Temperature Control and the Role of Supplemental Oxygen

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ABSTRACT

Unrecognized and untreated intraoperative hypothermia remains a common avoidable scenario in the modern operating room. Failure to properly address this seemingly small aspect of the total operative care has been shown to have profound negative patient consequences including increased incidence of postoperative discomfort, surgical bleeding, requirement of allogenic blood transfusion, wound infections, and morbid cardiac events. All of these ultimately lead to longer hospitalizations and higher mortality. To avoid such problems, simple methods can be employed by the surgeon, anesthesiologist, and ancillary personnel to ensure euthermia. Similarly, another effortless method to potentially improve surgical outcomes is the liberal use of supplemental oxygen. Promising preliminary data suggests that high-concentration oxygen during and after surgery may decrease the rate of surgical site infections and gastrointestinal anastomotic failure. The precise role of supplemental oxygen in the perioperative period represents an exciting area of potential research that awaits further validation and analysis. In this article, the authors explore the data regarding both temperature regulation and supplemental oxygen use in an attempt to define further their emerging role in the perioperative care of patients undergoing colorectal surgery.

KEYWORDS: Hypothermia, temperature regulation, supplemental oxygen, colorectal surgery

Objectives: On completion of this article, the reader should be able to summarize the importance of intraoperative normothermia and different adjuncts available to avoid hypothermia, and the role of supplemental oxygen in the perioperative period.

Surgeons spend tremendous energy and expense in efforts to improve surgical results; nevertheless, it is easy to forget about simple maneuvers that can positively impact patients' postoperative outcomes. In the operating room, adjuncts such as appropriate thermoregulation can have a profound positive influence on postoperative patient recovery. Similarly, the use of supplemental

oxygen for more than straightforward respiratory support may significantly decrease complications related to surgical incisions and anastomoses. In this article, we discuss the importance of strict temperature regulation while avoiding hypothermia in the perioperative period and the emerging role of increased supplemental oxygen to aid in improving overall patient care and outcomes.

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TEMPERATURE MONITORING AND REGULATION

Humans are able to maintain core body temperature within remarkably narrow physiologic limits; however, surgery, and specifically general anesthesia, alters this normal balance between heat loss and production by depressing the hypothalamic thermoregulatory center.¹⁻⁵ The end result, hypothermia, has been found to impact surgical outcomes adversely by increasing postoperative discomfort, incidence of surgical bleeding, requirement of allogenic blood transfusion, incidence of wound infection, and the incidence of morbid cardiac events; all ultimately leading to longer hospitalizations.^{3,6-13} Given these negative consequences, hypothermia still occurs in a majority of surgical patients, with approximately one-third of patients developing hypothermia to a temperature less than 35°C during surgery.^{14,15} The American Society of Anesthesiologists, in recognition of the importance of proper intraoperative temperature regulation, has published standards that state "to aid in the maintenance of appropriate body temperature during all anesthetics," temperature monitoring must be performed.¹⁶ Deliberate hypothermia may be beneficial in select operative settings, such as its neuroprotective role in cardiac surgery during cardiopulmonary bypass.^{17,18} However, in the setting of elective colon and rectal surgery, not only adequate monitoring, but also appropriate interventions to maintain normothermia should become standard practice in every procedure.

Several methods of intraoperative temperature measuring are available. Arguably, the gold standard for measuring core body temperature is through the pulmonary artery catheter, which allows for accurate measurement of central blood temperature.¹⁹ The disadvantage of this method is the required central access and risks associated with proper positioning of the catheter. However, in patients requiring intensive perioperative hemodynamic monitoring, pulmonary artery catheters may offer the most appropriate method of temperature monitoring. Another commonly employed method of monitoring is an esophageal probe, which is usually a thermistor or thermocouple that is incorporated into an esophageal stethoscope. Esophageal temperature readings may be affected during general anesthesia by the use of humidified gases if the probe is not inserted far enough into the esophagus.^{20,21} Temperature measurements through the urinary bladder are another reliable method of measuring core body temperature via a thermistor attached to an appropriately modified bladder catheter. Again, decreased temperature accuracy is possible, especially with low urine output and during surgical procedures in the lower abdomen.²² Finally, despite being the least reliable method of intraoperative temperature monitoring, cutaneous skin temperature monitors are the least invasive and the most commonly used.

Because of changes in ambient temperature in the operating room and cutaneous blood flow alterations during anesthesia, skin temperature measurement is the least desirable method of temperature monitoring.

Given the numerous adverse affects of hypothermia, it is imperative for the anesthesia provider, surgeon, and all members of the operating room team to be proactive in the thermal management of patients. First, maintaining proper operating room ambient temperature should be part of the initial room set-up. Operatively, technical precision such as avoiding blood loss and decreasing the time of "an open abdomen," is an obvious goal of every surgeon, but simple steps such as avoiding cooled irrigation can impact core temperature and should not be overlooked. During laparoscopic surgery, some have suggested actively humidifying the insufflated gas for temperature regulation.^{23,24} In one prospective study, however, insufflation with heated and humidified CO₂ did not alter core body temperature.²⁵ Other investigators have further minimized the importance of heated insufflation because the use of laparoscopic techniques may already improve intraoperative temperature control by reducing heat loss produced by bowel exteriorization.²⁶⁻²⁸ Although these benefits of laparoscopic surgery are certainly reasonable, they do not obviate the need for other methods of thermoregulation.²⁹ The liberal use of forced-air warming or circulating water garments (i.e., BAIR Hugger; Arizant Healthcare, Eden Prairie, MN) can be effective in maintaining normothermia and should be routinely applied during both laparoscopic and open operations. Finally, although heating intravenous fluids and blood products does not warm patients, it does prevent fluid-induced hypothermia.³⁰

ADVERSE EFFECTS OF HYPOTHERMIA

The negative effects of hypothermia impact nearly every facet of the postoperative course from cardiac morbidity to increased length of hospital stay. Specifically for the colorectal surgeon, intraoperative hypothermia has been found to increase the rate of wound complications, increase cardiac morbidity, and prolong time of post-anesthetic recovery. The following represents three prospective trials that best highlight these adverse outcomes.

Surgical site infections (SSIs) are the third most common hospital acquired infection and account for 14 to 16% of all such infections.³¹ In colorectal surgery, the reported incidence of SSIs has varied widely based on the series and ranges from 3 to 30%.³¹⁻³⁸ The impact of these infections are tremendous considering SSIs are directly attributable to an increased incidence of mortality, prolonged hospitalization, greater overall cost of care, and in the long term lead to a predisposition to hernia formation.^{11,34,35} In a study evaluating the financial impact of SSIs alone, development of a single

preventable surgical site infection was associated with an increased length of stay of almost 11 days, at a resultant cost of \$27,000 for each patient.³⁹ Although well studied factors such as the routine use of antibiotic prophylaxis and shaving have been incorporated into the latest Centers for Disease Control (CDC) guidelines to reduce the incidence of SSI, other perioperative factors, namely temperature regulation, should be considered an important manageable factor that positively impacts overall outcome after colorectal surgery.⁴⁰

In 1996, on behalf of The Study of Wound Infection and Temperature Group, Kurz et al¹¹ published their results of a prospective, double-blind, randomized trial to determine whether mild core hypothermia increased the incidence of surgical wound infection and the length of hospitalization in patients undergoing colorectal surgery. Over a 2-year period, 200 patients undergoing elective colorectal resection for malignancy or inflammatory bowel disease were randomized to either the normothermia group (core temperature 36.5°C, 104 patients) or the hypothermia group (core temperature 34.5°C, 96 patients). Both groups were administered perioperative antibiotics until 4 days postoperatively; however, temperature regulation was only applied intraoperatively to the normothermia group using either warmed fluids or forced air cover. Within 14 days from surgery, the overall wound complication rate was 12%, with 6 SSIs in the normothermia group compared with 18 in the hypothermia group ($p=0.009$). On secondary analysis, normothermia was associated with other benefits to include earlier tolerance of solid food ($p=0.006$), earlier suture removal ($p=0.002$), and decreased duration of hospitalization (12.1 ± 4.4 days versus 14.7 ± 6.5 days, $p=0.001$). Not surprisingly, wound infections increased hospital length of stay by an average of 2 to 3 days.

In addition to the benefits for surgical incisions, the importance of maintaining normothermia on cardiac morbidity was confirmed in a study by Frank and colleagues⁹ from the Johns Hopkins Hospital (Baltimore, MD). In this randomized, controlled trial comparing routine thermal care (hypothermic group) to the supplemental warming group (normothermic group), 300 patients undergoing noncardiac procedures were evaluated. Inclusion criteria included patients older than 60 years with risk factors for or known coronary artery disease undergoing urologic, general surgical, and vascular procedures. Their endpoint, cardiac events within the first 24 hours postoperatively, was favorable for the normothermic group compared with the hypothermic group with regards to electrocardiographic events (7% versus 16%, $p=0.02$) and morbid cardiac events (1% versus 6%, $p=0.02$) defined as unstable angina, cardiac arrest, and myocardial infarction. In this study, the primary difference between the groups in temperature regulation intervention was the use of a

forced-air warming cover intraoperatively as well as 2 hours postoperatively in the recovery unit for the normothermia group. Proposed explanation for the detrimental effects of hypothermia stemmed from the increased adrenergic response as well as increased metabolic demands related to shivering, both of which stress the cardiovascular system.

Finally, in a study by Lenhardt and associates,¹² 150 patients undergoing elective major abdominal surgery were randomly assigned to routine thermal management (34.5°C) or normothermia (36.5°C). In their study, regardless of the length of operation, hypothermic patients required 40 minutes longer to meet criteria for discharge from the postanesthetic recovery unit and 90 minutes longer to reach a core temperature $>36^{\circ}\text{C}$. The clinical implication of this particular study relates to the cost-effectiveness of maintaining normothermia during the operative period. Initial costs of using a forced-air warming system can be more than realized by shortening the time to recovery in the postanesthesia care unit.

HYPERTHERMIA

Although the focus of this article is avoiding hypothermia, it is important to point out that hyperthermia in the perioperative period may represent an ominous sign for the patient. In its basic element, hyperthermia (core temperature $>38^{\circ}\text{C}$) indicates that heat production is greater than heat loss. From the metabolic standpoint, hyperthermia may represent a wide spectrum of clinical states ranging from sepsis, a febrile response from other sources of infection, blood product transfusion reaction, to an uncontrolled metabolic state such as malignant hyperthermia.^{41,42} Needless to say, the underlying cause should be promptly addressed: source control when infection is the cause, stopping the transfusion, immediate cessation of the offending agent, including the anesthetic, along with the administration of dantrolene if malignant hyperthermia is suspected, or changing ambient temperature if all other causes have been ruled out.

SUPPLEMENTAL OXYGEN

Unlike the importance of temperature regulation, evidence for the use of supplemental oxygen has yet to be conclusively elucidated in the literature. Supplemental oxygen refers to oxygen delivered passively at high concentration beyond what is routinely required for oxygen saturation and is thought to enhance the oxidative killing by neutrophils, which are dependent on tissue oxygen partial pressure.⁴³⁻⁴⁵ Therefore, by increasing the oxygen tension, increased neutrophilic activity is expected. Although this hypothesis has been investigated in prospective randomized trials in surgical patients, as presented in the following, this concept has yet to gain

widespread acceptance from the colorectal and general surgical communities.

In 2000, Greif and the co-investigators of the Outcomes Research Group⁴⁶ published the results of a prospective randomized trial of 500 patients undergoing elective open colorectal resection in Austria and Germany enrolled from 1996 through 1998. The patients were evenly distributed, had similar comorbidities, similar risk factors for development of surgical wound infection, and were randomized to a mixture of 30% oxygen/70% nitrogen or 80% oxygen/20% nitrogen for the duration of the case and 2 hours postoperatively. Blinded observers from outside the operative team examined the surgical wound daily, and patients were followed for at least 2 weeks. In this study, enrollment was discontinued after 500 patients secondary to interim analysis, which revealed a statistically significant difference between the two groups. Those patients in the lower oxygen concentration group had an 11.2% wound infection rate; the 80% oxygen group had a 5.2% infection rate ($p < 0.012$). Notably, patients with postoperative wound complications stayed on average one week longer than their counterparts.

In 2005, in another double-blind controlled trial from Spain, investigators randomized 300 patients undergoing elective colorectal surgery to either 30 or 80% oxygen intraoperatively and 6 hours postoperatively.⁴⁷ Of their 291 patient cohort, 143 patients received 30% oxygen and 148 patients received 80% oxygen. Again, baseline patient characteristics, risk factors for surgical wound complications, and operative factors were similar for the two patient cohorts. Although the overall wound complication rate was 39.3%, patients receiving 30% oxygen had a wound infection rate of 24.4% compared with only 14.9% for patients randomized to 80% oxygen ($p < 0.04$). Overall, the relative risk of infection in those patients receiving 80% supplemental oxygen was 0.62.

Pryor et al⁴⁸ found differing results from their prospective randomized trial published in 2004. In this double-blind, randomized trial over a 2-year period 165 patients undergoing major intraabdominal surgery were assigned to receive either 80% oxygen or 35% oxygen for the first 2 hours after surgery. The overall primary endpoint of SSI incidence within 14 days of surgery was 18.1%. Surprisingly, in contrast to the aforementioned studies, the incidence of infection was significantly higher in the group receiving 80% oxygen versus the group in the 35% group (25% versus 11.3%, $p < 0.02$). The authors concluded that routine high-dose postoperative oxygen did not reduce SSI, and in fact may have *deleterious* effects on surgical wounds. Although unsure of the exact mechanism, the authors proposed differences in an adaptive response of bacterial pathogens might be influenced by higher oxygen tension. Certain limitations of this study may mitigate

the importance of their findings. First, this study was not adequately powered to detect a difference between the two treatment arms. Furthermore, unlike the other studies, baseline patient characteristics were different among the treatments groups. Finally, wound infections were determined by an investigator, albeit blinded to the treatment arm, which may have introduced bias. This is in distinction to the other two prospective trials where independent observers performed wound surveillance.

Pryor's study, as well as other nonrandomized trials,⁴⁶⁻⁴⁹ which have also produced discordant or equivocal results, highlight some challenges that have yet to be overcome before mainstream acceptance of the use of supplemental oxygen. It is hoped that future studies will clarify the exact duration of supplemental oxygen therapy, the optimal oxygen concentration, and the potential adverse consequences from hyperoxygenation.⁵⁰ Preliminary data are encouraging, but further studies need to be performed to determine the practical components of supplemental oxygen therapy.

EFFECTS OF SUPPLEMENTAL OXYGEN ON SURGICAL ANASTOMOSIS

Anastomotic failure is one the most dreaded complications for the colorectal surgeon and can result in a wide variety of complications including death. Although the technical basics of creating an anastomosis includes joining two healthy vascularized portions of bowel in a tension-free manner, ongoing research aims to identify factors that ensure a successful anastomosis. One of these factors may be better optimization of oxygenation of the injured tissues at the level of the anastomosis. Angiogenesis and collagen synthesis require oxygen at a partial pressure that is high enough making these processes critically dependant on blood perfusion and oxygen tension.⁵¹ Oxygen tension is known to directly correlate with collagen deposition and tensile strength.^{52,53} Thus, enhancing oxygen delivery at a cellular level to injured tissue would be expected to promote healing. In a more extreme example of tissue oxygenation, hyperbaric oxygen has been demonstrated to improve colonic anastomosis in various animal models. Conversely, hypoxia was associated with a significant decrease in colorectal anastomotic bursting pressure and overall wound healing in rats.⁵⁴⁻⁵⁶

Based on the premise that ischemia is an integral component of anastomotic failure, investigators from Spain randomized 45 patients undergoing an anterior resection with stapled anastomosis for sigmoid or rectal cancer to 30 or 80% FiO₂ for the duration of the surgery and 6 hours postoperatively.⁵¹ Their aim was to assess the effect of administration of perioperative supplemental oxygen therapy on colorectal anastomotic pH and partial pressure of carbon

dioxide as a surrogate for ischemia. Tissue oxygenation, measured by tonometry in both the stomach through a nasogastric tube as well as at the anastomosis by a transanastomotic tonometer, was recorded at 30 minutes, 6 hours, and 24 hours after surgery. In their analysis, the cohort of patients administered 80% oxygen had an improvement in relative anastomotic perfusion with respect to the untouched gastric mucosa. Overall, their results represent the first published attempt at prospective evaluation on the effects of oxygen on a surgical anastomosis in humans.

Based on these encouraging results, at our institution all patients undergoing either an open or laparoscopic colorectal resection with an anastomosis are placed on a standardized postoperative protocol of high-flow oxygen at 15 L/minute through a nonrebreather mask for 2 hours after extubation while monitored in the recovery room. For those unable to be extubated postoperatively, they are maintained on 100% FiO₂ for 2 hours with standard ventilator protocol afterwards. After the 2-hour window, supplemental oxygen is weaned as the patient tolerates. Early data analysis is encouraging and we continue to accrue patients under this protocol.

Laparoscopy has impacted the field of colorectal surgery, including colorectal resections for benign disease, complex oncologic resections, and even perforated viscera addressed through the use of a laparoscope. As all of the presented trials only included conventional open surgeries, the benefits of temperature regulation and supplemental oxygen on laparoscopic surgery can only be extrapolated from the open data. This represents additional exciting opportunities for future clinical investigation.

SUMMARY

The importance of avoiding hypothermia in the operating room should be a paramount concern for all members of the operative team, but especially the surgeon who will ultimately manage any complications. Numerous studies have clearly demonstrated that hypothermia adversely impacts a wide range of clinical factors including bleeding, cardiac events, and hospital length of stay. Simple, cost-effective management strategies are readily available in most operating rooms and have been shown to benefit patients at minimal risk for adverse outcomes. On the other hand, the use of supplemental oxygen represents a research opportunity with promising small-scale studies supporting improved outcomes in wound complications and anastomotic failure rates. Although optimal implementation strategies and significant adverse consequences of liberal oxygen therapy have yet to be determined, it does represent an additional straightforward, inexpensive method to potentially improve surgical outcomes.

DISCLAIMER

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or reflecting the views of the Department of the Army or the Department of Defense.

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