The Influence of 2 Surgical Bandage Systems on Wound Tissue Oxygen Tension

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Hypothesis: Local wound heating improves tissue oxygen tension in postoperative patients.

Setting: University hospital.

Patients: Forty normothermic and well-hydrated patients recovering from elective open abdominal surgery.

Interventions: A comparison between an experimental bandage system (Warm-Up; Augustine Medical Inc, Eden Prairie, Minn) and conventional gauze covered with elastic adhesive (Medipore Dress-it; 3M, St Paul, Minn). The experimental system is heated to 38°C and does not touch the wound.

Main Outcome Measures: Subcutaneous tissue oxygen tension was measured postoperatively and on the first postoperative day. In a subgroup, we also evaluated the effects of bandage pressure per se on tissue oxygen.

Results: Initial postoperative tissue oxygen tensions were approximately 30 mm Hg greater with the experimental bandage, even before warming. Subcutaneous oxygen tension during heating remained significantly greater in patients with the warmed bandage than the conventional elastic bandage (116±40 vs 85±34 mm Hg, respectively) while the patients were breathing approximately 50% oxygen. The difference was smaller on the first postoperative day, but still statistically significant (82±30 vs 65±22 mm Hg, respectively). In the subgroup analysis, tissue oxygen tension increased significantly by 12±4 mm Hg when the heating bandage was substituted for a conventional bandage (P<.001).

Conclusion: In normothermic and well-hydrated surgical patients, much benefit from the heating bandage system appears to result from pressure relief. These data suggest that relieving wound pressure markedly improves tissue perfusion and oxygenation.


WOUND infections are common and serious complications of anesthesia and surgery.1,2 The morbidity associated with surgical infections is considerable and includes substantial prolongation of hospitalization.3,4 Because the incidence of perioperative wound infections remains high, interventions producing even small decreases in rate must be seriously considered.

The primary defense against surgical pathogens is oxidative killing by neutrophils.3 Oxygen is a substrate for this process;4 and the reaction thus critically depends on tissue oxygen tension throughout the observed physiologic range.5 The primary determinant of tissue oxygen availability is local perfusion.6 Thermoregulatory status is one of the major factors influencing tissue perfusion.7 In particular, local warming induces precapillary vasodilation and improved tissue oxygenation.8 Recently, a bandage has been developed that provides gentle local heating to restore normothermia in wounds. We therefore tested the hypothesis that local wound heating improves tissue oxygen tension in postoperative patients. Our initial results suggested that bandage pressure, independent of heating, also altered subcutaneous tissue oxygen. We thus evaluated the effects of bandage type per se on tissue oxygen in a subgroup of patients.

RESULTS

Morphometric and demographic characteristics of the patients in each group were comparable (Table 1). Potential confounding factors, such as preoperative hematocrit, duration of surgery, intraoperative and postoperative hemodynamic responses, core temperature, and oxygen saturation, were similar in both groups (Table 2).
**PATIENTS AND METHODS**

With the approval of the ethics committee at the University of Vienna, Vienna, Austria, we studied 40 patients undergoing abdominal surgery involving an incision at least 20 cm in length. Patients having diabetes, abnormalities of healing, or peripheral vascular disease were excluded. Patients were also excluded if they used tobacco or took β-adrenergic blockers or opioids.

Anesthesia was induced with propofol (2-3 mg/kg), fentanyl citrate (1-3 μg/kg), and vecuronium bromide (0.1 mg/kg). Isoflurane in 60% nitrous oxide was titrated to maintain mean arterial pressure within 20% of preinduction values. Additional fentanyl was given on completion of surgery to improve postoperative analgesia. Intraoperative distal esophageal temperature was maintained near 36°C with forced-air warming.15

Patients were aggressively hydrated during and after surgery because hypovolemia decreases wound perfusion.14,15 We administered 15 mL·kg⁻¹·h⁻¹ of crystalloid throughout surgery and replaced blood loss with crystalloid at a 4:1 ratio or colloid at a 2:1 ratio. Fluids were administered intravenously at a rate of 3.5 mL·kg⁻¹·h⁻¹ for the first 24 postoperative hours. Leukocyte-depleted blood was administered per judgment of the attending anesthesiologist.

On completion of surgery, at least 5 cm of a 15-cm-long Luer-hubbed silicone tonometer (1-mm outer diameter, 0.8-mm inner diameter) was inserted subcutaneously several centimeters lateral to the incision. This was used to measure subcutaneous tissue oxygen tension (see below). Postoperative pain was treated by bolus injections of the opioid piritramide.

Patients were randomly assigned to either active local warming with a Warm-Up bandage and heater (Augustine Medical Inc, Eden Prairie, Minn) or a conventional gauze and elastic surgical bandage (Medipore Dress-it; 3M, St Paul, Minn). The designated bandage was positioned in the operating room by the surgeons after the skin was closed. Randomization was assigned on the basis of computer-generated codes; codes were kept in sequentially numbered opaque envelopes until just before use.

The heating bandage consists of an adhesive shell and a foam frame that supports a clear window about 1 cm above the surface of the wound. A battery-powered heating card can then be inserted into the window to provide gentle warming of the wound. The surface temperature of the heating card is fixed at 38°C, and heat is usually provided for 2 hours at a time. Ikeeda et al16 previously described this system in greater detail. The conventional elastic bandage consisted of several layers of gauze covered with a special adhesive bandage.

Throughout recovery, oxygen was given at a rate of 12 L/min via a venturi mask; this system provides approximately 50% inspired oxygen, which usually increases arterial oxygen tension to approximately 250 mm Hg. Baseline tissue oxygen measurements (see below) were obtained during the first 30 minutes of recovery. The heating card was then inserted into the window of the heating bandage in patients assigned to active heating. Measurements continued for 2 hours in each case.

In a subgroup of 10 patients, we also evaluated the effects of bandage pressure per se on tissue oxygen. After the primary recovery measurements were completed, patients were switched to the alternative bandage for an additional 30 minutes of measurements. No heating was used in either group during this portion of the study. The originally designated bandage was then replaced.

**MEASUREMENTS**

Demographic and morphometric characteristics of the patients were recorded. We similarly recorded potential confounding factors, including hematocrit, anesthetic management, duration of surgery, mean arterial pressure, and oxygen saturation.

Skin-surface temperature was recorded from disposable thermocouples positioned under the bandages and about 5 cm lateral to the bandages. Temperature was measured with thermometers that are accurate to 0.1°C (Mon-a-Therm 6510; Mallinckrodt Anesthesiology Products, St Louis, Mo).

Tissue oxygen tension was measured with a polygraphic electrode system (Licox Medical Systems Corp, Greenvile, NY) as previously described.17-19 The oxygen electrode was calibrated with room air (154 mm Hg) and then positioned within the silicone tonometer that was inserted 2 to 3 cm lateral to the surgical incision. A thermocouple was inserted into the opposite lumen of the tonometer and positioned approximately 1 cm from the oxygen electrode. The system was flushed with hypoxic saline to remove air from the catheter. Calibration and stabilization of the system required approximately 1 hour.

In vitro accuracy of the polygraphic probes (in a water bath at 37°C) is ±3 mm Hg for the range from 0 to 100 mm Hg and ±5% for the range from 100 to 360 mm Hg. Temperature sensitivity is 0.25%/°C, but thermistors are incorporated into the probes and temperature compensation is included in the calculations of subcutaneous oxygen tension. Probe calibration remains stable (within 8% of baseline value for room air) in vivo for at least 8 hours. Consequently, the device used measures oxygen tension accurately and reliably over a broad range of subcutaneous temperatures and PO₂ values.18

On the first postoperative day, subcutaneous oxygen tension and temperature were again recorded, along with oxygen saturation. One hour before measurements, the bandage heater was briefly disconnected and then reconnected to restart a 2-hour warming cycle. During this time, the oxygen catheter was calibrated. Subcutaneous oxygen tension and temperature were then recorded at 10-minute intervals for 30 minutes with the patient breathing 7 L of oxygen per minute via nasal prongs.

**DATA ANALYSIS**

Differences between the treatment groups were evaluated with 2-tailed, unpaired t tests. In the subgroup of patients in whom the effects of bandage pressure were evaluated, differences in tissue oxygen tension were compared with paired t tests. Results are presented as means±SDs; P<.05 was considered statistically significant.
Initial postoperative tissue oxygen tension in the patients given the heating bandage (110±40 mm Hg) differed significantly from those with a conventional bandage (80±31 mm Hg), even before local warming started. Subcutaneous oxygen tension during heating remained significantly greater in patients with warmed than unwarmed wounds (116±40 vs 85±34 mm Hg, respectively). On the first postoperative day, tissue oxygen tension was considerably less than during recovery. However, the average value was again significantly greater in patients assigned to the heating bandage than those given conventional gauze and elastic bandages (82±30 vs 65±22 mm Hg, respectively) (Table 3).

In the subgroup analysis of bandage pressure, tissue oxygen tension increased significantly by 12±4 mm Hg when the heating bandage was substituted for a conventional bandage (n=4; P=.001). In contrast, subcutaneous oxygen tension decreased significantly by 13±3 mm Hg when the conventional bandage was substituted for the heating bandage (n=6; P=.005).

**COMMENT**

Oxidative killing is the most important immune defense against surgical pathogens. It depends on the production of bactericidal superoxide radical from molecular oxygen. The rate of this reaction is P O2 dependent, and oxidative killing is oxygen dependent throughout the physiologic range from 0 to 150 mm Hg or more. All wounds disrupt the local vascular supply as a result of vessel injury and thrombosis. Consequently, wounds are hypoxic compared with normal tissue. Tissue oxygen availability is highly correlated with the risk of surgical wound infection. Tissue oxygen availability is largely determined by local perfusion, which, in turn, is markedly influenced by thermoregulatory status.

We evaluated local warming because heat exposure triggers active precapillary vasodilation that is mediated by a yet-to-be-determined factor released from sweat glands. As might be expected, acute local warming to a skin temperature near 38°C with circulating water or hot packs significantly increases perfusion and tissue oxygen tension.

Tissue oxygen tension was approximately 30 mm Hg greater in patients assigned to the heating bandage than...
those given conventional gauze and elastic. This difference is highly clinically important and is associated with increased collagen deposition (scar formation). More importantly, it corresponds to a substantial reduction in infection risk. This difference in tissue oxygenation is similar to the reduction that results from smoking. As might be expected, the incidence of surgical wound infection is increased 4-fold in smokers. Furthermore, smoking reduces collagen deposition and survival of random flaps. All these complications are believed to be mediated primarily by reduced tissue oxygen tension.

A curious aspect of our results is that baseline tissue oxygen tensions—even before heating—differed by approximately 30 mm Hg. An obvious potential explanation for this initial difference is bias. However, selection bias seems unlikely, since patients were enrolled well before randomization envelopes were opened at the end of surgery. (An audit confirmed that patients were assigned to the designated treatments.) Measurement bias also seems unlikely, since all reported values are objective.

Another potential explanation for differing initial oxygen tensions is an insufficient sample size. However, it seems unlikely that potential confounding factors were unevenly distributed in our relatively large study population (n=40). Furthermore, we evaluated all major factors likely to influence tissue oxygen tension. None of these factors differed significantly, including mean arterial pressure, hemoglobin, blood oxygen saturation, core temperature, perioperative fluid management, and the duration of surgery. These data suggest that our populations were in fact well matched.

Our experimental bandage differs from a conventional elastic gauze bandage in being heated; however, it also does not contact the wound. Wounds treated with this bandage thus had no pressure applied to them. In contrast, those assigned to a conventional dressing had not only gauze on the wound, but an elastic pressure bandage. This difference turned out to be more important than we had anticipated: tissue oxygen tension was approximately 12 mm Hg less with the conventional bandage, even when the experimental bandage was unheated. Obviously, little or no difference might be observed with a gauze and paper tape dressing, rather than elastic.

The bandage crossover study was performed after completion of the primary recovery measurements. This may have reduced the magnitude of the difference because by that time patients had largely recovered from the acute vascular volume perturbations associated with surgery. Their pain was also under better control. Both of these factors are known to influence tissue oxygen tension. The bandage test portion of the study lasted only 30 minutes, whereas our primary recovery measurements were averaged across 2 hours. To the extent that the effects of pressure continue to accumulate for more than 30 minutes, our study may have underestimated the effects of pressure on tissue oxygenation. Taken together, it seems likely that the observed difference in initial tissue oxygen tension can largely be explained by differing wound pressures with the two bandage systems.

The initial difference in tissue oxygenation with the 2 bandage systems remained unchanged after activation of the heating card in the heating bandage. This observation suggests that in normothermic and well-perfused surgical patients, wound heating per se does not further improve tissue oxygenation. This result contrasts with volunteer studies in which the heating bandage system significantly increased local perfusion and tissue oxygenation. Surgical patients, though, differ considerably from healthy, unstressed volunteers because they are subject to large variations in blood pressure and vascular volume status. They are also given vasoactive drugs (including anesthetics) and suffer postoperative pain. All of these factors are known to influence cutaneous perfusion. It also remains likely that local heating would benefit the typical surgical patient who is hypothermic and somewhat volume depleted.

In summary, inadequate tissue oxygen available is highly correlated with the risk of surgical wound infection. We thus evaluated the effects of an experimental heated bandage system on tissue oxygenation. Tissue oxygen tension was approximately 30 mm Hg greater with the heating bandage than with a gauze and elastic bandage during recovery. The difference was smaller on the first postoperative day but remained statistically significant. However, initial postoperative tissue oxygen tension was approximately 30 mm Hg greater with the experimental bandage, even before warming was started. A considerable fraction of this difference appears to result from lack of wound pressure with the heating bandage system. In contrast, little additional difference resulted from wound heating per se. These data suggest that, in surgical patients, relieving wound pressure markedly improves tissue perfusion and oxygenation.

This study was supported by grant GM58273 from the National Institutes of Health, Bethesda, Md; the Joseph Drown Foundation, Los Angeles, Calif; the Fonds zur Förderung der wissenschaftlichen Forschung, Vienna, Austria; the Austrian National Bank Foundation, Vienna, Austria; and Augustine Medical Inc, Eden Prairie, Minn.

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Presented in part at the Annual Meeting of the American Society of Anesthesiology, Orlando, Fla, October 21, 1998.

This article is from the Outcomes Research Group, of which Dr Sessler is director and Dr Kurz is associate director. Participating institutions in the Outcomes Research Group are the Departments of Anesthesiology and General Intensive Care and General Surgery, University of Vienna, Vienna, Austria; Department of Anesthesiology, University of
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