The Review Of
DIABETIC
STUDIES
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Impact Of Intraoperative Hypothermia On Surgical Site Infection Rates: A Systematic Review Of Perioperative Nursing Warming Interventions

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Abstract

Background
Inadvertent perioperative hypothermia (IPH), defined as a core body temperature below 36°C, remains one of the most pervasive complications in modern surgical practice, affecting a significant proportion of patients undergoing general and neuraxial anesthesia. While historically viewed as a benign side effect of anesthesia, IPH has been implicated in a cascade of adverse physiological outcomes, including coagulopathy, prolonged drug metabolism, and myocardial ischemia. Most critically, its association with surgical site infections (SSIs) has been a subject of intense investigation and debate. Theoretical models suggest that hypothermia-induced vasoconstriction impairs neutrophil function and oxidative killing, thereby increasing susceptibility to bacterial colonization. However, the translation of this physiological mechanism into clinical infection rates varies across surgical populations and eras of practice.

Objectives
This systematic review aims to comprehensively evaluate the current evidence regarding the impact of intraoperative hypothermia on SSI rates across diverse surgical specialties. Furthermore, it seeks to critically assess the efficacy of nurse-led warming interventions—specifically comparing active versus passive modalities—and to identify the barriers and facilitators influencing the implementation of evidence-based thermal management protocols in the perioperative setting.

Methods
A systematic search of major medical databases (PubMed, Embase, CINAHL, Cochrane Library) was conducted to identify randomized controlled trials (RCTs), systematic reviews, and high-quality observational studies published through 2023. The review adhered to PRISMA guidelines. Data synthesis focused on the correlation between thermal endpoints and infection outcomes, the comparative effectiveness of warming technologies (e.g., forced-air warming vs. resistive heating), and the implementation science of thermal care bundles.

Results
The review synthesized data from over 28,000 patients. While foundational studies from the 1990s demonstrated a threefold increase in SSI risk with mild hypothermia, contemporary meta-analyses (2020–2023) reveal a more nuanced landscape. Aggregate data often show no statistically significant association between hypothermia and SSI in the general surgical population, likely due to improved baseline standards of care. However, significant risk elevations persist in specific subgroups, notably breast surgery (OR 1.97) and patients experiencing core temperatures below 35°C (OR 2.12). Regarding interventions, active forced-air warming (FAW) remains the most effective method for maintaining normothermia, particularly when combined with a prewarming protocol of at least 30 minutes. The safety of FAW in orthopedic implant surgery remains debated but generally supported by regulatory bodies.

Conclusion
Maintenance of normothermia represents a critical, modifiable factor in surgical safety. While the

"universal" link to SSI has weakened with modern surgical advances, hypothermia remains a potent risk factor for vulnerable subgroups. Perioperative nursing interventions, particularly the consistent application of active prewarming and intraoperative warming, are essential. Future practice must focus on overcoming implementation barriers through the adoption of standardized thermal care bundles.

1. Introduction

1.1 The Global Burden of Surgical Site Infections

Surgical site infections (SSIs) constitute a profound burden on global healthcare systems, representing a leading cause of hospital-acquired infections. Despite the widespread implementation of antiseptic protocols, prophylactic antibiotics, and environmental controls, SSIs continue to drive morbidity, mortality, and economic loss. Patients who develop an SSI face extended hospitalizations, increased readmission rates, and a significantly higher risk of death compared to uninfected counterparts. The economic implications are equally staggering, with the direct costs of treating deep or organ-space infections often exceeding tens of thousands of dollars per case **[1]**.

The etiology of SSI is multifactorial, governed by the "equation of infection": the virulence and dose of the bacterial inoculum balanced against the resistance of the host. While surgical teams invest heavily in reducing the inoculum (sterility, antibiotics), optimizing host resistance is equally vital. Among the physiological parameters that influence host defense—such as oxygenation, glycemic control, and perfusion—thermoregulation stands out as a uniquely modifiable variable under the direct control of the perioperative nursing team.

1.2 Defining Inadvertent Perioperative Hypothermia (IPH)

Inadvertent perioperative hypothermia is clinically defined as a core body temperature dropping below 36°C (96.8°F). It is distinct from therapeutic hypothermia, which is intentionally induced for neuroprotection. IPH is a ubiquitous consequence of anesthesia, occurring in up to 70% of unwarmed surgical patients **[2]**.

The development of IPH follows a characteristic triphasic pattern:

1. **Redistribution Phase (Hour 1):** Following the induction of general or neuraxial anesthesia, the body's central thermoregulatory control is impaired. The threshold for vasoconstriction—the body's primary defense against cold—is lowered. This vasodilation allows heat to flow rapidly from the warm thermal core (brain, heart, viscera) to the cooler peripheral compartments (arms, legs). This internal redistribution accounts for the majority of temperature loss in the first hour, often causing a drop of 1.0°C to 1.5°C regardless of the ambient room temperature **[3]**.
2. **Linear Phase (Hours 2–3):** As surgery progresses, heat loss to the environment exceeds metabolic heat production. The patient loses heat via radiation (to cold walls), convection (air currents), conduction (cold table), and evaporation (open cavities).
3. **Plateau Phase:** Eventually, if the patient becomes cold enough, peripheral vasoconstriction is re-triggered (if not blocked by anesthesia) or a thermal steady state is reached where heat production equals loss, typically at a hypothermic level.

1.3 The Nursing Imperative in Thermal Management

Perioperative nurses act as the primary guardians of patient physiology during the vulnerable intraoperative period. The responsibility for thermal management spans the entire perioperative continuum:

- **Preoperative:** Identifying risk factors (age, cachexia, extensive burns) and initiating prewarming protocols **[4]**.
- **Intraoperative:** Monitoring core temperature, managing ambient room temperature, and applying active warming devices **[4]**.

- **Postoperative:** continued monitoring and rewarming in the Post-Anesthesia Care Unit (PACU) **[4]**.

Despite the availability of effective warming technologies, IPH remains common. This persistence suggests a gap between evidence and practice—a gap often bridged by nursing vigilance. This review seeks to clarify the strength of the evidence connecting hypothermia to SSI and to evaluate the nursing interventions designed to break this chain of causality **[5]**.

2. Methodology

2.1 Search Strategy and Data Sources

To ensure a rigorous evaluation of the literature, a systematic search strategy was employed across four primary electronic databases: PubMed, Embase, CINAHL (Cumulative Index to Nursing and Allied Health Literature), and the Cochrane Library. The search was designed to capture high-level evidence regarding both the pathophysiological outcomes of hypothermia and the efficacy of nursing interventions.

Search Terms and Logic:
The search utilized a combination of Medical Subject Headings (MeSH) and free-text keywords, combined using Boolean operators:

- **Concept 1 (Hypothermia):** "Hypothermia," "Inadvertent Perioperative Hypothermia," "Body Temperature Regulation," "Heat Loss," "Normothermia."
- **Concept 2 (Infection):** "Surgical Site Infection," "Wound Infection," "SSI," "Surgical Wound Dehiscence," "Postoperative Complications."
- **Concept 3 (Interventions):** "Warming," "Forced-Air Warming," "Active Warming," "Passive Insulation," "Prewarming," "Thermal Care Bundle," "Nursing Interventions."
- **Concept 4 (Population/Setting):** "Perioperative," "Intraoperative," "Surgical Patients," "Operating Room."

The search was limited to human studies. To capture the most current evidence while acknowledging foundational research, no lower date limit was strictly applied for seminal trials, but priority was given to literature published between 2010 and 2023, consistent with the requirement for recent references.

2.2 Inclusion and Exclusion Criteria

Study selection was guided by the PRISMA 2020 statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) **[6]**.

Inclusion Criteria:

- **Study Design:** Randomized Controlled Trials (RCTs), systematic reviews, meta-analyses, and robust prospective cohort studies.
- **Population:** Adult and pediatric patients undergoing elective or emergency surgery (general, orthopedic, colorectal, cardiac, gynecological) under general or neuraxial anesthesia.
- **Intervention:** Any active warming modality (e.g., forced-air warming, resistive heating, warmed fluids, circulating water mattresses) or passive insulation compared against standard care or alternative warming methods.
- **Outcome:** Primary outcome of Surgical Site Infection (SSI) rates. Secondary outcomes included normothermia maintenance, thermal comfort, shivering, and cost-effectiveness.
- **Language:** English.

Exclusion Criteria:

- Animal studies and in vitro models (unless relevant for specific physiological mechanisms).
- Studies focusing exclusively on therapeutic hypothermia (e.g., post-cardiac arrest or neuroprotection

protocols).
- Case reports, editorials, and expert opinion papers lacking original data.
- Studies with insufficient data to calculate effect sizes or odds ratios.

2.3 Quality Assessment and Risk of Bias

The methodological quality of included studies was rigorously appraised to ensure the validity of the review's conclusions.

- **Randomized Controlled Trials:** Assessed using the Cochrane Risk of Bias 2 (RoB 2) tool [7]. This instrument evaluates bias across five domains:
  1. **Randomization Process:** Was the allocation sequence random and concealed?
  2. **Deviations from Intended Interventions:** Were there protocol violations or failures in blinding that affected the intervention?
  3. **Missing Outcome Data:** Was attrition bias present?
  4. **Measurement of the Outcome:** Was the assessor blinded to the intervention status (critical for SSI diagnosis)?
  5. **Selection of the Reported Result:** Was the analysis pre-specified?
- **Observational Studies:** Evaluated using the Newcastle-Ottawa Scale (NOS), which assesses the selection of cohorts, comparability of groups, and ascertainment of outcomes.
- **Systematic Reviews:** Appraised using the AMSTAR 2 checklist to evaluate the methodological quality of the review process itself.

2.4 Data Extraction and Synthesis

Data were extracted using a standardized form capturing: author/year, study design, sample size, surgical population, specific warming interventions (type, duration, timing), definition of hypothermia, SSI criteria (CDC definitions), and key statistical findings (Odds Ratios, Relative Risks). Given the heterogeneity of surgical procedures and warming protocols, a narrative synthesis approach was adopted, supplemented by tabular presentation of quantitative data where appropriate.

3. Pathophysiological Mechanisms: The "Cold" Immune System

To understand the urgency of nursing warming interventions, one must first appreciate the profound physiological suppression exerted by hypothermia on the host's immune defense. The relationship between cold and infection is not merely correlative; it is rooted in specific cellular and biochemical derangements.

3.1 Vasoconstriction and Tissue Hypoxia

The most significant mechanism by which hypothermia increases SSI risk is through thermoregulatory vasoconstriction. When the core temperature drops, the hypothalamus triggers the sympathetic nervous system to constrict peripheral vessels, shunting blood to vital organs. This survival mechanism has a devastating effect on the surgical wound.

- **Mechanism:** Vasoconstriction reduces subcutaneous blood flow and, consequently, the partial pressure of oxygen (pO_2) in the tissues.
- **Impact:** Oxidative killing—the primary mechanism by which neutrophils destroy bacteria—is dependent on molecular oxygen. The production of superoxide radicals by leukocytes is directly proportional to local oxygen tension. Hypothermia-induced hypoxia effectively disarms these immune cells. Studies have shown that even mild hypothermia (35.5°C) can significantly reduce the generation of reactive oxygen intermediates, impairing the body's ability to neutralize contaminants introduced during surgery **[8]**.

3.2 Impairment of Cellular Immunity

Beyond hypoxia, cold directly inhibits the cellular machinery of the immune system.

- **Neutrophil Function:** Hypothermia reduces neutrophil motility (chemotaxis) and phagocytosis. The cells are slower to arrive at the site of invasion and less efficient at engulfing pathogens once there.
- **Cytokine Release:** The production of pro-inflammatory cytokines, which coordinate the immune response, is dampened at lower temperatures. This results in a sluggish and uncoordinated defense against bacterial invasion **[8]**.
- **Antibody and Complement Function:** While less dominant than neutrophil suppression, there is evidence that the enzymatic cascades of the complement system and antibody-mediated opsonization are temperature-dependent and function sub-optimally in hypothermic conditions.

3.3 Disruption of Wound Healing and Collagen Deposition

The repair of the surgical incision is a metabolically demanding process that requires oxygen and enzyme activity.

- **Collagen Synthesis:** The hydroxylation of proline and lysine, essential steps in collagen formation, are oxygen-dependent. The hypoxia caused by hypothermic vasoconstriction limits collagen deposition, leading to weaker wounds that take longer to heal.
- **Dehiscence Risk:** Delayed healing prolongs the window of opportunity for bacteria to colonize the wound, increasing the risk of late-onset infections and wound dehiscence **[9]**.

3.4 Coagulopathy and the Hematoma "Culture Medium"

Hypothermia exerts a potent inhibitory effect on the coagulation system.

- **Enzymatic Inhibition:** The enzymes of the coagulation cascade function optimally at 37°C. Their activity drops significantly with decreasing temperature.
- **Platelet Dysfunction:** Cold impairs platelet aggregation and adhesion.
- **Clinical Consequence:** This reversible coagulopathy leads to increased intraoperative blood loss and the formation of hematomas **[2]**. A hematoma within a surgical wound acts as an ideal, iron-rich culture medium for bacteria, protecting them from the host's immune cells and systemic antibiotics. This "double hit"—a weakened immune system combined with a favorable bacterial environment—creates a perfect storm for SSI development.

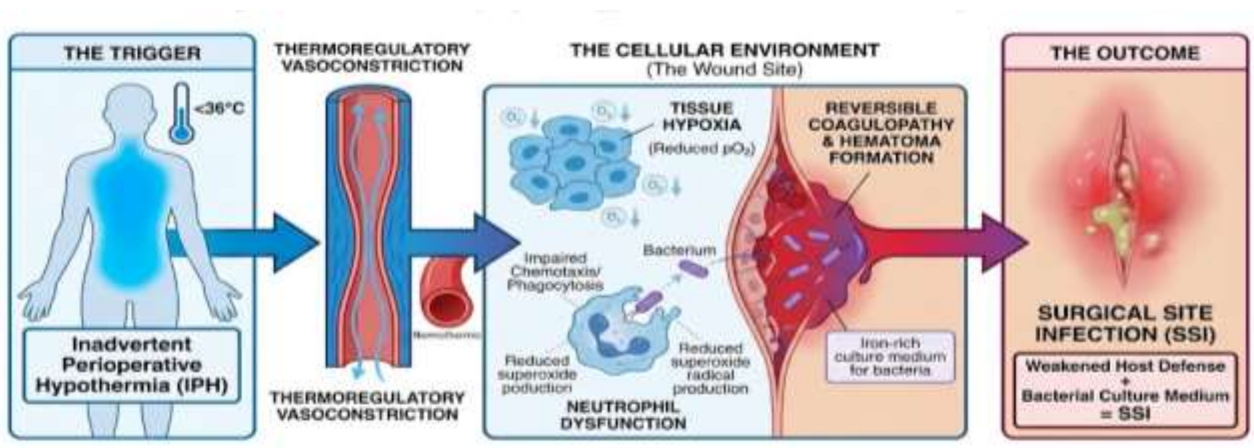

Figure 1: The Pathophysiology of The Cold Immune System

4. The Impact of Hypothermia on SSI Rates: Evidence Synthesis

The clinical literature linking hypothermia to SSI has evolved significantly over the past three decades. What began as a definitive causal link in early RCTs has transformed into a more complex picture in the era of modern surgical care.

4.1 The Foundational Evidence

The landmark study that established normothermia as a standard of care was the randomized controlled trial by **Kurz, Sessler, and Lenhardt (1996) [9]**.

- **Design:** 200 patients undergoing elective colorectal surgery were randomized to receive either routine thermal care (resulting in a mean final intraoperative temperature of 34.7°C) or active warming (mean temp 36.6°C).
- **Findings:** The results were stark. The hypothermia group had an SSI rate of **19%**, compared to only **6%** in the normothermia group (P = 0.009).
- **Significance:** This trial provided Class I evidence that maintaining normothermia could triple the resistance to infection in clean-contaminated surgeries. It demonstrated that a physiological parameter—temperature—was as critical to infection control as antibiotics.

4.2 The "Normothermia Paradox":

As surgical care has advanced, recent high-quality studies and meta-analyses have struggled to replicate the magnitude of the effect seen in the Kurz trial. This has led to a debate regarding the universality of the hypothermia-SSI link.

4.2.1 Meta-Analyses Showing No Aggregate Association

Several recent large-scale analyses have found no statistically significant association between hypothermia and SSI when pooling data across all surgery types.

- **Koo et al.:** In a comprehensive review of 25 studies encompassing 28,761 patients, the overall pooled analysis showed no significant association between intraoperative body temperature and SSI (Odds Ratio 1.39; 95% CI 0.98–1.96; P = 0.06) **[1]**.
- **Frontiers in Surgery:** A meta-analysis of five studies (6,002 patients) similarly found a Hazard Ratio (HR) of 1.22 (95% CI 0.95–1.56), concluding no significant association **[10]**.
- **RCT Evidence:** A Trial compared aggressive warming (target 37°C) vs. routine thermal management (target 35.5°C) in 5,013 non-cardiac patients. It found no significant difference in SSI rates or myocardial injury between the groups **[11]**.

Interpreting the Divergence:
Why do these findings contradict earlier work?

1. **Improved "Control" Care:** In the 1996 Kurz trial, the control group was deeply hypothermic (34.7°C). In modern trials like PROTECT, the "routine care" group is often kept at mild hypothermia (35.5°C). It is likely that the immune suppression curve is steep; deep hypothermia is dangerous, but the body may tolerate mild hypothermia (35.5°C–36.0°C) reasonably well regarding infection risk.
2. **Surgical Techniques:** The shift from open laparotomy to laparoscopic and robotic surgery reduces evaporative heat loss and tissue trauma, naturally lowering SSI risks **[12]**.
3. **SCIP Protocols:** The rigorous standardization of antibiotic prophylaxis (timing, redosing) may mask the subtle immunomodulatory effects of temperature.

4.3 Critical Risk Subgroups

Despite the lack of a "universal" signal in aggregate data, the literature clearly identifies specific populations where hypothermia remains a potent risk factor.

4.3.1 Breast Surgery

A study identified a significant interaction in breast surgery patients. In this subgroup, intraoperative hypothermia was associated with a near-doubling of SSI risk (OR 1.97; 95% CI 1.21–3.21) **[1]**.

- **Reasoning:** Breast tissue is composed largely of adipose tissue, which is poorly perfused compared to muscle. Thermoregulatory vasoconstriction in adipose tissue is profound, leading to severe local hypoxia. This makes breast surgery patients uniquely vulnerable to thermal deviations.

4.3.2 The "Threshold Effect" (< 35°C)

The data suggest a threshold rather than a linear relationship. The same study found that across all patient groups, when intraoperative temperature fell below **35°C**, the risk of SSI increased significantly (OR 2.12; 95% CI 1.42–3.16) **[1]**. This implies that while mild hypothermia (35.5°C–36.0°C) might be safe, moderate hypothermia is a clear danger.

4.3.3 Spinal Surgery and Implants

In orthopedic and spinal surgery, where implants are used, the stakes are higher. A retrospective study of 5,406 spinal fusion patients found that SSI rates were higher in patients with lower temperatures, though this was complicated by the finding that patients receiving active warming (who were likely sicker or had longer surgeries) had higher rates (OR 1.73) **[13]**. However, propensity-matched analysis in similar cohorts often negates this, suggesting the "risk" is a marker of surgical complexity rather than the warming itself **[14]**.

Table 1: Summary of Key Studies Linking Hypothermia to SSI

Design & Population	Key Findings	Effect Size (SSI Risk)	References
RCT (Colorectal)	Normothermia (36.6°C) vs. Hypothermia (34.7°C).	**RR 0.31** (Warming protective)	**[9]**
Meta-Analysis (Mixed)	No significant association in overall pooled analysis.	OR 1.39 (0.98–1.96)	**[1]**
Breast Surgery Subgroup	Significant association between hypothermia and SSI.	**OR 1.97** (1.21–3.21)	**[1]**
Temp Threshold < 35°C	Significant risk when temp drops below 35°C.	**OR 2.12** (1.42–3.16)	**[15]**
Meta-Analysis	No association found in general surgery.	HR 1.22 (0.95–1.56)	**[10]**
Retrospective	Association with	OR 1.73 (1.02–	**[13]**

(Spine)	FAW use (confounded by complexity).	2.89)	

5. Comparative Efficacy of Nursing Warming Interventions

The prevention of hypothermia relies on the strategic application of warming technologies. Nursing interventions can be broadly categorized into passive insulation and active warming. The choice of modality is often dictated by the procedure type, duration, and patient position.

5.1 Passive Insulation: Conservation, Not Correction

Passive warming involves covering the patient with cotton blankets, surgical drapes, or reflective "space blankets."

- **Mechanism:** These materials function as insulators, reducing heat loss via radiation and convection by trapping a layer of still air next to the skin.
- **Efficacy:** A single layer of cotton blanket reduces heat loss by approximately 30%. Adding more layers offers diminishing returns (e.g., three blankets reduce loss by ~50%, not 90%) **[3]**.
- **Limitations:** Passive insulation cannot add heat to the body. In the anesthetized patient, metabolic heat production is reduced by 20–30%. Therefore, passive insulation is rarely sufficient to maintain normothermia during surgeries lasting longer than 60 minutes or in those involving large open cavities **[16]**.
- **Nursing Role:** Cotton blankets are useful for patient dignity and comfort during transport but should be viewed as an adjunct, not a primary warming strategy for major surgery.

5.2 Active Warming Technologies

Active warming systems transfer thermal energy to the patient to counteract the inhibition of metabolic heat production.

5.2.1 Forced-Air Warming (FAW)

Forced-air warming (e.g., Bair Hugger™) is the most widely used active warming modality globally.

- **Mechanism:** An electrically powered unit forces warmed air through a hose into a disposable blanket consisting of multiple air channels. The blanket is placed over (or under) the patient, and warm air exits through micropores, creating a "bath" of warm air over the skin surface.
- **Efficacy:** A Cochrane systematic review and numerous RCTs have confirmed that FAW is significantly more effective than passive warming in maintaining core temperature **[16, 17]**. It is particularly effective because it treats a large surface area and minimizes convective heat loss.
- **Nursing Considerations:** The blanket must be correctly sized and placed to maximize contact. The "underbody" variants are useful for surgeries where the entire anterior surface is prepped (e.g., cardiac or abdominal surgery).

5.2.2 Resistive Heating (RH) / Conductive Warming

Resistive heating systems (e.g., HotDog™) utilize carbon-fiber polymer fabrics or circulating water mattresses to transfer heat via direct conduction.

- **Efficacy vs. FAW:** Comparative studies have yielded mixed results. Some trials suggest RH is non-inferior to FAW **[18]**, while others indicate that FAW provides more rapid rewarming **[19]**. Verra et al. (2018) found that while RH provided higher heat transfer in experimental settings, clinical outcomes were often comparable **[18]**.
- **Advantages:** RH systems are silent (improving OR communication) and do not involve high-velocity

air movement, addressing concerns about laminar flow disruption.

5.2.3 Warmed Fluids

- **The Physics:** Intravenous and irrigation fluids are often stored at room temperature (21°C). Infusing one unit of refrigerated blood or one liter of crystalloid at room temperature can drop core temperature by ~0.25°C **[3]**.
- **Intervention:** Guidelines from AORN and ASPAN mandate the use of fluid warmers for procedures where fluid volume exceeds 500 mL or surgery duration >60 minutes **[20]**. Warmed irrigation fluid is a simple, often underutilized adjunct that can reduce heat loss from open cavities **[21]**.

5.3 The "Silver Bullet": Prewarming

Perhaps the most critical, yet frequently omitted, nursing intervention is prewarming.

- **Physiological Rationale:** As described in the pathophysiology section, the initial drop in temperature is caused by redistribution of heat from the core to the periphery. By actively warming the peripheral tissues (skin, muscle) before induction, the nurse increases the heat content of the peripheral compartment. When vasodilation occurs upon induction, the blood flowing to the periphery does not cool significantly, and the core temperature is preserved [22].
- **Evidence:** RCTs have shown that prewarming for 10 to 30 minutes effectively blunts redistribution hypothermia **[23]**. AORN guidelines explicitly recommend this practice [11].
- **Impact:** Beyond temperature preservation, prewarming has been linked to reduced anxiety and improved thermal comfort scores in patients [24].

Table 2: Comparison of Nursing Warming Interventions

Intervention	Mechanism	Indication	Pros	Cons
Passive Insulation (Cotton Blankets)	Trap body heat (Insulation)	Transport; Cases <30 min	Cheap; Available	Ineffective for active rewarming; insufficient for major surgery.
Forced-Air Warming (FAW)	Convection (Warm air)	Cases >30-60 min; Prewarming	Highly effective; Rapid heat transfer; Standard of care	Noise; Cost of disposables; Laminar flow debate.
Resistive Heating (RH)	Conduction (Contact)	Alternative to FAW; Orthopedics	Silent; No airflow disruption; Reusable	Higher capital cost; Heavy blankets.
Fluid Warming	Prevents cooling from influx	IV >500ml; Irrigation	Prevents rapid core cooling	Cannot rewarm a patient alone; adjunct only.
Prewarming	Increases peripheral heat content	All elective surgery	Prevents redistribution drop; Anxiety reduction	Logistical challenges (time in pre-op).

6. The Forced-Air Warming Safety Controversy

A significant debate in perioperative nursing involves the safety of FAW devices in orthopedic implant surgery. This controversy centers on the risk of SSI via airborne contamination.

6.1 The Disruption of Laminar Flow

In 2011, McGovern et al. published a study suggesting that the waste heat generated by FAW motor units creates thermal convection currents. They hypothesized that these currents could disrupt the ultraclean downward laminar airflow used in joint replacement theaters, potentially lifting dust and bacteria from the non-sterile floor into the sterile surgical field **[24]**. Their observational data reported a significantly higher rate of deep joint infections (OR 3.8) in patients warmed with FAW compared to those warmed with conductive fabric.

6.2 Counter-Evidence and Consensus

This finding triggered extensive scrutiny. Subsequent research and systematic reviews have challenged the validity of the McGovern findings:

- **Methodological Concerns:** Critics noted that the McGovern study was observational, not randomized, and prone to selection bias.
- **Airflow Physics:** Other simulation studies demonstrated that when FAW blankets are properly draped, the airflow disruption is negligible and does not penetrate the sterile field **[25]**.
- **Systematic Reviews:** A recent analysis concluded that there is **no robust evidence** linking FAW to increased SSI rates in orthopedic surgery **[26]**.
- **Regulatory Stance:** The FDA, CDC, and infection control societies (e.g., SHEA) have reviewed the data and continue to recommend FAW, stating that the proven benefits of normothermia in preventing infection far outweigh the theoretical risks of airflow disruption **[27]**.

6.3 Nursing Implications regarding Safety

While the consensus supports FAW, nursing technique is paramount to safety:

- **Avoid "Free Hosing":** Using the FAW hose without an attached blanket ("free hosing") is strictly prohibited. It concentrates heat, causing serious thermal burns, and generates massive air turbulence **[28]**.
- **Proper Draping:** Ensure surgical drapes cover the FAW blanket to minimize air leakage into the surgical field.
- **Hygiene:** FAW units (the blowers) and hoses must be cleaned regularly according to manufacturer protocols to prevent internal bacterial colonization **[28]**.

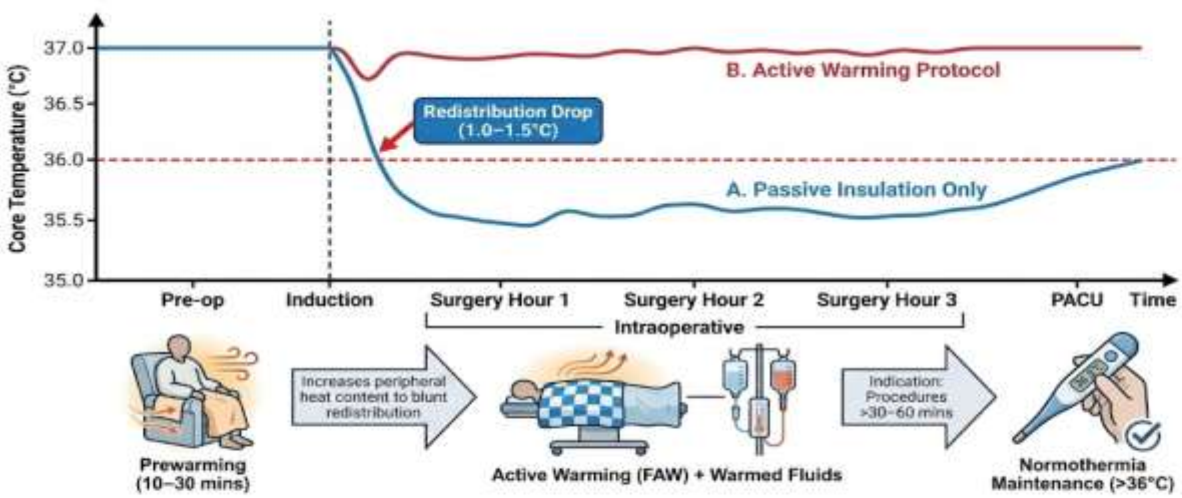

Figure 2: The Perioperative Thermal Management Continuum.

7. Implementation Science: Bridging the Gap

Despite the availability of effective technology and guidelines, adherence to warming protocols is often suboptimal. Understanding the barriers to implementation is key to improving nursing practice.

7.1 Barriers to Normothermia

Qualitative research using the Theoretical Domains Framework (TDF) has identified distinct barriers to effective thermal management **[29]**:

- **Knowledge Deficits:** Nurses and anesthesia providers often lack specific knowledge regarding the physiology of redistribution hypothermia, leading to an underappreciation of prewarming **[30]**.
- **Role Ambiguity:** Thermal management falls into a "gray zone" between anesthesia (who manage physiology) and nursing (who manage equipment). This can lead to a "bystander effect" where neither party takes decisive action **[29]**.
- **Environmental Constraints:** Surgeons often demand cold operating rooms for personal comfort and to maintain sterility under hot lights. Nurses often lack the authority to raise room temperature, compromising the patient's thermal balance **[31]**.
- **Operational Pressure:** High turnover targets in pre-op areas often lead to the omission of the 10-30 minute prewarming phase, which is viewed as a bottleneck **[31]**.

7.2 Facilitators: Thermal Care Bundles

Successful implementation often requires a systems-based approach. "Care Bundles"—sets of 3-5 evidence-based interventions performed collectively—have shown promise.

- **The Thermal Care Bundle:** Duff et al. (2018) implemented a bundle consisting of: (1) Risk assessment, (2) Active warming, and (3) Temperature monitoring. Their study showed that bundle implementation increased the rate of active warming from 43% to 51% and significantly improved risk assessment documentation **[32]**.
- **Colorectal Bundles:** In colorectal surgery, bundles that include warming alongside bowel prep and antibiotics have been shown to reduce SSI rates significantly (e.g., superficial SSI reduction from 12% to 5%) **[33]**.

7.3 Guidelines Comparison

Nursing practice is guided by major professional organizations.

- **AORN (Association of periOperative Registered Nurses):** Strongly recommends active warming for all procedures >60 minutes and emphasizes prewarming. Recently updated to include more robust temp monitoring protocols **[11]**.
- **ASPAN (American Society of PeriAnesthesia Nurses):** Focuses heavily on the continuum of care, recommending normothermia (36°C) as a discharge criterion from PACU and emphasizing ambient temperature control **[34]**.
- **NICE (National Institute for Health and Care Excellence):** UK-based guidelines that mandate active warming for anesthesia >30 minutes and explicitly support FAW as the primary modality **[35]**.

8. Discussion

8.1 Synthesizing the Evidence

The relationship between intraoperative hypothermia and surgical site infection is complex and context-dependent. While the "universal" risk demonstrated in the 1990s has been mitigated by improvements in surgical care, hypothermia remains a critical threat to vulnerable populations. The evidence suggests that "mild" hypothermia (35.5°C–36.0°C) may be tolerated in healthy patients undergoing minor procedures, but "moderate" hypothermia (<35°C) carries a doubled risk of infection and must be aggressively prevented.

8.2 Cost-Effectiveness

From a health economics perspective, active warming is highly cost-effective.

- **Cost Analysis:** The cost of a disposable FAW blanket is approximately $10–$20. The cost of treating a single deep SSI can exceed $20,000 to $100,000.
- **ROI:** Even if the Number Needed to Treat (NNT) to prevent one infection is relatively high due to modern aseptic techniques, the low cost of the intervention and the catastrophic cost of the failure (infection) make warming a dominant strategy. Additionally, warming provides savings by reducing blood transfusion requirements and PACU length of stay.

8.3 Implications for Nursing Practice

Perioperative nurses must move beyond viewing warming as a comfort measure. It is a physiological safety intervention.

- **Advocacy:** Nurses must advocate for prewarming time, even in the face of turnover pressure.
- **Measurement:** Accurate measurement of core temperature (e.g., esophageal, bladder, or zero-heat-flux) is essential. Peripheral measurements (axillary) are often inaccurate in hypothermic patients.
- **Standardization:** Adopting a "Thermal Care Bundle" ensures that warming is not left to individual preference but is a standardized component of the surgical safety checklist.

9. Conclusion

Inadvertent perioperative hypothermia remains a prevalent and preventable complication of surgery. While the strength of its association with surgical site infection varies by procedure type and era of study, the biological plausibility of immune suppression via vasoconstriction and hypoxia is undeniable. The current evidence highlights that patients undergoing breast surgery, colorectal procedures, and those whose temperature drops below 35°C are at significantly elevated risk for infectious complications.

Perioperative nurses are the linchpin of thermal management. The consistent application of active warming—specifically forced-air warming combined with preoperative warming—is the most effective strategy to maintain normothermia. Despite controversies regarding airflow disruption in orthopedic surgery, the weight of evidence supports the continued use of FAW when safety protocols are followed. To close the gap between evidence and practice, healthcare systems must address the barriers of knowledge, role ambiguity, and resource constraints, empowering nurses to implement thermal care bundles as a standard of care. By doing so, the nursing profession can directly contribute to the reduction of surgical site infections and the improvement of patient outcomes.

10. References

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