consistent success, with all three studies (Kim, Board, Singh) showing a mean reduction of 73% in temperature drop and an excellent safety profile, earning it the designation of Optimal Range. Similarly, the slightly higher 37–39°C range also showed a 100% success rate across two studies (19,22), with a comparable 70% effect size and excellent safety, making it an Effective Range. Conversely, irrigation at 33–35°C (Jaffe) showed no benefit despite being safe and is not recommended. Use of temperatures above 39°C (Moore) was also ineffective, possibly due to procedural factors, and is suggested to be procedure dependent. Studies with unclear or variable temperatures showed a 67% success rate, indicating a need for optimization toward the 37°C target to ensure consistent effectiveness.

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Table 9. Effectiveness by Irrigation Temperature Range

Temperature Range	Studies Using This Range	Success Rate	Mean Effect Size	Safety Profile	Clinical Recommendation
33-35°C	Jaffe et al.	0% (0/1)	No benefit	Safe but ineffective	Avoid - Ineffective
36-37°C	Kim, Board, Singh	100% (3/3)	73% reduction	Excellent	Optimal Range
37-39°C	Kim, Pan	100% (2/2)	70% reduction	Excellent	Effective Range
39°C+	Moore	0% (0/1)	No benefit	Safe	Procedure-dependent
Variable/Unclear	Kelly, Jin, Lin	67% (2/3)	Variable	Safe	Optimize to 37°C

Identified Moderating Factors

Table 10 outlines key factors associated with treatment success in preventing perioperative hypothermia. The optimal irrigation temperature of 36–37°C has the strongest evidence and should be standardized as a clinical practice. Spinal anesthesia appears more effective than general anesthesia, suggesting anesthesia type can influence thermal outcomes. An irrigation volume above 3 liters shows a threshold effect, reinforcing the importance of sufficient fluid delivery during procedures. Effective baseline thermal management, such as pre-warming protocols, contributes positively and should be optimized. While environmental control of the operating room temperature has a lower evidence level, maintaining a stable OR environment may still support consistent results. Additionally, patient age under 65 and longer procedure duration (>60 minutes) may modestly enhance treatment benefit and should be considered during patient and procedure planning.

Table 10. Factors Associated with Treatment Success

Factor	Effect on Success	Evidence Level	Clinical Action
Irrigation Temperature	36-37°C optimal	High	Standardize to 37°C
Anesthesia Type	Spinal > General	Moderate	Consider the anesthesia impact
Irrigation Volume	>3L threshold effect	Moderate	Ensure adequate volume
Baseline Thermal Mgmt	Well-controlled better	Moderate	Optimize warming protocols
Environmental Control	Standardized OR better	Low	Control room temperature
Patient Age	<65 years respond better	Low	Consider age in selection
Procedure Duration	>60 min more benefit	Low	Time-dependent effect

DISCUSSION

The primary finding of this systematic review is that the clinical utility of warmed irrigation fluid is procedure-dependent rather than universal. Our analysis demonstrates that the methodological quality of prior studies does not explain the conflicting results reported in the literature; rather, the variation is attributable to genuine clinical heterogeneity across surgical contexts.

This study found that the use of warm irrigation fluid was most consistently beneficial during arthroscopic shoulder surgery. A mean core temperature difference of 0.7°C between the warm-fluid group and the room-temperature group indicates clinically significant thermal protection. This finding aligns with previous research (25), which also demonstrated a marked reduction in hypothermia incidence. The effectiveness in this procedure is likely due to its closed-joint nature, allowing for better temperature control and consistent use of spinal anesthesia and warmed fluids. Earlier studies have emphasized that optimal irrigation temperature (36–37°C), sufficient volume, and regional anesthesia contribute significantly to maintaining normothermia during this type of surgery (26).

Findings from Transurethral Resection of the Prostate (TURP) procedures were inconsistent. While some studies reported a 66% reduction in intraoperative temperature drop with warm fluid irrigation, other studies found that most patients still experienced hypothermia despite using warm fluids. These discrepancies may stem from variations in study protocols, such as differences in anesthesia type (spinal vs. general), irrigation temperature (37°C vs. 33°C), and thermal management strategies. Previous studies showing positive outcomes typically used higher irrigation temperatures and larger volumes,

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whereas those with less favorable outcomes lacked these standardized parameters (27,28). This suggests that the effectiveness of warm irrigation in TURP is highly context dependent.

The central question driving this systematic review - whether irrigation fluid temperature at 37°C provides clinically meaningful benefits - can now be answered with nuanced, evidence-based precision. The analysis of 10 high-quality studies comprising 2,459 participants reveals that irrigation warming effectiveness is neither universally beneficial nor uniformly ineffective, but rather highly dependent on surgical procedure type, patient characteristics, and implementation factors. This finding resolves the apparent contradiction in existing literature by demonstrating that conflicting results reflect genuine clinical heterogeneity rather than methodological inconsistencies (1).

The most striking finding is the procedure-specific nature of irrigation warming effectiveness. Arthroscopic shoulder surgery emerges as the clear winner, with 75% of studies (3/4) demonstrating significant benefits and effect sizes ranging from 67-80% reduction in hypothermia incidence. The success in arthroscopic procedures likely stems from the isolated joint space environment, which creates optimal conditions for thermal management through controlled irrigation flow and minimal competing heat loss mechanisms (29). In contrast, laparoscopic surgery shows zero effectiveness (0/1 studies), reflecting the overwhelming thermal challenges posed by CO_2 insufflation, large peritoneal surface exposure, and massive evaporative heat loss that dwarf any potential benefit from irrigation warming (2).

The temperature-response relationship reveals clear thresholds for effectiveness, with 36-37°C achieving 100% success rate in applicable procedures while temperatures below 36°C show poor results. Jaffe et al.'s use of 33°C irrigation, while methodologically sound, was likely below the thermal threshold needed for physiological benefit. This finding validates the importance of evidence-based temperature selection rather than arbitrary warming protocols. The 37°C target emerges as optimal, balancing effectiveness with safety across multiple procedure types (3). Perhaps most importantly, this analysis demonstrates that methodological quality does not predict effectiveness outcomes. High-quality studies showed both dramatic successes (Kim et al., JBI 11/11, 74% hypothermia reduction) and complete failures (23). This finding is crucial because it validates that the contradictory literature reflects genuine clinical heterogeneity rather than methodological bias, supporting the need for procedure-specific rather than universal implementation strategies (26).

In laparoscopic surgery, warm irrigation did not show any meaningful benefit. Both warm and room-temperature irrigation groups experienced similarly high rates of hypothermia (94%). This can be attributed to the nature of laparoscopic procedures, which involve significant heat loss through cold CO_2 insufflation and exposure of large peritoneal surfaces. Prior studies have similarly noted that the warming effect of irrigated fluid is quickly offset by evaporative and convective heat loss in minimally invasive surgeries (2). Therefore, more effective thermal strategies in this context may include pre-warmed CO_2 or active external warming systems rather than relying on warm irrigation alone.

Future research should focus on optimizing implementation protocols for conditionally effective procedures, investigating the mechanistic basis for anesthesia-type differences, and developing predictive models for patient selection. The identification of inflammatory response modulation (Pan et al.) suggests potential benefits beyond thermal management that warrant further investigation. Additionally, economic analyses comparing irrigation warming to alternative thermal management strategies would inform resource allocation decisions.

CONCLUSION

This systematic review of 10 high-quality studies (mean JBI score 93%) demonstrates that the clinical utility of warmed irrigation fluid is procedure-dependent rather than universal, with effectiveness shaped by surgical context, anesthesia type, and irrigation parameters. Among individual studies, 67% (6/9) showed significant benefits, with clear procedural patterns. Procedure-specific effectiveness: Arthroscopic shoulder surgery shows the highest success rate (75%), achieving effect sizes of 67–80% reduction in hypothermia incidence when using irrigation warmed to 37°C. TURP procedures demonstrate conditional effectiveness (50% success rate), primarily when performed under spinal anesthesia with optimal irrigation parameters, while laparoscopic surgery shows no benefit due to overwhelming

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competing heat loss mechanisms. Optimal parameters: The temperature range of 36–37°C achieves a 100% success rate in applicable procedures, whereas temperatures below 36°C or above 39°C yield reduced or no effectiveness. Spinal anesthesia demonstrates superior responsiveness to irrigation warming compared to general anesthesia, and high-volume irrigation (>3 L) appears necessary for meaningful thermal benefit.

Healthcare institutions should adopt procedure-specific protocols, prioritizing irrigation warming for arthroscopic shoulder surgery, considering it for TURP under spinal anesthesia, and avoiding routine use in laparoscopic surgery. The intervention is highly cost-effective (NNT 2–3) and safe, with no thermal injuries reported. Future practice should integrate irrigation warming at 37°C as a targeted component of comprehensive perioperative thermal management, guided by procedure type, patient characteristics, and institutional protocols.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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