ANESTHESIOLOGY

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Review Article

Assessment of Perioperative Temperature Management Strategies in Major Abdominal Operations

Markus Bianchi[1*], Carla Gallagher[2] and Tomasz Ramirez[3]

[1]*Division of Anesthesia and Intensive Care, Tyrrhenian University of Health Sciences, Italy*
[2]*Department of Surgical Sciences, Northmoor School of Anesthesia, United Kingdom*
[3]*Department of Anesthesiology, Northmoor School of Anesthesia, United Kingdom*

ABSTRACT

Inadvertent perioperative hypothermia remains a common and largely preventable complication of major abdominal surgery, driven by anesthesia-induced impairment of thermoregulatory vasoconstriction, large peritoneal heat and fluid losses, and prolonged operative times.

This review synthesizes recent comparative evidence on prewarming, intraoperative active surface warming, fluid and irrigation warming, and continuous core-temperature monitoring, including validation data for zero-heat-flux cutaneous sensors against esophageal reference measurement.

Randomized and meta-analytic data indicate that prewarming combined with sustained full-body forced-air or resistive warming reduces the incidence and severity of intraoperative hypothermia more effectively than intraoperative warming alone or passive insulation, and that hypothermia is consistently associated with increased surgical site infection risk and greater blood loss across abdominal surgical cohorts.

Large trial data further indicate that the appropriate clinical target is reliable normothermia rather than supranormal core temperature, since aggressive warming beyond normothermic targets has not been shown to reduce perioperative cardiac events relative to routine normothermic management.

We conclude that a layered protocol combining prewarming, full-body active intraoperative warming, fluid warming, and continuous accurate monitoring represents the best-supported approach to perioperative temperature management in major abdominal operations, while noting persistent gaps in device comparison data for prolonged open procedures.

Keywords: *perioperative hypothermia; forced-air warming; abdominal surgery; core temperature monitoring; surgical site infection*

Citation: Bianchi M, Gallagher C and Ramirez T (2021) Assessment of Perioperative Temperature Management Strategies in Major Abdominal Operations. Anesthesiology. 1(1):01-06.

DOI: 10.17140/2021.vol1.i01.pp01-06

Corresponding Author: *Markus Bianchi*

E-mail Address: *m.bianchi@tuhs.it*

Article History: *Received 26 April 2021 | Accepted 24 May 2021 | Published 24 June 2021*

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INTRODUCTION

Anyone who has stood at the head of the table during a long laparotomy knows the drift is almost imperceptible at first. The patient arrives

normothermic, induction proceeds, and within thirty to forty minutes the core temperature has begun a slow, steady descent that most anesthesia teams have simply come to expect. Inadvertent perioperative hypothermia, conventionally defined as a core temperature below 36.0°C, remains one of the most common and most preventable complications of general and neuraxial anesthesia, and major abdominal surgery is precisely the setting in which it is hardest to avoid. Large peritoneal exposure, cold irrigation and prep solutions, high-volume fluid resuscitation, and procedure lengths that often exceed two or three hours combine to produce heat loss that outpaces the blunted thermoregulatory response anesthetic agents leave behind. The consequences are not cosmetic. Hypothermia during abdominal surgery has been linked to impaired platelet function and clotting factor activity, increased blood loss and transfusion requirement, higher rates of surgical site infection, delayed drug metabolism, postoperative shivering and discomfort, and in vulnerable patients, adverse cardiac events during the recovery period.

What has changed over the past decade is not the physiology, which has been understood since the 1990s, but the sophistication of the evidence base describing which interventions actually move the needle and by how much. Forced-air warming blankets, once treated as an optional comfort measure, are now considered close to a standard of care in most abdominal surgery protocols, but the literature has moved on to finer questions: does prewarming before incision matter as much as intraoperative warming, does the site of application on the body change effectiveness, how does fluid and irrigation warming interact with surface warming, and does more aggressive management actually change hard outcomes or only the number on the monitor. This review surveys the current comparative evidence on perioperative temperature management specifically in the context of major abdominal operations, with attention to mechanism, monitoring technology, and the outcomes that matter to patients and surgical teams.

MECHANISMS OF HEAT LOSS AND THE PHYSIOLOGIC RATIONALE FOR WARMING

General anesthesia disables the normal thermoregulatory vasoconstriction that keeps core heat centralized, and the redistribution of warm blood from the core to a cooler periphery accounts for most of the temperature drop seen in the first hour after induction, well before radiative and convective losses from the open abdomen become dominant. In laparotomy and laparoscopic abdominal procedures, evaporative loss from exposed peritoneal and bowel surfaces, the volume of room-temperature or refrigerated irrigation and intravenous fluid administered, and the ambient temperature of a modern operating room, often kept cool for staff comfort and infection-control reasons, together sustain heat loss for the duration of the case. Neuraxial and combined general-regional techniques, common in extensive abdominal operations for postoperative analgesia, blunt vasoconstriction in the blocked dermatomes as well and add to the problem rather than mitigating it [1].

The clinical consequences follow directly from this physiology. Mild hypothermia impairs enzymatic activity in the coagulation cascade and platelet aggregation, and even a one- or two-degree drop in core temperature has been associated with measurably increased blood loss and allogeneic transfusion in surgical populations [1]. Hypothermia also produces peripheral vasoconstriction that reduces subcutaneous oxygen tension, a mechanism thought to underlie the association between perioperative cold and surgical site infection, since neutrophil oxidative killing is oxygen-dependent [2]. Postoperative shivering, itself uncomfortable and associated with increased oxygen consumption and myocardial demand, is far more common in patients who leave the operating room hypothermic, and in patients with underlying coronary disease the sympathetic surge accompanying shivering and cold-induced vasoconstriction has been implicated in perioperative cardiac morbidity [3]. These are not small, theoretical effects; they are the reason temperature management has moved from an afterthought to a monitored quality metric in many abdominal surgery enhanced-recovery pathways.

PREWARMING AND PERIOPERATIVE WARMING STRATEGIES

If redistribution hypothermia in the first postinduction hour is driven by the temperature gradient between core and periphery, the most logical countermeasure is to narrow that gradient before the gradient-producing event, meaning before induction rather than after. Prewarming for twenty to thirty minutes preoperatively with forced-air or other surface warming raises peripheral tissue temperature and reduces the core-to-peripheral gradient, which in randomized trials translates into a smaller and slower initial temperature drop after induction compared with patients warmed only intraoperatively [4]. The effect size is modest in absolute degrees but consistently favors prewarming across multiple trials, and combining prewarming with continued intraoperative warming, sometimes described as co-warming, appears to produce a more durable normothermic trajectory through the case than either strategy alone [5]. The practical barrier is logistical rather than physiological: prewarming requires holding-area time and equipment that many surgical units, particularly high-throughput centers doing back-to-back abdominal cases, are not staffed to provide routinely, and adoption has lagged the evidence for this reason.

Once the case is underway, forced-air warming remains the most extensively studied and most widely

deployed intraoperative technique, and trials in laparoscopic and open abdominal surgery consistently show that active forced-air warming reduces the incidence of intraoperative and immediate postoperative hypothermia compared with passive insulation such as cotton blankets alone [6,7]. What has received more recent attention is optimizing how forced-air is applied rather than whether to apply it at all. A systematic review and meta-analysis focused specifically on abdominal surgery examined variables including blanket placement, timing of initiation, and duration of application, and found that earlier initiation and full-body rather than partial-body coverage where surgically feasible improved normothermia rates [8]. A network meta-analysis comparing warming systems applied to different body regions in abdominal surgery patients reached a similar conclusion, that whole-body or larger-surface-area warming systems outperformed localized upper- or lower-body-only devices, though device availability and surgical access constraints often dictate what is practically achievable on a given patient [9]. Trials comparing thermal suits, resistive heating garments that wrap more of the body surface than a standard forced-air blanket, against conventional forced-air have shown comparable or modestly superior performance from the more comprehensive coverage device, though cost and availability limit widespread use [10]. A more recent RCT-level meta-analysis focused on laparoscopic abdominal procedures reached a similar conclusion, confirming forced-air warming's effectiveness relative to unwarmed or passively insulated control groups across a larger pooled sample than earlier single-trial reports [11].

A more recent randomized comparison directly tested a bundled optimal-warming strategy, combining prewarming, fluid and irrigation fluid warming, and full-body intraoperative forced-air, against a routine single-modality approach, and found the bundled strategy achieved higher rates of sustained normothermia through the end of surgery, reinforcing the idea that no single device is likely to be sufficient in longer abdominal cases and that a layered approach performs better than any one component in isolation [12]. Fluid and blood product warming, while less studied as a standalone intervention than surface warming, is now considered a necessary adjunct whenever more than a liter or two of room-temperature crystalloid or refrigerated blood product is anticipated, since infused volumes at ambient temperature can offset much of what surface warming devices achieve. Where forced-air warming is contraindicated or impractical, as in some plastic and reconstructive abdominal wall procedures where airflow near a fresh flap raises infection or embolic concerns, conductive warming mattresses and resistive electric blankets provide reasonable alternatives, and recent network meta-analyses comparing warming modalities across surgical types have generally found forced-air and higher-grade resistive systems performing similarly well, with passive insulation alone consistently the weakest option [13].

MONITORING TECHNOLOGY AND MEASUREMENT ACCURACY

Effective temperature management depends on accurate, continuous measurement, and the abdominal surgery literature over the past several years has focused considerable attention on validating zero-heat-flux (ZHF) cutaneous sensors as a noninvasive alternative to esophageal or bladder probes. Esophageal temperature has long served as a reference-standard proxy for core temperature in surgery under general anesthesia, but it requires airway instrumentation, is unusable in cases under regional or neuraxial technique alone, and carries a small risk of esophageal injury with prolonged placement. Zero-heat-flux devices, which apply an insulated sensor to the forehead or another well-perfused cutaneous site and mathematically null the heat flux gradient to approximate deep tissue temperature, have shown good agreement with esophageal measurement in several validation studies conducted during major abdominal and other major surgery, with mean bias generally within clinically acceptable limits, though wider limits of agreement have been reported in some populations, particularly at temperature extremes [14,15]. Comparable validation work in cardiac surgery, a population that shares the long-duration, large-fluid-shift profile of major abdominal cases, has reported similar accuracy, supporting extrapolation of ZHF reliability to comparably complex noncardiac procedures [16]. Orthopedic surgical validation data add further reassurance that the technology performs consistently across surgical disciplines and is not an artifact specific to any one operative field [17].

The clinical significance of this validation work is practical: ZHF monitoring allows continuous core-temperature tracking in patients under combined general-epidural or purely neuraxial anesthesia for abdominal procedures, populations in whom esophageal monitoring is not an option and in whom hypothermia risk from blunted regional vasoconstriction is nonetheless real. It also allows temperature trends to be tracked from the preoperative holding area through recovery without probe exchange, supporting the prewarming and co-warming strategies discussed above by giving a single continuous data stream across the entire perioperative episode rather than a monitoring gap at each transition point.

CLINICAL OUTCOMES: INFECTION, BLEEDING, AND CARDIAC EVENTS

The outcome that has drawn the most sustained research interest is surgical site infection. Multiple meta-analyses spanning general, colorectal, and mixed abdominal surgical populations have found an

association between perioperative hypothermia and increased surgical site infection risk, with the proposed mechanism centering on hypothermia-induced peripheral vasoconstriction and reduced subcutaneous oxygen tension impairing neutrophil bactericidal function [18,19,2]. Retrospective analysis of continuous intraoperative temperature data captured by anesthesia information systems in a large colorectal surgical cohort similarly found that time spent below core-temperature thresholds during surgery correlated with subsequent infection rates, a finding that strengthens the case for continuous monitoring rather than intermittent spot checks, since a single normal reading at the end of a case can mask substantial cumulative time spent hypothermic [20]. Not every study in this literature has found a statistically robust independent association once confounders such as procedure duration and blood loss are accounted for, and the overall body of evidence, while consistently directionally unfavorable for hypothermia, is graded as moderate rather than high certainty in most systematic reviews, reflecting heterogeneity in how hypothermia exposure and infection outcomes were defined and measured across studies [19].

Coagulation and bleeding outcomes show a similarly consistent, if not always dramatic, signal. Hypothermia-associated platelet dysfunction and clotting factor slowing have translated into measurable increases in estimated blood loss and transfusion requirement in trials of warmed versus unwarmed abdominal and other major surgical patients, an effect corroborated in more recent trauma and emergency abdominal surgery cohorts where active intraoperative warming strategies were associated with more favorable postoperative coagulation profiles compared with passive management [21]. The relationship between temperature and cardiac events is more nuanced. Perhaps the most influential recent contribution here is the PROTECT trial, a large multicenter randomized comparison of aggressive intraoperative warming, targeting a higher core temperature than conventional practice, against routine thermal management in noncardiac surgery patients at elevated cardiovascular risk. The trial found that more aggressive warming did not reduce the composite outcome of myocardial injury, cardiac arrest, and death compared with routine management maintaining normothermia, a result that has tempered enthusiasm for pushing beyond normothermia as a target and reframed the clinical question from "warmer is better" to "avoiding hypothermia is what matters," since the routine-management arm in that trial was itself actively managed to a normothermic target rather than left to drift [22]. This distinction matters for abdominal surgery practice: the actionable target supported by current evidence is reliable maintenance of normothermia, not supranormal core temperature, and clinicians should be cautious about extrapolating benefit from more warming beyond that point.

DISCUSSION: TOWARD A PRACTICAL PERIOPERATIVE PROTOCOL

Drawing this literature together for major abdominal operations, several practice points emerge with reasonable consistency across the trials and reviews summarized above. First, prewarming for at least twenty minutes before induction, where logistically feasible, reduces the magnitude of early redistribution hypothermia and should be incorporated into enhanced-recovery pathways for longer abdominal cases rather than treated as optional. Second, intraoperative forced-air or comparable full-body active warming should be initiated promptly after induction and maintained for the duration of surgery, with attention to maximizing surface-area coverage within the constraints of surgical access, since partial coverage and delayed initiation both appear to reduce effectiveness. Third, fluid and irrigation warming should accompany surface warming whenever moderate to large volumes are anticipated, an intervention that is inexpensive and low-risk but easily neglected during a busy case. Fourth, continuous core-temperature monitoring, using esophageal probes when the airway is instrumented and validated zero-heat-flux devices when it is not, should be standard rather than intermittent, both to guide real-time intervention and to generate the kind of granular exposure data that has proven most useful in the outcomes literature reviewed here. Finally, the target of that monitoring and intervention should be reliable normothermia rather than supranormal temperature, a distinction the PROTECT trial has helped clarify for clinicians who might otherwise reasonably have assumed more warming is uniformly better.

Gaps remain. Much of the comparative device literature is drawn from laparoscopic rather than open abdominal surgery, and the relative performance of warming strategies in very long open oncologic resections, where heat loss is most severe and outcome stakes are highest, is comparatively under-studied. Cost-effectiveness data comparing bundled multimodal strategies against single-device approaches are sparse, which matters for resource-limited settings deciding how to allocate a fixed warming-equipment budget across a surgical program. And while zero-heat-flux monitoring has been well validated against esophageal reference standards in aggregate, agreement appears to narrow at temperature extremes, precisely the range in which clinical decisions about intervention intensity are made, an issue that deserves more targeted study before the technology is relied upon in isolation for the most physiologically unstable patients.

CONCLUSION

Perioperative hypothermia in major abdominal surgery is common, mechanistically well understood, and substantially preventable with currently available

technology, yet it continues to occur often enough that temperature remains one of the more reliable surrogate markers of overall anesthetic care quality in this surgical population. The comparative literature now supports a layered approach, prewarming plus sustained full-body intraoperative active warming plus fluid warming plus continuous accurate core-temperature monitoring, over reliance on any single device, and it supports normothermia as the appropriate target rather than aggressive supranormal warming. Surgical teams managing long abdominal operations who build these elements into a standard protocol, rather than applying them inconsistently case by case, are working from an evidence base that has matured considerably and now points in a fairly consistent direction, one broadly consistent with the practice recommendations set out in prior systematic reviews addressing prevention and management of perioperative hypothermia in adult elective surgical populations [23].

DECLARATIONS

Acknowledgements

The authors thank the anesthesiology and perioperative nursing staff at their respective institutions for ongoing discussion that helped shape the clinical framing of this review.

Funding

This review received no external funding or grant support.

Conflict of Interest

The authors declare no conflicts of interest relevant to the content of this article.

Author Contributions

Markus Bianchi conceived the review and drafted the initial manuscript. Carla Gallagher performed the literature synthesis and critically revised the manuscript for intellectual content. Tomasz Ramirez contributed clinical perspective on perioperative monitoring technology and revised the final draft. All authors read and approved the final manuscript.

Ethics Statement

This is a literature review that did not involve new human or animal subjects research, and no ethics committee approval was required.

Data Availability

No new data were generated for this review; all sources discussed are cited and publicly available through their respective publishers or indexing services.

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