3M™ Bair Hugger™ System
Research Compendium

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Since 1987, the 3M™ Bair Hugger™ system has become an indispensable component in the care of surgical patients, providing safe and effective warming therapy to patients across the globe.

The cornerstone of the Bair Hugger system's leadership has been the wealth of research available that demonstrates the safety and effectiveness of these products. The Bair Hugger system has been utilized in far more published studies than any other patient warming modality.

The sheer volume of research is overwhelming, but so is the history of actual clinical use. More than 200 million patients have been warmed with the Bair Hugger system—a number which grows by nearly 50,000 patients each day.

This compendium includes summaries of publications and was compiled through a comprehensive literature search, across a wide range of surgeries, in which the Bair Hugger system is either the subject of, or utilized during, the clinical investigation. Also included are review articles, case studies and letters to the editor which introduce relevant information or real-world user experience with the Bair Hugger system. Research conducted using the Bair Hugger system in a manner not intended (for example, utilizing the warming unit without a disposable blanket connected) is excluded from this collection.

The search utilized multiple search engines and five databases including Medline, Embase, Biosis, Elsevier Biobase and Chemical Abstracts. All are premium content databases that use highly indexed terms and codes. In addition, several of the included studies measure the performance of the Bair Hugger system against competing technologies, including convective warming, circulating-water warming, and resistive polymer technologies.

The compendium should be used by readers to grasp the scope of research specific to the Bair Hugger system and the clinical benefits associated with its use. Literature is organized in chronological order, with the most recent information found toward the end of the table of contents. A study index and author index are included to help the reader find relevant information more quickly. Literature cited in this document are current through January 1, 2016.

Readers who want to delve deeper into a particular publication should consult the article referenced.

Michelle Hulse-Stevens
Medical Director
3M Infection Prevention Division

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Hypothermia during epidural anesthesia results mostly from redistribution of heat within the body, not heat loss to the environment.

Sessler, D.I. and J. Ponte, *Hypothermia during epidural anesthesia results mostly from redistribution of heat within the body, not heat loss to the environment*. Anesthesiology, 1989. 71 Suppl(3A): p. 882.

The authors tested the hypothesis that hypothermia during epidural anesthesia results from central to peripheral redistribution of heat, not heat loss to the environment. After four non-pregnant volunteers got two epidural injections of 30 ml, 1% lidocaine, two volunteers were randomly assigned to lower body skin warming with a Bair Hugger warming unit set to ~35°C or "low" (n=2), and two without additional warming.

The authors measured heat flux (Thermonetic, San Diego), tympanic membrane and average skin temperature at 2 minute intervals for 15 minutes before and 1.5 hours after each injection. The results shows that the two volunteers without warming became hypothermic by ~1°C, and warmed volunteers remained normothermic. Increased heat loss from the legs was balanced by vasoconstriction and decreased loss from the arms. Average skin-surface temperature and total heat flux remained constant, despite decreasing central temperature.

The authors concluded that central-to-peripheral redistribution of heat caused the hypothermia, not loss to the environment. Rewarming after 60 minutes produced a net increase in body heat content.

The Bair Hugger warmer significantly decreases heat loss to the environment.

Sessler, D.I., R. Stoen, and B. Glosten, *The Bair Hugger warmer significantly decreases heat loss to the environment.* Anesthesiology, 1989. 71 Suppl(3A): p. A4111.

The authors evaluated cutaneous heat loss using heat flux transducers (Thermonetics™, San Diego). Cutaneous heat loss accounts for > 80% of the total loss during recovery from anesthesia. They recorded heat flux across 10 skin sites at 2-minute intervals in each of five healthy volunteers in a 28°C environment. Heat losses over 15 minute epochs before, during, and after application of a Bair Hugger™ air blanket warmer set to "low" (~ 35°C) were compared using ANOVA and Student-Newman-Keuls tests. Volunteers were covered with a single cotton blanket during the control periods.

Results shows that flux across sites covered by the warming blanket (chest, thigh, calf, and foot) decreased from -30 ± 9 (SD) watts to -4±7 (SD) watts (P = 0.007) (fig). Heat flux from the head was 13 ± 5% (SD) of the total cutaneous loss, similar to that from the lower legs or lower arms. These data indicate that heat flux is almost completely eliminated by a Bair Hugger warmer set to its lowest temperature. The decrease in total flux would have been considerably greater had the ambient temperature been lower (e.g., the 23°C typical for postanesthetic recovery areas).

When cutaneous heat loss is suppressed by the Bair Hugger system, the heat generated solely by basal metabolism can rewarm adult patients at a rate of approximately 1°C/hour. The heat loss from the head is a very small fraction of the total, and, therefore, does not merit suppression.

Forced air warming minimizes hypothermia during orthotopic liver transplantation.

Kelley, S.D., et al., *Forced air warming minimizes hypothermia during orthotopic liver transplantation.* Anesthesiology, 1990. 73(3A): p. A433.

In this article authors tested how forced air warming would minimize intraoperative hypothermia during liver transplantation.

The investigators recorded distal esophageal temperature during liver transplantation in 22 patients. The patients were randomized so that 11 patients (control group) got standard methods of temperature control: warming blanket, airway humidifier, 2 L/minute fresh gas flows, plastic head wrappings, insulated wrapping of the lower extremities, and warming of all blood products and intravenous fluids to 37°C. The other 11 were warmed with a Bair Hugger™ forced air warmer set on "high" (=43°C). Their legs were left unwrapped, and a pediatric sized air blanket covered the legs to the level of the symphysis pubis.

After the induction of anesthesia, all methods of temperature control were initiated. Esophageal temperature was recorded at the time of incision, 15 minutes before the anhepatic period (11-15), the midpoint of the anhepatic period (Mid-II), at 30 (111+30), 60 (111+60) and 90 (111+90) minutes following graft reperfusion, and at closing of the abdominal incision.

Results show that the forced air warmer produced significantly higher temperatures at all times after the anhepatic period. At closure of the abdominal incision, this group had reached a temperature of 35.6 ± 0.2°C compared with 34.7 ± 0.2°C in the control group.

The investigators concluded that the Bair Hugger forced-air warmer is an efficient way to minimize intraoperative hypothermia during liver transplantation.

Evaluation of a Forced-Air System for Warming Hypothermic Postoperative Patients.

Lennon, R.L., et al., *Evaluation of a forced-air system for warming hypothermic postoperative patients*. Anesth Analg, 1990. 70(4): p. 424-7.

In this prospective study, 30 adult surgical patients with postoperative oral temperatures <35°C were randomly assigned to warming therapy with either cotton blankets (warmed to 37°C) or Bair Hugger™ forced-air warming therapy in the recovery room.

Both groups had a mean oral temperature of 34.3°C when admitted to the recovery room. Upon initiation of warming therapy, patients who received forced-air warming were found to be significantly warmer at all measured time points. Length of stay in recovery for the group warmed with cotton blankets was 156.0 minutes, compared to 99.7 minutes for the forced-air warming group (P<0.003).

In addition, the incidence of shivering was significantly higher in the group warmed with cotton blankets.

Skin-surface warming: heat flux and central temperature.

Sessler, D.I. and A. Moayeri, *Skin-surface warming: heat flux and central temperature.* Anesthesiology, 1990. 73(2): p. 218-24.

This study of five healthy volunteers compared the efficacy of four postoperative warming devices: infrared heat lamps, the Thermal Ceiling™ MTC XI UL radiant warming device, a circulating-water mattress, and the Bair Hugger™ forced-air warming blanket. All devices were used for 30 minutes, temperatures were measured with thermocouples, and heat transfer rates measured with thermal flux transducers.

Skin-surface temperatures were highest for subjects warmed with the Bair Hugger forced-air system set on "high." When set on "medium," the performance of the forced-air warming system was equal to the circulating-water mattress in decreasing heat loss, and better than the radiant warming devices.

The circulating-water mattress was most effective at warming a transducer placed on the chest in contact with both the circulating-water mattress and forced-air warming system; however, the Bair Hugger system transferred the greatest amount of heat because of its recruitment of a greater body surface area. There was no correspondence between forehead skin and tympanic membrane temperatures.

The effects of two warming methods on core and surface temperatures, hemoglobin oxygen saturation, blood pressure, and perceived comfort of hypothermic postanesthesia patients.

Summers, S., et al., *The effects of two warming methods on core and surface temperatures, hemoglobin oxygen saturation, blood pressure, and perceived comfort of hypothermic postanesthesia patients*. J Post Anesth Nurs, 1990. 5(5): p. 354-64.

Ninety-one adult patients were randomly assigned to either the Bair Hugger warming system or warmed bath blankets in this experimental study to measure the impact of two warming methods on hypothermic postanesthesia patients.

The study measured core and surface temperature, oxygen hemoglobin saturation, blood pressure and perceived comfort. Multiple analysis of variance with repeated measures demonstrated significant differences between the two groups in all but core temperature and blood pressure.

According to the authors, these results implied that the Bair Hugger forced-air warming system could be effective at promoting thermal comfort and a cost-effective adjunct to care by PACU nurses.

Shivering during epidural anesthesia.

Sessler, D.I. and J. Ponte, *Shivering during epidural anesthesia*. Anesthesiology, 1990. 72(5): p. 816-21.

This study was conducted to test the following hypothesis for patients under epidural anesthesia: 1) Shivering-like tremor is primarily normal thermoregulatory shivering; 2) Hypothermia does not produce a subjective sensation of cold; and 3) Injectate temperature does not influence tremor intensity.

An epidural catheter was inserted into 10 healthy, nonpregnant volunteers randomly assigned to skin-surface warming below the T10 dermatome (warmed group) or no extra warming (unwarmed group). Each volunteer was given two 30-ml epidural injections of 1% lidocaine (16.0 ± 4.7°C and 40.6 ± 0.7°C at the catheter tip), in random order separated by at least three hours.

Bair Hugger™ warming therapy was applied only to the legs of the subjects in the warmed group. The warming unit was set to "low" and prevented hypothermia in all of the warmed subjects.

Skin-temperature was measured at forearm, fingertip, and tympanic membrane, and average skin temperature was recorded. For this study, significant vasoconstriction was defined as a forearm-fingertip gradient of 4°C or more. Overall thermal comfort was evaluated using a visual analog scale.

The authors discovered that tympanic membrane temperatures decreased significantly in the unwarmed group (n = 6). Tremor occurred following 10 of 12 injections in unwarmed volunteers, but only one of eight injections in the warmed group. Tremor started when tympanic membrane temperature decreased about 0.5°C and continued until central temperature returned to within 0.5°C of control.

Hypothermia and vasoconstriction always proceeded tremor. Both groups reported improved thermal comfort after epidural injection, with the greatest comfort reported at the lowest tympanic temperatures.

Thermal balance using a forced air warmer (Bair Hugger™) during abdominal surgery.

Camus, Y., et al., *Thermal balance using a forced air warmer (Bair Hugger) during abdominal surgery*. Anesthesiology, 1991. 75(Suppl)(3A): p. A491.

The aim of this study was to evaluate the amount of heat transferred by the use of the Bair Hugger™ system under abdominal surgery where only the lower limbs are available for skin warming.

This study involved 16 ASA class I-II adult patients (randomly separated in two groups), undergoing nonhemorrhagic abdominal surgery. Eight patients received no additional prevention of hypothermia (control group). The other eight had their legs covered by a lower body size air blanket attached to a Bair Hugger system set at 'high' (Bair Hugger group). Anesthesia combined thiopental, fentanyl, pancuronlum, and enflurane with N_2O in O_2, under mechanical ventilation through a semi-closed circuit at 2 l/minute fresh gas flow. Operating room temperature was kept at ~21-22°C.

The core temperature and four skin temperatures (thorax, arm, midcalf, midthigh) were recorded at 15-minute intervals to calculate mean skin temperature and changes in body heat content (BHC, kJ). Mean skin temperature of the lower and upper parts of the body were calculated as the average of the thigh and calf temperature, and from the thorax and arm temperature, respectively. The temperature of the skin directly under the air blanket was monitored with a non-isolated thermistor probe placed on the ventral mid-thigh. Results (mean±SEM) were compared using ANOVA and t-test, as required.

Results showed that there were no significant difference between the two groups for age, weight, sex, duration of anesthesia (194 ± 20 minutes) and operating room temperature (21.6 ± 0.2°C). The forced air warmer was able to provide heat gain in anesthetized patients. That happened even when the warmed skin surface was restricted to the lower limbs, as during abdominal surgery.

Results at the end of surgery:

	Core temperature	Mean skin temperature	Δ BHC
Control	35.1 ± 0.2°C	32.8 ± 0.3°C	-265 ± 55
Bair Hugger	36.2 ±0.2°C	34.8 ± 0.3°C	+114 ± 74

Skin surface warming during surgery: effect of warmed skin temperature on heat gain.

During surgery, heat can be transferred only through a limited skin surface area. The authors used two different warming methods to study the relation between cutaneous heat transfer and warmed skin temperature.

Two warming devices covering the patients' lower limbs were successively studied in ASA class I-II adult patients, scheduled for abdominal surgery lasting more than 2 hrs. A total of 38 patients participated in two studies. The first study included 16 patients randomized into two groups: 8 had their lower limbs covered with a forced-air blanket attached to a Bair Hugger™ warming unit set at "high", while 8 did not.

In a second study, 22 patients were randomized in two groups: An electric warming blanket was used in 11, and not in the other 11. Recorded parameters were the four skin temperatures (thorax, arm, mid calf, mid thigh), the core temperature (tympanic, and esophageal after induction of anesthesia) and the operating room temperature (room T, °C), For each group, the change in total body heat content (deltaTBH, kJ) was calculated during the second hour of anesthesia, when the warmed skin had reached a steady temperature.

Results show that for both warming devices, core T at the end of surgery and deltaTBH were significantly higher in warmed group than in the control group.

Hypothermia in the PACU.

Feroe, D.D. and S.D. Augustine, *Hypothermia in the PACU*. Crit Care Nurs Clin North Am, 1991. 3(1): p. 135-44.

This paper reviews what is known about various warming therapies used in the postanesthesia care unit. Postanesthetic hypothermia is a common consequence of anesthesia and surgery, and the failure to treat it can produce bad outcomes associated with substantial cost.

Several therapies, including warmed cotton blankets, infrared warming lights, and fluid warmers have not been shown to be effective in the PACU setting; however, the use of the Bair Hugger™ warming system has been shown to be both effective and less expensive than the use of warmed cotton blankets.

More study is indicated in the area of thermoregulation during anesthesia to help identify additional seetings where active patient warming may reduce adverse consequences during emergence from anesthesia.

Mild intraoperative hypothermia increases duration of action and spontaneous recovery of vecuronium.

Heier, T., et al., *Mild intraoperative hypothermia increases duration of action and recovery time of vecuronium*. Anesth Analg, 1990. 70(2): p. S153.

It is known that hypothermia reduces the twitch tension of the adductor pollicus muscle by 15%/°C. The purpose of this study was to compare the activity and duration of action of vecuronium-induced neuromuscular blockade in normothermic and mildly-hypothermic patients.

A total of 14 patients were included in the study. Ten patients were warmed with a Bair Hugger™ system to keep their core temperatures greater than 36.5°C, and 4 patients were actively cooled to achieve core temperatures of 34-34.5°C. All subjects received a bolus injection of 0.1 mg/kg vecuronium and their twitch tension was measured in response to a 0.2 msec duration, supramaximal, train-of-four stimulus delivered to the ulnar nerve.

The duration of action of vecuronium was significantly prolonged in patients who were hypothermic. The authors conclude that the dose of vecuronium should be adjusted according to body temperature using the twitch response as an assay. Hypothermic patients should be given adequate time to recover, even after reversal with neostigmine.

Rewarming postoperative patients: lights, blankets, or forced warm air.

Giuffre, M., et al., *Rewarming postoperative patients: lights, blankets, or forced warm air*. J Post Anesth Nurs, 1991. 6(6): p. 387-93.

In this prospective study, 90 post-operative patients with admission temperatures ≤35°C were randomly assigned to be warmed with either warmed cotton blankets, radiant heat lamps, or Bair Hugger™ forced-air warming in order to compare the re-warming effectiveness of these methods. Warming with each method continued until patients reached 36°C.

For patients who shivered, mean rewarming times were similar for each method. Non-shivering patients were re-warmed significantly faster, and were ready for discharge sooner, using Bair Hugger forced-air in comparison to the other methods.

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Pre-induction skin-surface warming prevents redistribution hypothermia.

Moayeri, A., et al., *Pre-induction skin-surface warming prevents redistribution hypothermia*. Anesthesiology, 1991. 75 Suppl(3A): p. A1004.

The authors tested the hypothesis that internal redistribution of heat and hypothermia can be reduced by skin-surface warming before induction of general anesthesia (prewarming).

Ten volunteers participated in this thermoregulation study during isoflurane anesthesia. Five (control) participants had no external warming methods before induction or during the first 30 minutes of anesthesia. In the second group, five volunteers were warmed by using a Bair Hugger™ forced-air warmer for 45 minutes before induction. Warming was discontinued after induction. All volunteers were uncovered after induction of anesthesia. Tympanic membrane temperature and heat loss (thermal flux transducers, ten area-weighted sites) were measured.

The results indicate that despite greater heat loss in the prewarmed volunteers after induction of anesthesia, central temperature remained greater than in the control group where decrease in tympanic membrane temperature was ~0.8°C less than in the prewarmed group. The authors conclude that hypothermia following induction of general anesthesia can be reduced by skin surface warming before induction.

Intraoperative warming therapies: a comparison of three devices.

Hynson, J.M. and D.I. Sessler, *Intraoperative warming therapies: a comparison of three devices*. J Clin Anesth, 1992. 4(3): p. 194-9.

In this prospective clinical trial, 20 kidney transplantation patients were randomly assigned to one of four warming therapy groups: a circulating-water blanket, a heated humidifier, a Bair Hugger™ forced-air warming system, or no extra warming. All patients received warmed intravenous fluids.

All patients experienced a drop in pre-induction core temperature of approximately 1°C during the first hour of anesthesia, consistent with the theory of anesthesia-induced temperature redistribution.

The Bair Hugger warming system, applied to a limited skin surface area, transferred the most heat and maintained core temperature better than the other devices. At three hours, the reduction in core temperature was least among the forced-air warming group (-0.5 ± 0.4°C), followed by the circulating water group (−1.2°C ± 0.4°C), heated humidifier group (−2.0 ± 0.5°C), and the control group of unwarmed patients (−2.0 ± 0.7°C).

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Evaluation of the Bair Hugger™ warming device.

Grange, C., et al., *Evaluation of the Bair Hugger warming device*. Anaesth Intensive Care, 1992. 20(1): p. 122-3.

This letter to the editor explains a randomized study evaluating the use of the Bair Hugger™ system in the operating room as well as post-operative recovery area, when compared to warming blankets (underlying heated water blankets).

Twenty patients were randomly assigned to either Bair Hugger forced-air warming or heated water blanket warming in the operating room. Both groups received warmed intravenous fluids and humidified anesthetic gases. There was no difference in the decrease of temperature observed in each group (0.7°C within the first hour of surgery), nor the rate of temperature decrease within 90 minutes.

The other study involved 26 patients who arrived to the post-operative recovery room with hypothermia (tympanic temperature <35°C). These hypothermic patients were randomly assigned to either forced-air warming or heated water blanket warming. Tympanic temperatures were recorded every 15 minutes and patients' feelings of warmth were noted and documented.

Patients in the Bair Hugger forced-air warming group warmed significantly faster (P=0.01) compared to blanket-warmed patients (1.4°C per hour (SD=0.35) and 0.6°C per hour (SD=0.25), respectively). Patients in the Bair Hugger forced-air warming group also felt significantly warmer (P=0.01) and more comfortable (P=0.02) than patients in the warming blanket group.

The authors concluded that the Bair Hugger system was extremely useful as a means of postoperative warming compared to conventional methods. The Bair Hugger system led to significantly more rapid temperature increase in post-operative recovery room and showed patient preference compared to warming blankets.

Limited heat transfer between thermal compartments during rewarming in vasoconstricted patients.

Ereth, M.H., R.L. Lennon, and D.I. Sessler, *Limited heat transfer between thermal compartments during rewarming in vasoconstricted patients*. Aviat Space Environ Med, 1992. 63(12): p. 1065-9.

Twelve hypothermic postsurgical patients (core temperature <35.5°C) were randomized to receive either Bair Hugger™ forced-air warming or warmed blankets after surgery to assess whether thermoregulatory vasoconstriction would limit heat transfer to the central compartment in warmed patients.

Skin surface temperature was significantly higher in active warming group, which received approximately 50 W of heat, compared to passive warming group (blankets), who experienced a heat loss of 50 W. However, no difference in core temperature was observed between the groups.

All patients experienced vasoconstriction. The authors concluded that vasoconstriction impeded heat transfer from skin surface preventing body core warming. The study also found that the rate of increase in mean skin temperature was also significantly greater in the active warming group and the authors also observed an increased rise in pulmonary temperature (although not a statistically significant rise) in the subjects warmed with Bair Hugger therapy.

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Heat conservation during abdominal surgery.

Iwasaka, H., et al., [*Heat conservation during abdominal surgery*]. Masui, 1992. 41(4): p. 666-669.

In this prospective study, 16 abdominal surgery patients were randomly assigned to warming with the Bair Hugger™ forced-air warming system or warmed hospital blankets to compare the heat-conservation effects of each method. Three core temperature measurements were taken at hourly intervals.

Core temperatures were significantly higher in the Bair Hugger warming group. The authors conclude that forced-air warming is effective at maintaining patient core temperature during surgery.

Leg warming minimizes core hypothermia during abdominal surgery.

Camus, Y., et al., *Leg warming minimizes core hypothermia during abdominal surgery*. Anesth Analg, 1993. 77(5): p. 995-9.

Two prospective studies evaluated the effectiveness of leg warming in preventing hypothermia and shivering among abdominal surgery patients. In the first, 22 patients were randomly assigned to receive no active warming (control group) or warming with an electric blanket. In the second, 33 patients were randomly assigned to receive no active warming, warming from a Bair Hugger™ forced-air warming system, or Bair Hugger therapy with added insulation. Both core and skin temperatures were measured.

In both studies, active warming of the legs resulted in less core temperature reduction and shivering than no active warming. Mean end-of-surgery core temperatures for the unwarmed control groups were 34.6 ± 0.3°C and 35.1 ± 0.2°C, respectively. Core temperatures for the actively warmed groups were 36.4 ± 0.1°C (electric blanket), 36.3 ± 0.1°C (Bair Hugger therapy without added insulation), and 37.1 ± 0.1°C (Bair Hugger therapy with added insulation). Shivering occurred in one patient each among the actively warmed groups, and in nine and seven patients in the two unwarmed control groups, respectively.

The authors conclude that active warming of the legs of abdominal surgery patients is effective in counterbalancing heat loss during abdominal surgery.

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Preanesthetic Skin-Surface Warming Reduces Redistribution Hypothermia Caused by Epidural Block.

Glosten, B., et al., *Preanesthetic skin-surface warming reduces redistribution hypothermia caused by epidural block*. Anesth Analg, 1993. 77(3): p. 488-93.

This study of seven volunteers evaluated the effectiveness of active skin-surface warming before anesthesia (prewarming) in preventing inadvertent hypothermia caused by temperature redistribution following epidural block. Volunteers received two lidocaine epidural injections each in one day. No prewarming was provided before the first injection, and prewarming with a Bair Hugger™ forced-air warming blanket was provided before the second injection.

Skin temperature and heat loss were both greater after prewarming. Core temperature decrease was smaller among prewarmed volunteers (0.41°C; P = 0.003), and shivering was reduced.

The authors conclude that the most important cause of hypothermia after epidural anesthesia is redistribution, not heat loss. The results of the study also confirm that prewarming with forced-air warming decreases inadvertent hypothermia caused by post-epidural block temperature redistribution.

The effects of preinduction warming on temperature and blood pressure during propofol/nitrous oxide anesthesia.

This study of 6 volunteers undergoing general anesthesia compared the effect of skin-surface warming before induction (prewarming) versus no prewarming on core temperature and blood pressure. The authors hypothesized that prewarming of peripheral tissue would minimize hypothermia caused by anesthesia-induced temperature redistribution. Bair Hugger™ forced-air warming therapy was used for prewarming.

Each volunteer was anesthetized twice, first without warming and subsequently with prewarming, followed by exposure to ambient temperature typical of an operating room. Core temperature (tympanic membrane) before induction was similar for both unwarmed and prewarmed volunteers (36.7 ± 0.4°C and 36.7 ± 0.6°C, respectively), and remained the same for unwarmed volunteers prior to induction while increasing slightly for prewarmed volunteers.

Following induction, tympanic temperatures for unwarmed volunteers decreased to 34.9 ± 0.4°C, versus 36.1 ± 0.4°C for prewarmed volunteers. Blood pressures (radial arterial systolic, diastolic, and mean) for prewarmed volunteers were lower than those of unwarmed volunteers prior to induction, but prewarming did not reduce hypotension following induction. The authors conclude that prewarming of peripheral tissues does not prevent subsequent hypotension but can minimize anesthesia-induced hypothermia.

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Forced-air warming maintains intraoperative normothermia better than circulating-water mattresses.

Kurz, A., et al., *Forced-air warming maintains intraoperative normothermia better than circulating-water mattresses*. Anesth Analg, 1993. 77(1): p. 89-95.

Four groups of surgical patients were randomly assigned to receive either Bair Hugger™ forced-air warming (at approximately 40°C) or circulating-water mattress warming (at 40°C) in order to assess whether forced-air warming is a more effective method for preservation of core temperature during surgery.

These four groups included: adults undergoing major maxillofacial surgery, including radical node resection and flap reconstruction (n=16), adults undergoing hip arthroplasty, having approximately 25% of their body surface area available for warming (n=53), infants undergoing minor maxillofacial surgery (n=20), and young children undergoing pelvic or femoral osteotomies (n=10).

For adults undergoing maxillofacial surgery, Bair Hugger forced air warming was applied to the legs, while for those adults undergoing hip surgery, this type of warming was applied to one arm, the shoulders, and the neck. For children, conductive warming used a U-shaped, tubular forced-air cover placed around these patients.

Those who received forced-air warming experienced a core temperature increase, compared to patients warmed with circulating water mattress, whose core temperature remained the same or decreased (P < 0.01).

Hepatic cryosurgery with and without the Bair Hugger™.

In this retrospective cohort study, 28 hepatic cryosurgery procedures were performed without active skin-surface warming of patients, and 44 cases were performed with Bair Hugger™ therapy, to evaluate the effect of both approaches on patient core temperature.

Mean core temperature decrease was significantly lower in the group that received no Bair Hugger therapy (1.81°C vs. 0.73°C for the Bair Hugger group; P = < 0.0001), and the lowest mean core temperature recorded (34.2°C vs. 35.3°C; P = < 0.0001) was from the unwarmed group. No patients experienced clinically significant hypothermia when treated with the Bair Hugger system.

The authors conclude that Bair Hugger therapy is both safe and effective for managing patient temperature, and is an essential addition to hepatic cryosurgery.

Comparison of four intraoperative warming devices.

Ouellette, R.G., *Comparison of four intraoperative warming devices*. AANA J, 1993. 61(4): p. 394-6.

This prospective study of 60 patients undergoing elective cervical or lumbar laminectomy surgery compared the efficacy of various patient warming therapies. Patients were randomly assigned to one of five groups: a control group (no active warming), two humidifier-warming groups, a reflective space blanket, and a Bair Hugger™ upper body blanket connected to Bair Hugger warming unit turned on "low."

Mean esophageal temperatures were highest for the Bair Hugger therapy group at 60 minutes (36.2 ± 0.4°C), 90 minutes, and at end of surgery (36.3 ± 0.4°C), with no significant variance in mean core temperature between measurements.

In all other groups, mean core temperature at the end of surgery was lower than at the start (-0.6 ± 0.2°C for control, -0.57 ± 0.2°C and -0.32 ± 0.3°C for humidifiers, and -0.37 ± 0.3°C for space blanket).

Decreasing the degree of hypothermia during prolonged laparoscopic procedures.

This retrospective study of laparoscopic surgery patients examined average patient core temperature decrease following induction of anesthesia, and the efficacy of Bair Hugger™ forced-air warming therapy in mitigating perioperative hypothermia.

Average patient temperatures fell from 36.1°C to 33.3°C during the course of procedures lasting three to six hours. Patients who received warmed fluids and were warmed with a conductive pad experienced an average drop in temperature of 0.9°C, and returned to normal core temperature in the postoperative recovery room within one hour.

Patients who received Bair Hugger therapy in addition to the above warming methods experienced a drop of 0.5°C, with a return to normal temperature upon arrival in recovery.

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Convective warming therapy does not increase the risk of wound contamination in the operating room.

Zink, R.S. and P.A. Iaizzo, *Convective warming therapy does not increase the risk of wound contamination in the operating room*. Anesth Analg, 1993. 76(1): p. 50-3.

This balanced cross-over study evaluated whether Bair Hugger™ forced-air warming therapy increases the number of bacterial colonies, and thus risk of wound contamination, in a setting that mirrored intraoperative conditions during abdominal surgery.

Eight healthy volunteers lay on an operating table for four hours each, their lower bodies and legs covered with a sterile drape and warming cover. For half the subjects, Bair Hugger forced-air warming was activated for two hours. Unwarmed subjects served as the control group. A culture plate was placed through an opening in the surgical drape onto the abdomen of each subject.

There were no significant differences in bacterial counts between the groups. The authors concluded that Bair Hugger forced-air warming, when used correctly, does not increase the risk of airborne bacteria contaminating wounds during surgery.

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Prevention of hypothermia during hip surgery: effect of passive compared with active skin surface warming.

Bennett, J., et al., *Prevention of hypothermia during hip surgery: effect of passive compared with active skin surface warming*. Br J Anaesth, 1994. 73(2): p. 180-3.

In this prospective study of 45 patients undergoing elective hip arthroplasty under general anesthesia, patients were randomly assigned to a control group (no active intraoperative warming), a passive warming modality (the Thermolite™ metalized plastic sheet), or active, forced-air warming with Bair Hugger™ therapy to compare the relative efficacy of each approach.

In the first two groups, core temperatures measured in the aural canal decreased by 1.5°C and 1.0°C, respectively, accompanied by a significant decrease in mean body temperature. In the Bair Hugger therapy group, core temperature and body heat decreased by only 0.3°C and 3 KJ, respectively. The authors concluded that Bair Hugger therapy was very efficient in regulating patient temperature during surgery.

Bair Hugger™ forced-air warming maintains normothermia more effectively than thermo-lite insulation.

Borms, S.F., et al., *Bair Hugger forced-air warming maintains normothermia more effectively than thermo-lite insulation*. J Clin Anesth, 1994. 6(4): p. 303-7.

This prospective study compared the effectiveness of Bair Hugger™ forced-air warming therapy to a reflective insulation warming modality for maintaining intraoperative normothermia. Twenty patients undergoing elective total hip arthroplasty were randomly assigned to one of the two groups, and intraoperative core temperatures were taken with a distal esophageal sensor.

During the first 45 minutes of surgery, core temperature decreased by 0.5°C in both groups. Core temperature subsequently increased in the forced-air warming group, while decreasing in the other group. End-of-surgery mean core temperatures were 36.4 ± 0.6°C in the forced-air group and 35.4 ± 0.6°C in the group warmed with reflective insulation (P = < 0.01).

The authors concluded that Bair Hugger™ forced-air warming was effective in preventing inadvertent hypothermia during hip arthroplasty surgery, and reflective insulation was not.

Comparison of forced-air patient warming systems for perioperative use.

Giesbrecht, G.G., M.B. Ducharme, and J.P. McGuire, *Comparison of forced-air patient warming systems for perioperative use*. Anesthesiology, 1994. 80(3): p. 671-9.

This study of six male volunteers compared the efficacy of various forced-air warming systems: the Bair Hugger™ system, the Thermacare™ system (Gaymar Industries), the WarmAir™ system (Cincinnati Sub-Zero), and the WarmTouch™ system (Mallinckrodt Medical). Thermal flux transducers placed on 14 different body sites were used to measure total heat transfer and skin temperature in a 24.5°C ambient environment.

Bair Hugger therapy transferred the most overall heat: 95 ± 7 W, compared to 81 ± 6 W for the WarmTouch short hose system, 68 ± 8 W for the WarmTouch long hose system, 61 ± 5 W for the Thermacare system, and 38 ± 6 W for the WarmAir system (P < 0.05). When the warming covers from all systems were tested with the same warming unit, total heat transfer remained significantly greater for Bair Hugger therapy.

The authors concluded that Bair Hugger therapy was superior for transferring heat to the body core from peripheral skin surface areas.

Treatment of mild immersion hypothermia by forced-air warming.

Giesbrecht, G.G., M. Schroeder, and G.K. Bristow, *Treatment of immersion hypothermia by forced-air warming*, in Temperature Regulation: Advances in Pharmacological Sciences. 1994, Springer: Basel. p. 213-218.

This study of eight volunteers evaluated the efficacy of forced-air warming for treatment of immersion hypothermia. Hypothermia was induced by immersing subjects in 8°C water. They were then rewarmed with Bair Hugger™ forced-air warming, or without active warming by shivering inside a sleeping bag. Core and skin temperature, skin-surface heat flux, and metabolism measurements were taken.

While the rewarming rate for forced-air warming was not significantly different from shivering, skin temperature was significantly higher (3.7°C early, and 4.5°C in 35 minutes). The study found that forced-air warming reduced temperature afterdrop and the metabolic stress caused by shivering.

The authors concluded that Bair Hugger forced-air warming is a safe therapy that could be used for effective treatment of hypothermic patients in emergency departments.

Contact a 3M Representative

Rewarming cardiac surgery patients: radiant heat versus forced warm air.

Giuffre, M., T. Heidenreich, and L. Pruitt, *Rewarming cardiac surgery patients: radiant heat versus forced warm air*. Nurs Res, 1994. 43(3): p. 174-8.

This randomized control study of 38 postoperative cardiac surgery patients with induced hypothermia compared the performance of the Bair Hugger™ forced-air warming system and the Thermal Ceiling™ radiant heater for time to rewarm patients, incidence of patient shivering, and nurse preference. The study also collected data on six non-subjects treated with warmed blankets.

The forced-air warming system and noninfrared system were comparable in average time to rewarm (100.3 minutes and 99.3 minutes, respectively). Warmed blankets averaged 188.2 minutes to rewarm. The forced-air warming group experienced a significantly lower rate of shivering, higher skin temperatures, and reduced core temperature reduction after weaning from cardiopulmonary bypass (temperature afterdrop).

Nurses preferred Bair Hugger therapy over Thermal Ceiling radiant heating.

Effects of a forced-air system (Bair Hugger™, OR-type) on intraoperative temperature in patients with open abdominal surgery.

Matsukawa, T., et al., *Effects of a forced-air system (Bair Hugger, OR-type) on intraoperative temperature in patients with open abdominal surgery*. Journal of Anesthesia, 1994. 8(1): p. 25-27.

This randomized control study evaluated rectal (core) and fingertip temperature, (an index of the core-peripheral gradient), and incidence of shivering among 40 open abdominal surgery patients who received perioperative warming with or without the Bair Hugger™ forced-air warming system. All patients were warmed with a circulating-water mattress, while 20 patients also received Bair Hugger therapy.

The Bair Hugger therapy group experienced significantly higher core and fingertip temperatures, with significantly lower core-peripheral gradients. Neither group experienced shivering.

The authors conclude that Bair Hugger therapy is effective in warming open abdominal surgery patients.

Rate and gender dependence of the sweating, vasoconstriction, and shivering thresholds in humans.

Lopez, M., et al., *Rate and gender dependence of the sweating, vasoconstriction, and shivering thresholds in humans*. Anesthesiology, 1994. 80(4): p. 780-8.

The range of core temperatures not triggering thermoregulatory responses ("interthreshold range") remains to be determined in humans. Accordingly, the authors sought to (1) define the interthreshold range; (2) test the hypothesis that, at a constant skin temperature, the vasoconstriction and shivering thresholds are greater during rapid core cooling than during slowly induced hypothermia; and (3) compare the sweating, vasoconstriction, and shivering thresholds in men and women.

Eight men and eight women participated. No anesthesia or sedatives were administered. On two consecutive days, the male patients were cutaneously warmed with the Bair Hugger™ system until sweating was induced. The men then were cooled using infusion of cold fluid. The cooling rates were 0.7 ± 0.1°C/h on day one and 1.7 ± 0.4°C/h on day two, randomly ordered. Skin temperature was maintained near 36.7°C throughout each trial. The women were studied only once, in the follicular phase of their menstrual cycles, at the higher cooling rate.

Both men and women demonstrated an interthreshold range of approximately 0.2°C. However, all thermoregulatory response thresholds were approximately 0.3°C higher in women. All thresholds were virtually identical during slow and fast core cooling.

The authors successfully confirmed the existence of an interthreshold range in non-anesthetized humans, finding it to be small in magnitude. The research also showed that the interthreshold range is constant in both men and women, but that women thermoregulate at a much higher temperature than men.

Contact a 3M Representative

Use of forced-air warming during and after outpatient arthroscopic surgery.

Smith, I., C.D. Newson, and P.F. White, *Use of forced-air warming during and after outpatient arthroscopic surgery*. Anesth Analg, 1994. 78(5): p. 836-41.

In this prospective study, 127 arthroscopic knee surgery patients were randomly assigned to warming therapy with either a Bair Hugger™ forced-air warming system (active warming) or warmed cotton blankets (control). During the first phase of the study, both groups were warmed intraoperatively. In the second (unblended) phase, warming continued postoperatively.

Patients who received active warming with forced-air experienced a reduced decline in core temperature perioperatively, as well as increased skin temperature. Postoperative core temperature increased at the same rate for both groups, but the control group experienced lower core temperatures after one hour.

Thirty-five percent of all patients experienced postoperative shivering, but fewer actively warmed patients experienced prolonged postoperative shivering. Postoperative warming was observed to add little benefit beyond intraoperative warming. Though they experienced different rates of prolonged shivering, actively warmed patients and control patients had similar length of stay in recovery.

Evaluation of the efficacy of a forced-air warmer (Bair Hugger™) during spinal surgery in children.

This prospective study of 51 children undergoing posterior spinal fusion surgery under general anesthesia compared the perioperative rectal temperatures, time to the wake-up test, time to extubation, and blood loss among patients randomly assigned to warming treatment with either a 400W heat lamp (control) or the Bair Hugger™ forced-air warming system.

The minimum rectal temperature in the control group was 34.8 ± 0.6°C, versus a minimum temperature in the Bair Hugger therapy group of 35.6 ± 0.5°C. End-of-surgery temperatures were also significantly different: 35.4 ± 0.9°C in the control group and 36.5 ± 0.8°C in the Bair Hugger group (P<0.01).

The pattern of temperature decline was also markedly different. Rectal temperatures among the control group reached their lowest point at 180 minutes, and subsequent rewarming was reported as slow. In the Bair Hugger therapy group, lowest temperature was reached at 45 minutes, followed by more rapid rewarming. Time-to-wake up test, time to extubation, and blood loss for both groups were similar.

The authors conclude that Bair Hugger therapy is effective for warming spinal surgery patients, despite the fact that only about 20 percent of patient skin surface was accessible for warming.

Convective warming after hypothermic cardiopulmonary bypass.

Moors, A.H., et al., *Convective warming after hypothermic cardiopulmonary bypass*. Br J Anaesth, 1994. 73(6): p. 782-5.

This randomized study showed no effect of convective warming after hypothermic cardiopulmonary bypass on the rate of core body temperature increase, nor on the time to tracheal extubation. The convective warming systems used in this study were operated continuously at their medium (38°C) settings because of concerns regarding the low perfusion rates experienced by subjects during cardiopulmonary bypass.

Convective warming altered the relationship between core and peripheral temperature. The inadequate duration of rewarming on cardiopulmonary bypass prolonged body core warming time and prolonged time to tracheal extubation. The Bair Hugger™ Model 500 power unit set at 38°C was used with either Bair Hugger or Warm Touch (Mallinckrodt Medical UK Ltd, Northampton, UK) blankets to deliver convection warming. No difference between the two blanket types was observed.

Consequences and treatment of perioperative hypothermia.

Sessler, D.I., *Consequences and treatment of perioperative hypothermia*, in Anesthesiol Clin North America, J.L. Benumof, Editor. 1994, W.B. Saunders Company: Philadelphia. p. 425-456.

Perioperative hypothermia is common due to cold environment of the operating room combined with anesthetic-induced inhibition of thermoregulation. The recovery may take many hours after surgery completion. There are numerous complications associated with perioperative hypothermia (infections at incision site, coagulopathies, myocardial ischemia, prolonged action of drugs), as well as some potential benefits (protection against cerebral ischemia and malignant hypothermia).

While the authors called for risk/benefit analysis of thermal management, they also pointed out the existence of effective and extremely safe methods of prevention and treatment of perioperative hypothermia.

Postoperative warming therapy in the recovery room. A comparison of radiative and convective warmers.

Effective warming devices may accelerate rewarming. This leads to improved patient comfort and the suppression of shivering thermogenesis, in addition to other positive effects. This study was designed to compare the efficiency of warming devices in extubated postoperative patients and their effect on postoperative oxygen uptake (VO_2).

Thirty-five patients were randomly assigned to either postoperative nursing under a radiant heater (group R, n = 11, Aragona Thermal Ceilings CTC X), a forced air system (group L, n = 12, Bair Hugger™ therapy), or a normal cotton hospital blanket (group K, n = 12). Mean body temperature and total body heat were calculated from urinary bladder temperature and four subcutaneous temperature measurements. The rate of thermogenesis was calculated from continuous measurement of VO_2.

As measured by heat balance, both active treatments saved about 20% more body heat production than in the control group; however, rewarming rates did not differ among the groups. The low efficiency of postoperative heat transfer is likely caused by intense peripheral vasoconstriction following the reversal of anesthesia. In light of the postoperative difficulty in transferring heat to the thermal core, it is more reasonable to prevent intraoperative heat loss.

Hypothermia during elective abdominal aortic aneurysm repair: The high price of avoidable morbidity.

Bush, H.L., Jr., et al., *Hypothermia during elective abdominal aortic aneurysm repair: the high price of avoidable morbidity*. J Vasc Surg, 1995. 21(3): p. 392-400; discussion 400-402.

This retrospective study of 262 elective abdominal aortic aneurysm (AAA) repair patients compared, CICU Length of stay, hospital length of stay, and mortality and morbidity between patients with hypothermic (<34.5°C) or normothermic core temperatures. Both groups had similar preoperative risk factors.

Core body temperature was initially supported during surgery with a recirculating alcohol blanket. For the last nine months of the study, a forced-air system (Bair Hugger™ therapy) was applied to the head, neck, chest, and upper extremities.

Hypothermic patients were found to have significantly greater requirement for fluid ($p < 0.05$), transfusion ($p < 0.01$), vasopressor ($p < 0.05$), and inotrope ($p < 0.05$), and experienced significantly higher rates of organ dysfunction (53.0% vs 28.7%, $p < 0.01$) and death (12.1% vs 1.5%, $p < 0.01$). Hypothermia was also associated with significant increases in ICU length of stay (9.2 ± 2.0 vs 5.3 ± 0.6, $p < 0.05$) and hospital length of stay (24.3 ± 2.9 vs 15.0 ± 0.08, $p < 0.01$).

The authors conclude that regulation of patient temperature is important during AAA surgery.

Pre-induction skin-surface warming minimizes intraoperative core hypothermia.

Camus, Y., et al., *Pre-induction skin-surface warming minimizes intraoperative core hypothermia*. J Clin Anesth, 1995. 7(5): p. 384-8.

In this prospective study, 16 patients undergoing laparoscopic cholecystectomy surgery under general anesthesia were randomly assigned to one hour of active warming with Bair Hugger™ forced-air prior to induction (prewarming), or one hour of preoperative passive warming with a wool blanket (control). Skin surface and core (tympanic) temperature were measured.

The actively prewarmed group experienced an increase in skin temperature from 34.0 ± 0.1°C to 37.0 ± 0.2°C preoperatively, while the control group experienced no change in skin temperature. Preoperative core temperatures did not significantly change for either group. After induction of anesthesia, core temperature in the control group declined at a rate of >1°C per hour, compared to a decline of 0.6 ± 0.1°C per hour for patients who were actively prewarmed ($p < 0.05$). After one hour under anesthesia, core temperatures for six of eight patients prewarmed with forced-air were at least 36.5°C, versus one of eight control patients ($p < 0.05$).

The authors conclude that Bair Hugger active warming for one hour prior to induction reduced inadvertent hypothermia, and that prewarming is especially beneficial for meeting the challenge of treating redistribution hypothermia during short procedures.

Contact a 3M Representative

Haemodynamic and metabolic effects of surface rewarming after coronary revascularization.

Thirty cardiac surgery patients were randomized to either receive active warming using a Bair Hugger™ forced-air warming system (group A) or passive warming using cotton blankets (group B).

Temperatures (blood, esophagus, and skin at foot and thigh) were measured at admission to the ICU and thereafter at 30, 60, 90, 180, 270, and 450 minutes. Oxygen consumption and lactate concentration were also determined. Skin warmed more quickly in group A compared to group B, but there was no difference between the groups in core temperatures. Lower cardiac index, as well as lower oxygen consumption and lactate levels were observed in group A.

The authors concluded that active warming may benefit cardiac surgery patients by decreasing metabolic demand, even though no effect on core temperature was observed.

Rewarming hypothermic postanesthesia patients: a comparison between a water coil warming blanket and a forced-air warming blanket.

In this prospective study, 32 hypothermic (≤ 34.4°C) surgical patients were assigned to post-operative warming therapy with either the Bair Hugger™ forced-air warming system or a Blanketrol™ (Cincinnati Sub-Zero) water coil-heated hypothermia blanket to compare the efficacy of these methods in rewarming patients to a core (tympanic) temperature of 36.1°C. Temperature measurements were recorded every 30 minutes.

Bair Hugger therapy rewarmed patients nearly twice as fast (70 minutes vs. 139 minutes) than the conductive water mattress coil-heated device (p < 0.001).

The etiology and management of inadvertent perioperative hypothermia.

General anesthesia is associated with mild perioperative hypothermia, thus core temperature monitoring should be required during surgery. Core temperature can be measured reliably at a number of sites, such as the tympanic membrane, nasopharynx, esophagus, bladder, rectum, and pulmonary artery.

However, the skin surface is not an appropriate site for core temperature monitoring due to internal redistribution of heat following anesthetic-induced vasodilation. Such anesthetic-induced impaired thermoregulation is associated with a range of temperatures where no autonomic response to cold or warm occurs.

The authors of this review proposed that pre-anesthesia induction skin surface warming (prewarming) is effective in preventing the initial redistribution hypothermia and suggested that, intraoperatively, forced-air warming was the most effective method of rewarming for hypothermic patients. Among the forced-air warming systems available, the Bair Hugger™ system was found to be most effective.

Postoperative hemodynamic and thermoregulatory consequences of intraoperative core hypothermia.

Kurz, A., et al., *Postoperative hemodynamic and thermoregulatory consequences of intraoperative core hypothermia*. J Clin Anesth, 1995. 7(5): p. 359-66.

This study evaluated the postoperative hemodynamic and thermoregulatory consequences of intraoperative core hypothermia.

Seventy-four healthy patients undergoing elective colon surgery were randomly assigned to be kept normothermic with the Bair Hugger™ system or approximately 2.5°C hypothermic during surgery. Anesthesia was maintained with isoflurane, nitrous oxide, and fentanyl. Postoperatively, surgical pain was treated with patient-controlled analgesia (PCA) opioid.

Hypothermic patients felt uncomfortably cold during recovery, and their postoperative core temperatures remained significantly less than in the normothermic patients for more than four hours. Peripheral vasoconstriction and shivering were common in the hypothermic patients but rare in those kept normothermic.

Intraoperative hypothermia caused substantial postoperative thermal discomfort, and full recovery from hypothermia required many hours. Delayed return to core normothermia apparently resulted largely from postoperative thermoregulatory impairment.

Mild hypothermia alters propofol pharmacokinetics and increases the duration of action of atracurium.

Leslie, K., et al., *Mild hypothermia alters propofol pharmacokinetics and increases the duration of action of atracurium*. Anesth Analg, 1995. 80(5): p. 1007-1014.

In this study, the effects of mild hypothermia are examined by analyzing propofol pharmacokinetics, hepatic blood flow, and atracurium duration of action in healthy volunteers.

Six young volunteers were studied on two randomly assigned days, at core temperatures of either 34°C or 37°C. Anesthesia was induced with thiopental, 3 mg/kg, and maintained with 70% N_2O and 0.6% isoflurane. Core hypothermia was induced by conductive and convective cooling. On the other study day, normothermia was maintained by a Bair Hugger™ (Augustine Medical, Inc., Eden Prairie, MN) forced-air warmer.

Propofol blood concentrations averaged approximately 28% more at 34°C than at 37°C ($P < 0.05$). Also, the duration of action of atracurium was significantly prolonged in the hypothermic conditions.

Contact a 3M Representative

Heat flow and distribution during induction of general anesthesia.

Matsukawa, T., et al., *Heat flow and distribution during induction of general anesthesia*. Anesthesiology, 1995. 82(3): p. 662-73.

This study of six male volunteers evaluated the effect of anesthesia on heat balance and regional body temperature. Volunteers wearing minimal clothing underwent general anesthesia after 2.5 hours of exposure to an ambient temperature of approximately 22°C. Temperature measurements continued for three hours post-induction.

Prior to induction, core temperatures remained largely unchanged, but declined by 1.6 ± 0.3°C for the first hour following induction. Temperature redistribution from the core to periphery accounted for 81 percent of this reduction. A subsequent decline in core temperature of 1.1 ± 0.3° C per hour over the next two hours of anesthesia was 41 percent attributable to temperature redistribution. Over the three-hour duration of anesthesia, redistribution is responsible for a total of 65% of the reduction in core temperature. Subjects in the study were rewarmed using the Bair Hugger™ system.

The authors conclude that temperature redistribution, though reduced after one hour of anesthesia, remained the leading cause of core temperature decrease throughout the three hours of anesthesia.

Optimal duration and temperature of prewarming.

Sessler, D.I., et al., *Optimal duration and temperature of prewarming*. Anesthesiology, 1995. 82(3): p. 674-81.

This randomized crossover trial of seven volunteers evaluated the minimum duration of active prewarming (active warming prior to induction of anesthesia) necessary to significantly reduce anesthesia-induced temperature redistribution and accompanying hypothermia. In light of the fact that prewarming can cause thermal discomfort and sweating, the study also evaluated the optimal (lowest) temperature settings necessary for a forced-air warming device to effectively prewarm.

Volunteers participated in two separate study periods. Each began with a two-hour control period, followed by two hours of active warming with forced-air. During the first study period, the Bair Hugger™ forced-air warmer was set on "medium" (~40°C). During the second, the heater was set on "high" (~43°C). Intramuscular needle thermocouples, as well as temperature measurements on the skin and deep measurements in the feet, were used to determine heat content in the arms and legs.

Heat content in the arms and legs increased by 69 kcal during the 30 minutes of warming at the "high" setting, and 136 kcal overall during the first hour. Seventy-five percent of all heat content increase occurred during the first hour of warming. The increase in heat to arms and legs was only slightly less during the first hour when the heater was set on "medium." None of the volunteers experienced discomfort from the warming devices during the first hour, though many did after the first hour.

The authors conclude that 30 minutes of Bair Hugger forced-air warming increased the heat content of peripheral tissue by more than is normally lost through temperature redistribution during the hour following induction, and attribute the effectiveness of prewarming to a substantial increase in heat content in the arms and legs. During the first hour of warming, the subjects did not sweat or experience thermal discomfort despite an increase of almost 100 kcal of body heat.

Heat flow and distribution during epidural anesthesia.

Matsukawa, T., et al., *Heat flow and distribution during epidural anesthesia*. Anesthesiology, 1995. 83(5): p. 961-7.

Core hypothermia after induction of epidural anesthesia results from not only the flow of heat to the periphery, but also a net heat loss to the environment. This study was conducted to determine the contributions of each mechanism.

Twelve minimally clothed male volunteers were evaluated in an approximately 22°C environment for 2.5 control hours before induction of epidural anesthesia, The subjects were then monitored for an additional three hours. Epidural anesthesia produced a bilateral sympathetic block in only six volunteers, and only their results were reported. Shivering, when observed, was treated with intravenous meperidine. Overall heat balance was determined from the difference between cutaneous heat loss (thermal flux transducers) and metabolic heat production (oxygen consumption).

Arm heat content decreased approximately 5 kcal/hour after induction of anesthesia, but leg heat content increased markedly. Most of the increase in leg heat content was in the lower legs and feet. Core temperature increased slightly during the control period but decreased 0.8 ± 0.3°C in the first hour of anesthesia. Redistribution accounted for 89% of the initial decrease, requiring a net transfer of 20 kcal from the trunk to the extremities.

During the subsequent 2 hours of anesthesia, core temperature decreased an additional 0.4 ± 0.3°C, with redistribution contributing 62%. Thus, only 7 kcal were redistributed during the second and third hours of anesthesia. Redistribution therefore contributed 80% to the entire 1.2 ± 0.3°C decrease in core temperature during the three hours of anesthesia. Study subjects were rewarmed using the Bair Hugger™ system.

The authors concluded that core hypothermia during the first hour after induction of epidural anesthesia resulted largely from redistribution of body heat from the core to the legs. Despite the greater fractional contribution of redistribution during epidural anesthesia, core temperature decreased only half as much as during general anesthesia because metabolic rate was maintained and the arms remained vasoconstricted.

Convective warming combined with vasodilator therapy accelerates core rewarming after coronary artery bypass surgery.

In this prospective study, 20 coronary artery bypass patients were randomly assigned to receive postoperative warming therapy with either the Bair Hugger™ forced-air warming system or an aluminized plastic "space" blanket (control) to compare the effect of each on core (nasopharyngeal and rectal) temperature.

Nasopharyngeal temperatures for all patients were <36°C on admission to the ICU. During the first two hours after the procedure, Bair Hugger therapy ("high" setting) increased core temperature at a rate of 0.95°C/hour (nasopharyngeal) and 0.75 °C/hour (rectal). Rates for the control group were 0.4°C/hour and 0.25°C/hour, at the nasopharyngeal and rectal sites, respectively (P ≤ 0.01).

Evaluation of two warming systems after cardiopulmonary bypass.

In this prospective study, 30 adult cardiac surgery patients were randomly assigned to post-operative warming therapy with either the Thermomat™ electric undermattress (JMW Systems) or the Bair Hugger™ forced-air warming system to compare their effect on core (esophageal) temperature and skin temperature (lateral thigh). Both devices were adjusted to the highest setting.

The Bair Hugger therapy group experienced a more rapid increase in core temperature (0.5 vs 0.75°C/hour; P < 0.0002) and skin temperature (0.86 vs 1.3°C/hour; P < 0.001). There were no significant differences in the number of patients who reached a core temperature of 36°C or 37°C after four hours, or reached skin temperatures of 37°C in the same period. In the Bair Hugger therapy group, 12 patients reached skin temperatures of 36°C in four hours, versus two patients in the Thermomat group.

The authors conclude that Bair Hugger therapy warmed core and periphery faster than the alternative method, and warmed more patients to an esophageal temperature of 37°C in four hours; however, it did not reduce time to extubation.

Delayed forced-air warming prevents hypothermia during abdominal aortic surgery.

Karayan, J., et al., *Delayed forced air warming prevents hypothermia during abdominal aortic surgery*. Br J Anaesth, 1996. 76(3): p. 459-60.

This prospective study randomly assigned 18 abdominal aortic surgery patients to either no intraoperative warming (control), or active intraoperative warming with a Bair Hugger™ forced-air warming system utilizing an upper body blanket. Bair Hugger therapy began when patient core temperature declined to <36°C.

In both groups, core temperature declined by 0.6°C in the first hour of anesthesia and 0.4°C in the following hour. Core temperatures stopped declining after one hour in the Bair Hugger group, then began to rise. For the control group, core temperature continued to decline until the end of surgery.

End-of-surgery core temperatures for the Bair Hugger group were similar to temperatures before anesthesia, and were greater than those of the control group (P < 0.003).

Perioperative normothermia to reduce the incidence of surgical-wound infection and shorten hospitalization. Study of Wound Infection and Temperature Group.

In this prospective study, 200 colorectal surgery patients were randomly assigned to receive either no intraoperative active warming (control group; Bair Hugger™ forced-air system set to ambient), or active warming with the Bair Hugger forced-air system (positioned on the upper body), to compare subsequent rates of surgical site infection. Following surgery, surgical sites were evaluated daily while patients remained in the hospital, and two weeks after discharge.

Mean end-of-surgery core temperature was higher for the Bair Hugger therapy group than for the control group (36.6 ± 0.5°C versus 34.7 ± 0.6°C, P<0.001). Six percent (6 of 104) of patients in the forced-air warming group developed surgical site infections, compared to nineteen percent (18 of 96) patients in the control group (P=0.009).

The control group remained in the hospital an average of 2.6 days, or approximately 20 percent longer than the Bair Hugger therapy group (P = 0.01).

The authors conclude that hypothermia may affect wound healing and make patients more susceptible to wound infection, and that it is probable that preventing perioperative hypothermia will decrease rates of surgical site infection and shorten hospital length of stay for colorectal surgery patients.

The benefits of active rewarming after cardiac operations: a randomized prospective trial.

This prospective study compared the efficacy of the Bair Hugger™ forced-air warming system, an electric cover blanket, and passive warming with a "space" blanket (control), for rewarming patients following hypothermic coronary artery bypass grafting or first-time valve-replacement surgery.

Forced-air warming patients were rewarmed to normothermic levels in three hours versus four hours for the electric blanket groups and seven hours for the control group. Time to extubation for the Bair Hugger therapy group was 10.8 ± 0.6 hours, compared to 11.3 ± 1.0 hours for the electric blanket groups and 14.8 ± 0.8 hours for the control group. In the first 12 hours following surgery, the electric blanket group required lower dosages of morphine compared to the control group 6.5 vs. 10.4 mg; p = 0.004).

The authors found no significant differences between warming with forced-air or the electric blanket, and therefore recommended use of the electric blanket for routine surgeries as a cost-saving measure.

The effects of forced-air warming on postbypass central and skin temperatures and shivering activity.

Mort, T.C., T.D. Rintel, and F. Altman, *The effects of forced-air warming on postbypass central and skin temperatures and shivering activity*. J Clin Anesth, 1996. 8(5): p. 361-70.

A randomized study compared two patient postoperative rewarming techniques (Bair Hugger™ forced air warming and passive warming using cotton blankets) to address if forced-air skin-surface warming used after hypothermic cardiopulmonary bypass (CPB) would reduce the incidence and severity of postbypass shivering. It also evaluated whether forced-air warming would rapidly increase skin-surface temperatures and whether it would lead to excessive core temperature increase compared to cotton blankets.

After hypothermic CPB, 47 patients were randomly assigned to either warmed cotton blankets or Bair Hugger forced-air warming. Shivering was assessed using four lead electromyographic recordings and core and skin temperatures were measured every 30-minutes during the 5.5 hours postoperative evaluation period. Compared to cotton blankets, forced-air warming led to significant decreases in shivering. While the skin surface temperatures were clinically and significantly increased with forced-air warming, the increase in central temperatures were comparable to the temperatures with the use of cotton blankets.

The authors concluded that forced-air warming reduced shivering, while not causing excessive central temperature elevation when compared to the use of cotton blankets.

Mild hypothermia increases blood loss and transfusion requirements during total hip arthroplasty.

Schmied, H., et al., *Mild hypothermia increases blood loss and transfusion requirements during total hip arthroplasty*. Lancet, 1996. 347(8997): p. 289-92.

In this prospective study, 60 total hip arthroplasty patients were randomly assigned to normothermia (defined as end-of-surgery core temperature of 36.6°C) or mild hypothermia (≤ 35°C) to compare blood loss and transfusion requirements between the two groups. Bair Hugger™ forced-air warming therapy was used to maintain normothermia in the first group. Strict protocols were used for blood and fluid administration.

The hypothermic group experienced significantly higher intra- and postoperative blood loss: 2.2 (0.5) L vs 1.7 (0.3) L, P = <0·001. Only one normothermic patient required packed red blood cells (one unit), compared to a total of eight units for seven hypothermic patients (p = <0.05).

The authors conclude that prevention of intraoperative hypothermia among total hip arthroscopy patients reduces blood loss and transfusion requirement.

Forced air speeds rewarming in accidental hypothermia.

Steele, M.T., et al., *Forced air speeds rewarming in accidental hypothermia*. Ann Emerg Med, 1996. 27(4): p. 479-84.

This randomized study was carried out in two university-affiliated emergency departments, and it enrolled 16 adult hypothermia victims with core temperatures less than 32°C. The patients were randomized to receive either active warming with the Bair Hugger™ system (forced air group) or passive warming (cotton blankets, control group). Both groups received warmed IV fluids.

The initial temperatures were similar in both groups: 28.8 ± 2.5°C in the forced air group and 29.8 ± 1.5°C in the control group. However, in the forced air group the temperature rose by 1°C per hour faster than in control group (2.4°C/hour and 1.4°C/hour, respectively, P=0.01).

Therefore, forced air warming was more effective by accelerating the rate of rewarming without producing complications in hypothermic patients.

Contact a 3M Representative

Convection warmers--not just hot air.

Avidan, M.S., et al., *Convection warmers--not just hot air*. Anaesthesia, 1997. 52(11): p. 1073-6.

This study was conducted to determine whether the forced air convection warmers (nine Bair Hugger™ warming units, Augustine Medical, and one WarmTouch™, Mallinkrodt Medical) used in the authors' operating theatres could be a source of microbial pathogens.

Agar plates were placed directly in the air stream of the warmers. Four of these grew potentially pathogenic organisms. Three of the nine Bair Hugger units and the WarmTouch unit grew potentially pathogenic organisms. When the airstream of two of the three Bair Hugger units was tested with the perforated blankets attached, no growth occurred.

The paper reports that when the devices were used properly (i.e., with a blanket attached) no contamination was found. Avidan and colleagues conclude that forced-air warming is safe when the blanket is attached and the filter is changed regularly.

Thermal softening of tracheal tubes: an unrecognized hazard of the Bair Hugger™ active patient warming system.

The Bair Hugger™ system is a new and highly effective active patient warming system which produces a layer of warm air between the patient and the warming system. This paper reports an instance of marked softening and distortion of a polyvinyl chloride tracheal tube caused by inadvertent placement of the warming blanket.

Active warming, not passive heat retention, maintains normothermia during combined epidural-general anesthesia for hip and knee arthroplasty.

Berti, M., et al., *Active warming, not passive heat retention, maintains normothermia during combined epidural-general anesthesia for hip and knee arthroplasty*. J Clin Anesth, 1997. 9(6): p. 482-6.

Investigators enrolled 30 orthopedic surgery patients with ASA physical status I and II who underwent elective hip or knee arthroplasty into this randomized, controlled study.

The patients were anesthetized through a combination of epidural and general anesthesia. The patients received either of three treatments: low-flow anesthesia only (control, n=10), low flow anesthesia and reflective blankets (blankets, n=10) or low flow anesthesia and active forced air warming (Bair Hugger™ forced-air, n=10). Temperature was measured at OR arrival (baseline), at anesthesia induction and every 30 minutes after that until 120 minutes from anesthesia induction.

The results showed that 30 minutes after induction, temperature decreased in all three groups, compared to baseline (P<0.01). In all three groups, the temperature significantly decreased from baseline after 30 minutes from induction (P<0.01). Then, the temperature in control and blanket group continued to decrease reaching 2°C and 1.6°C reduction in control and blanket groups, respectively, by the end of the surgery. However, after the initial drop, core temperature in the forced-air group started to increase, reaching levels similar to baseline (35.8 ± 0.6°C) and were significantly higher compared to the other two groups (P=0.004).

Therefore, passive heat maintenance using passive warming or reflective blankets were ineffective in maintaining intraoperative normothermia. Forced-air warming was superior to either reflective blankets or conventional heat preservation techniques in maintaining intraoperative core temperature.

Air-convection heater for abdominal surgery. A study of the relation between surgical time and the efficacy of body temperature maintenance.

Campos-Suarez, J.M., et al., [*Air-convection heater for abdominal surgery. Study of the relation between surgical time and the efficacy of body temperature maintenance*]. Rev Esp Anestesiol Reanim, 1997. 44(2): p. 47-51.

This prospective study of 27 adult abdominal laparotomy patients compared the efficacy of the Bair Hugger™ forced-air warming system against no active warming (control) for maintaining intraoperative patient core temperature (esophageal). Temperatures were recorded every 30 minutes post-induction.

Significant differences in core temperature were observed between the two group after two hours of surgery, and these differences increased throughout the length of the procedure. End-of-surgery core temperature for the Bair Hugger therapy group was 36.4 ± 0.5°C, versus 34.7 ± 1.1°C for the control group. Temperatures following ICU admission were 36.3 ± 0.6°C for the Bair Hugger therapy group and 34.8 ± 1.0°C for the control group (P= < 0.0001).

The authors conclude that Bair Hugger therapy limited core temperature decline after induction of anesthesia and reversed its course, and was effective for abdominal procedures of ≥ 2 hours, despite the initial drop in core temperature caused by anesthesia-induced vasodilation (redistribution).

Deep accidental hypothermia and cardiac arrest--rewarming with forced air.

This case report describes use of the Bair Hugger™ forced-air warming system instead of cardiopulmonary bypass (CPB) for rewarming five severely hypothermic (core temperature <30°C) emergency patients. Patients were treated with Bair Hugger therapy over-the-body blankets connected to warming units set at 38°C.

Upon initiation of warming therapy, core temperatures increased an average of 1°C per hour for all patients. There was no afterdrop in core temperature during rewarming. All patients had positive outcomes without neurological complications.

The authors conclude that Bair Hugger forced-air warming therapy is a viable alternative to CPB for patients with electrical activity, and could be especially useful for facilities without CPB capabilities or when patients cannot be transferred to major hospitals. They further note that forced-air warming is inexpensive, simple to implement, and allows for continued patient access during treatment.

Control of body temperature with forced-air warming system during neurosurgery.

The efficacy of forced-air warming in preventing intra-operative hypothermia and post-operative shivering was evaluated in 30 patients undergoing elective neurosurgery. The control group (n = 15) received no intra-operative warming device and the active warming group (n = 15) had Bair Hugger™ forced-air warming.

All the patients received general anaesthesia. The core temperature was measured at half-hourly intervals using oesophageal probe during intra-operative and post-operative periods. Postoperative level of consciousness and shivering were also observed.

Core temperature decreased by nearly 1°C in both the groups in first hour (35.58 ± 0.22°C in control group and 35.70 ± 0.28°C in forced-air warming group). In the control group however, the core temperature continued to decrease until the end of surgery (34.22 ± 0.37°C at the second and third hour and 34.73 ± 0.33°C at the end). But, in the Bair Hugger forced-air warming group the reduction in core temperature ceased after 1 hour of warming and then rewarming began (35.76 ± 0.28°C at second hour, 35.78 ± 0.25°C at third hour and 36.10 ± 0.56°C at the end).

All the patients of control group were hypothermic at the end of surgery. In contrast, all the patients remained normothermic in the Bair Hugger forced-air warming group (p < 0.001). 77% of patients in control group had post-operative shivering, but, in the forced-air warming group not a single patient had post-operative shivering.

The authors concluded that forced air-warming with the Bair-Hugger system is an effective method to maintain normothermia during and following neurosurgery.

Heat conservation vs convective warming in adults undergoing elective surgery.

The authors evaluated the efficacy of convective warming to maintain perioperative normothermia. The study randomized 37 patients undergoing elective surgery (gynaecological, orthopaedic, or general) lasting longer than two hours.

Group 1 received reflective blankets and warmed IV fluids preoperatively, while group 2 received convective warming with the Bair Hugger™ system and IV fluid at room temperature after anesthetic induction. Temperatures (tympanic and fingertip skin) were measured perioperatively every 15 minutes. Results showed that, after the initial decrease in temperature (35.9 ± 0.1°C and 36.0 ± 0.1°C in group 1 and 2, respectively), the temperature in group 2 increased to preinduction values, which were significantly higher than in group 1 ($P < 0.05$).

A significantly higher number of patients in group 2 were normothermic at the end of surgery (95% vs 69%, $P < 0.05$). During the first 30 minutes in PACU, central temperatures were higher in group 1 than in group 2, 36.8 ± 0.1 °C vs 36.2 ± 0.2°C, $P < 0.05$), but after 60 minutes, they were similar (36.8°C). Bair Hugger forced-air warming increased the likelihood the patients would leave the operating room normothermic.

Postanesthetic vasoconstriction slows peripheral-to-core transfer of cutaneous heat, thereby isolating the core thermal compartment.

Plattner, O., et al., *Postanesthetic vasoconstriction slows peripheral-to-core transfer of cutaneous heat, thereby isolating the core thermal compartment*. Anesth Analg, 1997. 85(4): p. 899-906.

This study included six volunteers who were anesthetized and passively cooled to a core temperature of 34°C, when anesthesia was discontinued.

Shivering was prevented with meperidine and the volunteers were warmed on day 1 with warmed cotton blankets for 2 hours. The cotton blankets were warmed to 50°C and replaced every 15 minutes. On the next day, the procedure was repeated and the volunteers were then warmed with a Bair Hugger™ forced-air warming blanket. Intramuscular and skin thermocouples were used to measure the peripheral temperature. Predicted changes in core temperature were calculated and compared to a previous day's similar study.

Compared to blanket warming, active forced-air warming significantly increased body heat content (159 ± 35 kcal (mean ± SD), P<0.001). Active forced-air warming also significantly increased both peripheral and core body temperature (3.3 ± 0.7°C and 1.1 ± 0.4°C, respectively). Compared to periodically-replaced warmed cotton blankets, forced-air increased the body temperatures faster.

The authors concluded from these results and those from other studies that anesthetic-induced vasodilation influences intercompartmental heat transfer and distribution of body heat more than thermoregulatory shunt vasomotion.

Mild Perioperative Hypothermia.

Sessler, D.I., *Mild Perioperative Hypothermia*. N Engl J Med, 1997. 336(24): p. 1730-7.

This comprehensive review article discusses the effects of operation of the human thermoregulatory system and its response to anesthesia. The human thermoregulatory system usually maintains a core body temperature near 37°C. Perioperative hypothermia, however, is common because of heat redistribution casued by the inhibition of thermoregulation induced by anesthesia and the patient's exposure to a cool environment.

Hypothermia leads to numerous complications, including coagulopathy, morbid cardiac events, and a decreased resistance to surgical-wound infection. Body temperature should be monitored during anesthesia and, in most cases, efforts should be made to maintain perioperative normothermia.

Prevalence of inadvertent hypothermia during the perioperative period: a quality assurance and performance improvement study.

Defina, J. and J. Lincoln, *Prevalence of inadvertent hypothermia during the perioperative period: a quality assurance and performance improvement study*. J Perianesth Nurs, 1998. 13(4): p. 229-35.

This quality improvement study of 502 surgical patients compared the effectiveness of Bair Hugger™ forced-air warming therapy to standard warming therapy for preventing inadvertent perioperative hypothermia, and evaluated length of stay in recovery for hypothermic versus normothermic patients.

Patients treated with Bair Hugger therapy were less likely to arrive in recovery with hypothermic core temperatures compared to patients who did not receive forced-air warming, even after longer procedures. Normothermic patients also experienced shorter stays in the recovery unit.

Following the study, Bair Hugger therapy was made available to operating rooms in this facility.

Normothermia is protective during infrarenal aortic surgery.

Elmore, J.R., et al., *Normothermia is protective during infrarenal aortic surgery*. J Vasc Surg, 1998. 28(6): p. 984-92; discussion 992-4.

In this prospective study, 100 infrarenal aortic surgery patients were randomly assigned to warming therapy with either a circulating water mattress or Bair Hugger™ forced-air warming to compare the effect of each on core temperature and assess the impact of hypothermia on patient outcomes.

The forced-air warming group had significantly higher core temperatures during surgery (36.3 ± 0.7°C vs 35.4 ± 0.8°C). End-of-surgery temperature was also significantly higher for the forced-air warming group (36.4 ± 0.7°C vs 35.6 ± 0.9°C). The forced-air warming group experienced significantly less perioperative metabolic acidosis than the circulating water mattress group (P = 0.03). Death rates, postoperative length of stay, and cardiac complications were not significantly different between the two groups; however, patients with aneurysms and who were normothermic had significantly improved postoperative outcomes.

The authors conclude that Bair Hugger forced-air warming therapy had a significant impact on metabolic acidosis, and that patients actively warmed with forced-air remained significantly warmer than those treated with a circulating water mattress.

Contact a 3M Representative

Benefits of intraoperative skin surface warming in cardiac surgical patients.

Hohn, L., et al., *Benefits of intraoperative skin surface warming in cardiac surgical patients*. British Journal of Anaesthesia, 1998. 80: p. 318-323.

This randomized, controlled study enrolled 86 patients undergoing cardiac surgery with hypothermic bypass.

The goal was to investigate whether skin surface warming in addition to systemic rewarming on bypass (heated group, N=43) would be effective in preserving perioperative thermal balance, compared to conventional management without skin warming (control group, N=43). Skin warming was achieved by using a water mattress and Bair Hugger™ forced warm air blanket over the face, neck and shoulders. The results showed that active warming in the heated group was effective in attenuating the afterdrop of nasopharyngeal temperature after being taken off bypass; the drop was 2.3 (1.2) °C and 1.3 (0.5) °C in control and heated group, respectively ($P<0.05$).

The blood loss from the chest tube was lower in heated group (600, (264) ml), versus 956 (448 ml) in the control group, ($P< 0.05$) and the requirement for IV colloid infusion was lower 1662 (404 ml) in the heated group versus 1994 (389 ml) in the control group ($P < 0.05$). Therefore, additional skin surface warming led to preserved perioperative thermal balance and may contribute to a reduction in bleeding after cardiac surgery.

Forced-air surface warming versus oesophageal heat exchanger in the prevention of perioperative hypothermia.

In this prospective study, 24 abdominal surgery patients were randomly assigned to either Bair Hugger™ forced-air warming (applied to the upper body and upper thorax), treatment with an esophageal heat exchanger, or no warming (control), to compare the effect of each on core, skin, and mean body temperature. Temperatures were recorded at induction of anesthesia and every 30 minutes intraoperatively.

There was no significant difference in core temperature between patients treated with the esophageal heat exchanger and the control group, so these groups were pooled into one internal group. Patients in this group experienced hypothermia. Patient temperatures were significantly different for the forced-air warming group versus the internal group, and patients in the forced-air warming group did not experience hypothermia.

The authors conclude that esophageal heat exchangers were not effective at preventing inadvertent perioperative hypothermia for patients undergoing abdominal procedures of ≥ 2 hours, whereas Bair Hugger forced-air warming of the upper body was effective at hypothermia prevention.

Forced air warming and intraoperative hypothermia.

Lindwall, R., et al., *Forced air warming and intraoperative hypothermia*. European Journal of Surgery, 1998. 164(1): p. 13-16.

In this prospective study, 28 patients undergoing lengthy thoracoabominal surgery under general and regional anesthesia were randomly assigned to intraoperative warming therapy with either Bair Hugger™ active forced-air warming or passive heat preservation (control) to assess perioperative patient temperature.

Patient temperature among the Bair Hugger forced-air warming group did not significantly change during surgery: mean temperature at the start of surgery was 36.8°C versus 36.9°C at three hours. Temperatures in the control group declined from 36.8°C to 35.1°C.

The authors conclude that intraoperative warming with Bair Hugger forced-air warming can prevent hypothermia during lengthy thoracoabdominal surgery.

Convective warming blankets improve peroperative heat preservation in congenital heart surgery.

Schlunzen, L., et al., *Convective warming blankets improve peroperative heat preservation in congenital heart surgery*. Paediatr Anaesth, 1998. 8(5): p. 397-401.

Maintenance of perioperative normothermia during congenital heart surgery in children has presented a challenge to anesthesiologists.

This retrospective study enrolled 50 children undergoing heart surgery involving hypothermic cardiopulmonary bypass (CPB) and randomly assigned them to two groups, comparable in age, weight and anesthetic management: group 1 (n=25) was rewarmed by CPB and heating mattress and group 2 (n=25) was rewarmed by CPB, heating mattress and Bair Hugger™ convective warming blankets.

While the peripheral temperatures were significantly lower in group 2, no difference in central temperature was observed at the end of bypass. However, both central and peripheral temperatures were significantly higher in group 2 at the end of surgery.

Thus, the authors concluded that convective blankets were effective in maintaining and even increasing the temperature during such congenital heart surgery.

Comparison of perioperative heating modalities in anesthetized adult patients: A prospective, randomized study.

The aim of this randomized study was to evaluate the maintenance of perioperative normothermia (>35.5°C) by using Bair Hugger™ convective warming with or without IV fluid warming in 58 adult patients undergoing elective surgery.

The patients were randomly assigned to either group I: convective warming with room temperature (~21°C) fluids, (n=20); group II: convective warming with IV fluid warming (n=19); or group III: IV fluid warming alone (n=19). The surgeries lasted >2 hours and were performed under general anesthesia. At the end of the surgeries, the average core temperature was >36°C in all groups. The rate of post-operative hypothermia (<35.5°C) was the highest in group III (26%), compared to groups I and II (0% and 11%, respectively), ($P < 0.05$ group III versus group I).

This was associated with higher rate of post-operative interventions and shivering in group III compared with the other two groups (37% versus 10% and 11% in groups I and II, respectively, $P < 0.05$). No clinical advantage for warming fluids was observed when such a modest rate of approximately 12.5 mL/minute was combined with convective warming.

Contact a 3M Representative

Bair Hugger active patient warming system.

Taylor, I., *Bair Hugger active patient warming system.* British journal of anaesthesia, 1998. 80(3): p. 409.

Comment on case report of Ayala and Coe (British Journal of Anaesthesia, (1997) Vol. 79, pp. 543-545).

Having personally experienced a similar problem I have a simple and effective solution. This is to make a small hole in the clear plastic region of the Bair Hugger (designed to cover the patient's head) and to pass the tracheal tube through this, thus effectively removing it from the warmed environment. I have encountered no recurrence of the problem since adopting this method.

Hypothermia does not result in more complications after colon surgery.

Barone, J.E., et al., *Hypothermia does not result in more complications after colon surgery*. Am Surg, 1999. 65(4): p. 356-9.

In this article, the authors conducted a chart review of 150 consecutive colorectal surgery patients to determine the prevalence of hypothermia, and determine whether patients experiencing hypothermia (intraoperative temperature <95.5°F) had increased incidence of complications compared to normothermic patients.

Nearly all patients were warmed with one or more modalities (111 patients were warmed with the Bair Hugger™ system). Analysis was performed on a number of parameters (intraoperative and postoperative temperature, use of warming devices, duration of surgery, transfusions, interval to oral intake and bowel function, length of stay, complications, infections, and laboratory values). There were 101 normothermic and 49 hypothermic patients.

The authors concluded that the rates of postoperative complications were similar in both groups. The authors also concluded that further studies would be needed to determine the adverse effects of hypothermia.

Inadvertent hypothermia prevention: the anaesthetic nurses' role.

Up to 90% of patients experience hypothermia perioperatively. Inadvertent hypothermia can have a profound physiological effect on the body, varying from mild vasoconstriction and feeling cold to cardiac arrest and death.

This article discusses why forced air warmers such as the Bair Hugger™ system are the most effective means of preventing and treating heat loss. Nurses should be aware of the risks of hypothermia so that modes of prevention can be employed to minimize the risks of inadvertent hypothermia.

Measurement of CO$_2$ hypothermia during laparoscopy and pelviscopy: how cold it gets and how to prevent it.

Jacobs, V.R., et al., *Measurement of CO$_2$ hypothermia during laparoscopy and pelviscopy: how cold it gets and how to prevent it*. J Am Assoc Gynecol Laparosc, 1999. 6(3): p. 289-95.

This is a prospective evaluation of intra-abdominal CO$_2$ temperature during a variety of standard operative laparoscopy procedures with different insufflators (BEI Medical, Snowden & Pencer, Storz Laparoflator, Storz Endoflator, Wolf) and devices to maintain body temperature (Bair Hugger™ system, fluid warmer, Blanketrol™ blankets).

Sixty-two consecutive patients underwent standard laparoscopic and pelviscopic procedures during which intraoperative temperature changes in the insufflation system, abdomen, and rectum were measured.

Preoperative and postoperative temperature comparisons showed no decline in rectal temperature (average +0.18°C) because warming equipment was sufficient. In operations longer than 1 hour, substantial core body temperature drop should be prevented with appropriate heating and hydration devices.

Mild hypothermia does not increase blood loss during total hip arthroplasty.

Johansson, T., B. Lisander, and I. Ivarsson, *Mild hypothermia does not increase blood loss during total hip arthroplasty*. Acta Anaesthesiol Scand, 1999. 43(10): p. 1005-10.

In this prospective study, 50 patients undergoing primary prosthetic hip surgery were randomly assigned to receive no active warming (n=25) or Bair Hugger™ forced-air warming (n=25) while under spinal anesthesia to determine the effect of forced-air warming on patient blood loss. Core temperature was measured on the tympanic membrane. Perioperative blood loss was measured using the lost hemoglobin method, and hospital-stay blood loss was calculated via hemoglobin balance.

There was no difference in preoperative variables or the number of allogeneic units transfused between the groups. Intraoperative temperature decreased by 0.5 ± 0.4°C (P<0.0001) among warmed patients, and 1.3 ± 0.6°C (mean ± SD) in the control group. There was no significant difference in blood loss between the two groups.

The investigators concluded that forced-air warming did not affect blood loss among patients, while noting that methods used to determine blood loss produced widely different results.

Warming with a forced air warming blanket minimizes anesthetic-induced hypothermia in cats.

In this prospective study, eight adult domestic shorthair cats (four female, four male) anesthetized with halothane in oxygen received various levels of warming therapy with a modified Bair Hugger™ forced-air warming blanket (43°C) to examine the effect of this warming treatment on prevention of anesthesia-induced hypothermia.

Each cat underwent four trials lasting 90 minutes: first with continual warming (90 minutes); followed by delayed warming (45 minutes of no warming, then 45 minutes of warming); discontinued warming (45 minutes of warming, followed by no warming); and no warming. Temperature measurements were taken at regular intervals from the tympanic membrane, caudal esophagus, deep rectum, and toe-web.

Cats receiving continuous forced-air warming had significantly higher mean body temperatures than those receiving no forced-air warming or delayed warming. The mean body temperature of cats receiving forced-air warming was 0.9°C higher than those who received no warming. The investigators concluded that forced-air warming may be a successful method of reducing anesthesia-induced hypothermia in cats.

Maintaining intraoperative normothermia: a meta-analysis of outcomes with costs.

This meta-analysis of 18 clinical studies, covering 1575 patients, examined outcomes and costs associated with inadvertent perioperative hypothermia. A total of 16 out of 18 studies referenced in the meta-analysis involved forced-air warming, and all but two of these studies included Bair Hugger™ therapy.

The author found that risk of costly complications among a wide variety of surgical patients significantly increased when intraoperative patient core temperature declined by 1.5°C.

Analysis of the combined results of all studies also revealed that forced-air warming was significantly more effective than other warming modalities (circulating water mattress, passive warming, humidified air, space blanket, or "method not specified") at maintaining perioperative normothermia. Among the studies referenced, the lowest core temperature reached for patients warmed with forced-air averaged 1.5°C higher than for other methods.

The author notes that (at the time of publication), forced-air warming was in use at two-thirds of U.S. hospitals, and cites 19 studies that support the effectiveness of forced-air warming in decreasing the risk of negative patient outcomes and their associated costs.

The cost of preventing intraoperative hypothermia is much less than the cost of treating the adverse outcomes that affect patients experiencing intraoperative hypothermia. The analysis concludes that hypothermia averaging only 1.5°C less than normal resulted in cumulative adverse outcomes adding between $2,500 and $7,000 per surgical patient to hospitalization costs across a variety of surgical procedures.

In conclusion, patients whose temperatures have been maintained at normal levels during the intraoperative period experience fewer adverse outcomes, and their overall hospital costs are lower. Intraoperative normothermia is maintained more effectively with the use of forced air warming.

Contact a 3M Representative

The potential for increased risk of infection due to the reuse of convective air-warming/cooling coverlets.

Sigg, D.C., A.J. Houlton, and P.A. Iaizzo, *The potential for increased risk of infection due to the reuse of convective air-warming/cooling coverlets*. Acta Anaesthesiol Scand, 1999. 43(2): p. 173-6.

The authors expressed that there is no information available as to the potential risks for infection associated with either the postsurgical reuse or the repositioning of Bair Hugger™ convective coverlets closer to the wound. Their hypothesis is that use of coverlets either intra- or postoperatively leads to increased contamination.

The bacterial contamination of commercially available coverlets before (control group, n=10) and after patient application (n=18) was investigated. Pieces of coverlet were removed and analyzed for bacterial contamination from 3 predetermined sites.

Following clinical use, the frequency of contamination was considerably increased; 17 out of 57 sampled sites (31.5%) elicited contamination (P<0.05, Fisher's exact test).

This study demonstrates that the reuse of the coverlets, intra- or postoperatively, can lead to significant bacterial contamination. The authors concluded that it is not advisable to reuse coverlets for multiple clinical applications.

Effectiveness of forced air warming after pediatric cardiac surgery employing hypothermic circulatory arrest without cardiopulmonary bypass.

Guvakov, D.V., et al., *Effectiveness of forced air warming after pediatric cardiac surgery employing hypothermic circulatory arrest without cardiopulmonary bypass*. Journal of Clinical Anesthesia, 2000. 12(7): p. 519-24.

In this prospective study, 24 pediatric cardiac surgery patients recovering from induced hypothermia were randomly assigned to receive post-surgical warming therapy with either Bair Hugger™ forced-air warming (N=13) or radiant heat (N=11) to test the rewarming effectiveness of forced-air therapy.

The subjects were noncyanotic patients undergoing repair of atrial or ventricular septal defects who had undergone perfusionless deep hypothermic circulatory arrest and had been initially rewarmed in the operating room with warm saline lavage of the pleural cavities.

The forced-air warming group experienced a greater ICU rewarming rate (rectal measurement) than the radiant heat group (2.43 ± 1.14°C/hr, versus 2.16 ± 1.02°C/hour, $p < 0.05$). ICU length of stay, and the duration of ventilator support, was the same for both groups.

The investigators concluded that both warming methods were effective for rewarming moderately hypothermic pediatric patients, while the forced-air warming group experienced a 21 percent faster instantaneous rewarming rate when patients were admitted to recovery with core temperatures >33°C.

The Bair Hugger™ patient warming system in prolonged surgery.

In this observational study, air and wound-site bacterial colony counts were taken during 16 surgical procedures involving patients undergoing aortic surgery with graph insertion to test whether Bair Hugger™ forced-air warming increased risk of surgical site infection in prolonged surgery. Mean procedure and forced-air warming duration was 234 minutes.

Standard centrifugal air sampler and agar touch plate methods were used to collect air and wound-site specimens. Readings were taken at the start of the operation, when Bair Hugger forced-air warming was first applied, and at the end of the operation. There was a significant decrease in operating room colony counts at the end of surgery, and exhaust air colony counts remained similar throughout the procedures.

All wound-site specimens were found to be sterile, and no patients developed post-operative surgical site infections. The investigators concluded that Bair Hugger system does not increase contamination of the surgical field or increase risk of surgical site infection during prolonged surgery.

Prevention of intraoperative heat loss using a circulating air heating blanket during minimally invasive aorto-coronary bypass surgery.

In this prospective study of 18 patients undergoing minimally invasive aorto-coronary bypass (ACB) procedures, patients were randomly assigned to receive warming therapy with either the Bair Hugger™ forced-air warming system (Model 630 cardiac blanket) in combination with standard warming therapy (circulating water blanket and fluid warming), or with standard warming therapy alone. The study objective was to assess the efficacy of adding Bair Hugger therapy to standard warming therapy to achieve reduced intraoperative heat loss.

Operating room temperature was raised to 24°C (relative humidity 60%) for both groups to reduce heat loss. Intraoperative patient temperature in the Bair Hugger therapy group increased quickly, and end-of-surgery temperature was similar to baseline temperature.

The authors conclude that forced-air warming with the Bair Hugger system helped to reduce heat loss beyond standard warming therapy alone, and recommended use of the system.

Efficacy of two methods for reducing post bypass after-drop.

Rajek, A., et al., *Efficacy of two methods for reducing postbypass afterdrop*. Anesthesiology, 2000. 92(2): p. 447-56.

In this prospective study, 50 surgical patients undergoing cardiopulmonary bypass were randomly assigned to either Bair Hugger™ forced-air warming, vasodilation with sodium nitroprusside, or control, to compare post-bypass reduction in core temperature ("afterdrop") between each group. Twenty patients were assigned to the forced-air warming group, while the remaining 30 were randomly assigned to vasodilation or control.

During cardiopulmonary bypass, patients were cooled to approximately 32°C (nasopharyngeal measurement) and then rewarmed to approximately 37°C nasopharyngeal (rectal 36°C). Forced-air warming was initiated during bypass and continued to end of surgery. Sodium nitroprusside was administered to maintain a mean arterial pressure of approximately 60mm.

Core temperature afterdrop was 0.5±0.2°C for the forced-air warming group, 0.8±0.3°C for the nitroprusside group, and 1.1±0.3°C for the control group. Duration of afterdrop was 27±14 minutes, 34±10 minutes, and 44±13 minutes for the three groups, respectively. The investigators concluded that forced-air warming reduced core temperature afterdrop by approximately 60 percent, while the degree and duration of afterdrop for the nitroprusside group was similar to the control.

Avoiding hypothermia in the trauma patient.

This review examines the recent literature with regard to risk factors for developing hypothermia, significance of hypothermia, therapeutic use of hypothermia, and invasive and noninvasive methods to prevent and treat hypothermia. The authors conclude that prevention of additional heat loss in the trauma patient is essential and that convective warming appears to be the most effective treatment modality.

Contact a 3M Representative

Aggressive warming reduces blood loss during hip arthroplasty.

Winkler, M., et al., *Aggressive warming reduces blood loss during hip arthroplasty*. Anesth Analg, 2000. 91(4): p. 978-84.

In this prospective study, 150 patient undergoing total hip arthroplasty with spinal anesthesia were randomly assigned to receive "conventional" intraoperative warming (aimed at maintaining tympanic membrane temperature of 36°C) or "aggressive" intraoperative warming (36.5°C) to compare their effects on patient blood loss. Both groups were warmed with the Bair Hugger™ system.

The conventional warming group experienced significantly higher Intraoperative blood loss than the aggressive warming group (618 mL; interquartile range, 480-864 mL, versus 488 mL; interquartile range, 368-721 mL; P = 0.002). Postoperative blood loss for the two groups was not significantly different, however the conventional group experienced significantly greater blood loss over the following two days after surgery (1678 mL; interquartile range, 1366-1965 mL, versus 1,531 mL; interquartile range, 1055-1746 mL, P = 0.031).

There was also a significant different in total units of allogenic red blood cells given to both groups: 40 patients in the conventionally warmed group required 86 units, versus 29 patients and 62 units for the aggressively warmed group (P = 0.051 and 0.061, respectively). The investigators concluded that aggressive intraoperative warming that produces near-normothermic intraoperative temperatures reduces blood loss during hip arthroplasty, and may be beneficial for these patients.

A comparison study on the effects of prewarming patients in the outpatient surgery setting.

Fossum, S., J. Hays, and M.M. Henson, *A comparison study on the effects of prewarming patients in the outpatient surgery setting*. JOPAN, 2001. 16(3): p. 187-94.

In this prospective study, 100 surgical patients were randomly assigned to be warmed prior to induction of anesthesia ("prewarmed") with either a Bair Hugger™ forced-air warming system or warmed cotton blankets (control) to assess whether forced-air warming would increase patient core temperature on admission to the post-anesthesia care unit (PACU).

Pre- and post-operative temperatures were recorded every 15 minutes. Temperature on admission to the PACU was significantly higher for the forced-air warming group than the control group (P =.000). Pre- and post-operative patient temperature in the forced-air group remained consistent, with a change of 0.0067°C (± 0.52°C). In contrast, the control group experienced an average decrease in temperature of 0.22°C (± 0.48°C).

Comparison of two different temperature maintenance strategies during open abdominal surgery: Upper body forced-air warming versus whole body water garment.

In this prospective study, 53 open abdominal surgery patients were randomly assigned to intraoperative warming therapy with either a Bair Hugger™ forced-air warming system (upper body) or a circulating warm-water garment (covering the upper and lower body and the back), to compare the efficacy of these methods in preventing inadvertent hypothermia.

Core temperature (mean rectal and esophageal) for the water garment group was significantly higher (0.4-0.6°C) than for the forced-air group one hour after incision, at skin closure, and on admission to the recovery unit. Fourteen percent of patients in the forced-air group remained hypothermic (<35.5°C) one hour after surgery, and seven percent were hypothermic two hours after surgery. No patients in the water garment group were hypothermic during or after surgery.

The authors conclude that the water garment warmer results in improved prevention of inadvertent perioperative hypothermia versus forced-air warming of the upper body because it is able to warm a larger portion of the patient's skin surface.

Effects of preoperative warming on the incidence of wound infection after clean surgery: a randomised controlled trial.

In this prospective study, 421 patient undergoing clean surgeries (varicose vein, hernia or breast) were randomly assigned to be either actively prewarmed for a minimum of 30 minutes before surgery, or to receive no prewarming therapy, in order to compare subsequent rates of surgical site infection between the groups. Active warming was provided either systemically, using a Bair Hugger™ forced-air warming system, or locally to the operative site.

Fourteen percent (19 of 139) of the unwarmed group developed surgical site infections within six weeks after surgery, compared to five percent (13 of 277) of the actively warmed group (P=0.001). Warmed patients had significantly better wound scores than unwarmed patients, and were prescribed significantly fewer antibiotics.

The authors conclude that active prewarming before clean surgery appears to be beneficial in preventing surgical site infection, with the added benefit of having no known side-effects, and may serve as an alternative to antibiotics for clean surgeries.

Comparison of Traditional Thermal Support Devices with the Forced-Air Warmer System in Anesthetized Hispaniolan Amazon Parrots (Amazona ventralis).

Birds also suffer the effects of anesthesia-induced hypothermia, and active warming is required to minimize heat loss and restore normothermia during anesthesia. In this crossover trial, the performance of four warming devices and a control (no thermal support (control), surgical drape only, towel-covered circulating-water blanket and drape, infrared heat emitter and drape, and Bair Hugger™ forced-air warmer and drape.) was compared in 10 Hispaniolan Amazon parrots (Amazona ventralis) during isoflurane anesthesia.

Each bird underwent isoflurane anesthesia once a week for 60 minutes while its esophageal temperature was recorded during exposure to one of the warming methods or control therapy.

No warming method completely prevented a decrease of core temperature during anesthesia; however, Bair Hugger forced-air warming was superior to all other methods and kept the birds' core temperature in the acceptable range of 38.3–40.6°C.

Body morphology and the speed of cutaneous rewarming.

In this observational study, the core temperatures of infants, children and adults undergoing hypothermic neurosurgery under general anesthesia with cutaneous (Bair Hugger™ forced-air) warming were measured to test the hypothesis that rates of rewarming are inversely related to body surface area.

All patients were under general anesthesia (isoflurane, nitrous oxide, and fentanyl), and received warmed fluids (37°C) and forced-air warming with full-body blankets. The protocol for adjusting the temperature of the forced-air warming system intraoperatively and postoperatively was the same for all patients. Rewarming rates were calculated for each patient using linear regression.

The relation between rewarming rate (°C/h) and body surface area (m^2) was linear (rate = -0.59 x surface area + 1.9, $r^2 = 0.74$.), with the result that a patient with half the body surface area would rewarm nearly twice as fast.

The investigators concluded that infants and children rewarm two to three times faster than adults, and are thus able to rapidly recover from induced or inadvertent hypothermia.

Negative pressure rewarming vs. forced air warming in hypothermic postanesthetic volunteers.

This study of seven healthy volunteers compared post-anesthesia core temperatures, systemic heat loss, and heat balance among subjects who received post-anesthesia warming therapy with the VitalHeat® negative pressure/warming device, warmed cotton blankets (one layer), or Bair Hugger™ forced-air warming to compare the efficacy of these methods in restoring subjects to normothermic core temperature after anesthesia.

After induction of general anesthesia, subjects were cooled to a core temperature (tympanic) of approximately 34°C, whereupon anesthesia was discontinued and Meperidine was administered to prevent shivering. Subjects were then rewarmed for two hours using one of the two methods.

The cotton blanket group experienced continued heat loss (measured on 15 skin-surface sites) during the warming period. Heat loss was significantly reduced in both of the other groups. Systemic heat balance increased by 140 ± 21 kcal among the group warmed with the Bair Hugger system, compared to 66 ± 19 kcal for the VitalHeat group and 47 ± 18 kcal for the cotton blanket group. Core temperature in the group using Bair Hugger warming warming increased 2.6 ± 0.6°C, compared to 1.3 ± 0.4°C for the VitalHeat group and 1.2 ± 0.4°C for the cotton blanket group.

The authors conclude that the forced-air system is highly effective for post-anesthesia rewarming, and that the VitalHeat system is no more effective for rewarming patients than warmed cotton blankets.

Comparison of forced-air warming systems with upper body blankets using a copper manikin of the human body.

This comparison study was conducted to determine the heat transfer efficacy of eight upper body blankets and to gain more insight into the principles of forced-air warming.

Eight different forced-air warming systems were tested, and testing was performed on a previously validated copper manikin of the human body with surface temperatures measured using 11 calibrated heat flux transducers. Blanket temperature was measured using 11 thermocouples. The temperature gradient between the blanket and surface (ΔT) was varied between −8 and +8°C, and h was determined by linear regression analysis as the slope of ΔT vs. heat flux. Mean ΔT was determined for surface temperatures between 36 and 38°C, as similar mean skin surface temperatures have been found in volunteers in previous studies.

The total heat flow from the blanket to the manikin was different for surface temperatures between 36 and 38°C. At a surface temperature of 36°C the heat flows were higher (4−26.6 W) than at surface temperatures of 38°C (2.6−18.1 W). The highest total heat flow was delivered by the WarmTouch™ system with the CareDrape™ upper body blanket (18.1–26.6 W). The lowest total heat flow was delivered by the Warm-Gard® system with the single use upper body blanket (2.6−4 W). The heat exchange coefficient varied between 15.1 and 36.2 W m−2 °C−1, and mean ΔT varied between 0.5 and 3.3°C.

The changes in heat flow by forced-air warming systems with upper body blankets vary based on variations in manufacturer upper body blankets as well as surface temperatures (36 – 38). These systems are not only transferring heat to the body but are also helping to reduce heat losses from the covered area to zero. These differences are based on various heat exchange coefficients and different mean temperature gradients.

System	h	DT at 36°C	DT at 38°C	Heat exchange (36 to 38°C)
Bair Hugger™ Model 505, UBB	27.2	1.37	0.51	13.0-4.9
Thermacare® TC3003, UBB	28.8	1.88	1.14	19.0-11.5
Thermacare® TC3003, Optisan® UBB	25.9	2.26	1.28	19.8-11.2
WarmAir® Model 134, FiltredFlo® UBB	17.7	2.02	1.14	12.5-7.1
Warm-Gard® Model 30215, UBB	15.1	0.75	0.49	4.0-2.6
Warm-Gard® Model 30215, reusable UBB	20.4	2.46	1.58	17.6-11.3
WarmTouch® Model 5800, CareDrape® UBB	36.2	2.1	1.43	26.6-18.1
WarmTouch® Model 5800, MultiCover® UBB	22.1	3.31	2.28	25.6-17.6

Heat exchange coefficients (h), mean temperature gradients at surface temperature of 36°C (DT at 36°C) and 38°C (DT at 38°C) and the resulting heat exchange.

Falsely Elevated BIS^{TM} in a Series of Patients Undergoing Cardiac Surgery Using Forced-Air Warming Therapy of the Head.

This report is of several five (men, age 51-72 yr, general anesthesia) cases of falsely elevated BIS™ values which we were due to interference with a forced-air warming blanket. Monitoring the bi-spectral index™ (BIS™) plays an important part in fast tracking cardiac anesthesia in our hospital setting.

Active temperature control consisted of Bair Hugger™ (Augustine Medical Inc.) blankets for head (short pediatric heating blanket Model 536) and lower body (Cardiac blanket Model 630) and elevated room temperature of at least 24°C. One Bair Hugger warming device was attached to the head warming blanket, allowing the creation of a continuous warm air flow around the head. Within 5 minutes of commencement of this forced air flow, the BIS™ in all five patients increased significantly and showed values of consistently more than 70 in two patients and values of more than 90 in three patients throughout surgery.

The A 2000 monitor (Aspect Medical Company) showed an optimal signal quality in all patients with no signal indicating activity of facial muscles. The EEG raw signal showed fast moving waves of high amplitude as it would be expected in an awake state. BIS™ monitoring was continued and indexes checked intermittently by interrupting the forced-air flow.

At all these moments, the high BIS™ values decreased immediately to levels between 35 and 55, and increased again to values above 70 when forced-air flow returned. We recommend additional caution in interpretation of BIS™ readings whenever the monitoring sensor is in close proximity to the head when a forced warm air therapy blanket.

Active warming during Cesarean delivery.

Horn, E.P., et al., *Active warming during Cesarean delivery*. Anesth Analg, 2002. 94(2): p. 409-14.

In this randomized study, 30 elective cesarean delivery patients were randomly assigned to either Bair Hugger™ forced-air warming therapy (15 minutes prior to epidural anesthesia, and intraoperatively) or no passive insulation, to examine the efficacy of forced-air warming in maintaining normothermia (tympanic) and preventing shivering among these patients. Core temperature (rectal), umbilical vein pH, and Apgar scores were also collected among newborns.

After two hours of anesthesia, mean core temperature in the forced-air warming group was 37.1 ± 0.4°C, compared to 36.0 ± 0.5°C in the unwarmed group (P < 0.01). Two of 15 patients in the forced-air warming group experienced shivering, compared to 9 of 15 unwarmed patients (P < 0.05). Newborns in the forced-air warming group had a mean core temperature of 37.1 ± 0.5°C, compared to 36.2 ± 0.6°C in the unwarmed group. Umbilical vein pH was 7.32 ± 0.07 for the forced-air group, compared to 7.24 ± 0.07 for the unwarmed group.

Women undergoing elective cesarean section with epidural anesthesia and forced air warming have less maternal and fetal hypothermia, maternal shivering, and better umbilical vein pH.

Water warming garment versus forced air warming system in prevention of intraoperative hypothermia during liver transplantation: a randomized controlled trial.

Janicki, P.K., et al., *Water warming garment versus forced air warming system in prevention of intraoperative hypothermia during liver transplantation: a randomized controlled trial [ISRCTN32154832]*. BMC Anesthesiol, 2002. 2(1): p. 7.

In this prospective, randomized and open-label study, 24 adult patients undergoing orthotopic liver transplantation surgery were randomly assigned to receive intraoperative warming with either Bair Hugger™ forced-air warming (N=12) or a full-body water garment to compare the efficacy in maintaining intraoperative normothermia.

The forced-air group was warmed using both upper- and lower-body blankets. Core temperature measurement (esophageal) of both groups was taken intraoperatively and for two hours postoperatively.

Intraoperative mean core temperatures were significantly greater for the water garment group versus the forced-air group during incision, one hour after incision, and during skin closing (36.7 ± 0.1°C, 36.7 ± 0.2°C, 36.8 ± 0.1 vs 36.1° ± 0.4°C, 36.1 ± 0.4°C, 36.07 ± 0.4° C, respectively, $p<0.05$). Upon admission to the SICU, core temperatures for the water garment group were also significantly greater versus the forced-air group (36.75 ± 0.13°C vs 36.22 ± 0.3°C, respectively), as well as after one hour (36.9 5± 0.13°C vs 36.46 ± 0.2°C, respectively).

The investigators concluded that the full-body warmed water garment was more effective at maintaining intraoperative normothermia than routine forced-air warming with upper- and lower-body blankets.

Body Warmer and Upper Extremities Position Affect the Accuracy of Cutaneous Thermometers during Anesthesia.

Huang, J. and A. Kurz, *Body warmer and upper extremities position affect the accuracy of cutaneous thermometers during anesthesia*. Journal of Clinical Anesthesia, 2001. 13(4): p. 241-243.

This prospective, randomized study in a teaching hospital investigates the correlation between axillary skin temperature and core temperature in 48 ASA I-II adult patients undergoing abdominal surgery under general anesthesia. Temperature aberrance can represent a significant risk for patients undergoing anesthesia. Skin-surface thermometer has become popular for intraoperative temperature monitoring.

Patients' skin temperature and core temperature was measured under general anesthesia. Core temperature was recorded by Mon-a-Therm™ esophageal stethoscope with temperature probe. The esophageal probe was placed at the location at which the loudest heart sounds were heard. Skin temperature was measured from axillae by Mon-a-Therm skin temperature probe. The axillary probe was positioned high in the axilla. The arm was secured in an adducted 0-degree or abducted 90-degree position. The forehead temperature probe was applied parallel to and midway between the brow and hairline. Temperature measurements were taken 60 minutes after the induction of anesthesia.

The temperature at each site was recorded with or without upper body warmer (Bair Hugger™ system). The temperature at each site was recorded with abducted or adducted upper extremities. Accuracy of temperature measurements at each site was assessed using Student's t-test for paired data. Statistical significance was defined as p< 0.05

Of the 48 patients studied, 19 patients had abducted upper extremities with upper body warmer, 19 patients had abducted upper extremities without upper body warmer, and 10 patients had adducted upper extremities without upper body warmer. There were no significant differences in age, weight, height, and ASA physical status among these three groups.

Without upper body warming and abducted upper extremities position, there was a significant difference between axillary skin temperature (33.5 ± 0.7°C) and core temperature (36 ± 0.3°C); and there was a significant difference between forehead temperature (32.7 ± 0.8°C) and core temperature (36 ± 0.3°C).

With upper body warming and abducted upper extremities position, there was no difference between axillary skin temperature (36 ± 1.7°C) and core temperature (36 ± 0.7°C), and there was no significant difference between forehead skin temperature (33.7 ± 1.1°C) and core temperature (36 ± 0.7°C) when the upper extremity was adducted at 0 degrees.

Randomized Prospective Comparison of Forced Air Warming Using Hospital Blankets vs. Commercial Disposable Blankets in Surgical Patients.

Kabbara, A., et al., *Randomized prospective comparison of forced air warming using hospital blankets versus commercial blankets in surgical patients*. Anesthesiology, 2002. 97(2): p. 338-44.

This experimental, randomized study's purpose was to evaluate efficacy of convective warming versus hospital blankets.

Adult patients undergoing elective major surgery under general anesthesia were studied. Patients were randomized into one of two groups. Patients in the control group 1 (n=44; set point 44°C) were intraoperatively warmed using the Bair Hugger™ system. Patients in the experimental group 2 (n=39; set point 38°C) were warmed using standard hospital blankets. Patients were interviewed the following day. Distal esophageal temperature was monitored. Final temperatures at the end of surgery were recorded.

There was a similar decrease in core temperature after induction of anesthesia in both groups. Average core temperature was > 36°C at the end of surgery in both groups. No thermal injuries were noted or reported.

Standard hospital blankets heated to 38°C were equally as effective as commercial forced air warming blankets heated with forced air at the 43°C setting.

Novel Feedback Controlled Circular Water Warming System (Allon 2001) Is Superior to Forced Warmed Air Device in Maintaining Normothermia in Infants Undergoing Major Surgery.

In this prospective randomized study, 33 infants undergoing major abdominal surgery were randomly assigned to intraoperative warming therapy with either a circulating water garment (Allon® ThermoWrap™) or forced-air warming (Bair Hugger™ therapy). Set points for the devices were not disclosed.

In the first 30 minutes of anesthesia, core temperature declined in both groups, reaching 35.8°C in the water garment group and 35.1°C in the forced-air group, a statistically insignificant difference. After 30 minutes, core temperature differences between the groups were statistically significant. Core temperature began to rise in the water garment group at 30 minutes, and reached 36.7°C at 90 minutes. In the forced-air warming group, core temperature declined for 60 minutes after induction, then rose to 36.4°C at 150 minutes.

The duration of hypothermia for the water garment group was 75 minutes, compared to 180 minutes for the forced-air group.

The authors conclude that the Allon 2001 water garment system is more effective at maintaining perioperative normothermia for infants undergoing major surgeries than forced-air warming, and is reliable, safe, and simple to operate.

Intraoperative Evaluation of a Prototype Warming System.

Shamir, M., M. Leibergal, and C. Weissman, *Intraoperative Evaluation of a Prototype Warming System*. Anesthesiology, 2002. 96: p. A590.

In this study, the use of a new warming system (HTTP Hypothermia, Jerusalem, Israel), a disposable warming blanket was compared to a warm air convection system (Bair Hugger™ system (BH), Augustine Medical) to determine the ability of the HTTP system to maintain body temperature during major elective abdominal surgery.

Thirty-four adult patients undergoing major elective abdominal surgery were randomized to the HTTP (N=17) or BH (N=17) warming after anesthesia induction and throughout surgery. Temperature was monitored at the esophagus, chest wall, big toe, finger and thigh and was continuously recorded.

Length of surgery was similar in both groups (HTTP group: 227 ± 112 minutes and BH group: 226 ± 84 minutes). There was no statistically significant difference in esophageal temperature at start of surgery (HTTP: 36.1 ± 0.3°C and BH: 36.1 ± 0.4°C), nor at the end of surgery (HTTP: 36.1 ± 0.4°C and BH: 35.9 ± 0.5°C). Likewise, no significant differences were observed for thigh and finger temperatures in the two groups.

The only significant difference between HTTP and BH group was for big toe temperature; 180 minutes post-anesthesia induction, the HTTP group temperature remained unchanged (33.7 ± 0.6°C), while it decreased to 29.9 ± 1.1°C in the BH group ($p<0.001$).

The authors concluded that the HTTP system performed as well as the convective air Bair Hugger system and it might provide a more uniform warming (through warming of multiple surfaces), as the big toe temperature did not decrease in the HTTP group.

Evaluation of a New Automatic Body Temperature Control System.

Taguchi, A., et al., *Evaluation of new automatic body temperature control system*. Anesthesiology, 2002. 96: p. A588.

This study compared the effectiveness of a new conductive warming blanket (Allon® system) to forced-air warming (Bair Hugger™ system) for the prevention of unplanned hypothermia. Researchers also evaluated the heat transfer and heat balance of this new device.

This study included 4 adult volunteers. Each was evaluated on two randomly ordered study days. The subjects were anesthetized (with propofol and maintained with desflurane), then vecuronium was administered IV and an endotracheal tube was inserted. Ventilation was controlled to maintain end-tidal PCO_2 near 40mmHg. The subjects were cooled with forced-air to a core temperature of 34°C and active peripheral arteriovenous shunt vasoconstriction was established and maintained for 30 minutes.

Subjects were then randomly assigned to be warmed on each day for three hours using one of two methods: the Allon system or forced-air (Bair Hugger™ system, Augustine Medical). Core temperature (at esophagus and tympanic membrane) and area-weighted skin temperature and thermal flux (at 15 skin-surface sites) were measured using thermal flux transducers.

During the three hours of warming, the core temperature increased 1.2 ± 0.2°C/hour with the Allon device and 0.8 ± 0.2°C/hour with forced-air (p=0.05). Heat transfer during active warming was 41 ± 16 kcal/hour and 25 ± 5 kcal/hour, with the Allon system and forced-air warming, respectively (p=0.3).

As the core temperature increased faster with the Allon system, the authors concluded that conductive warming is more effective than forced-air warming in hypothermic and vasoconstricted subjects.

Efficacy of Vital-Heat Warming in Post-Anesthetic Volunteers.

The effectiveness of a new device, VitalHeat™ (Aquarius Medical Corp.), was compared to commonly used methods for rewarming of hypothermic patients. Heat balance was also evaluated.

Seven adult volunteers aged 27.9 ± 7.5 yrs were anesthetized with propofol and anesthesia was maintained with sevoflurane. Assisted ventilation with laryngeal mask airway and end-tidal PCO_2 was maintained near 40mmHg. Shivering was inhibited by meperidine. The subjects were then cooled to 34°C core temperature with forced-air and active peripheral arteriovenous shunt vasoconstriction was established.

After anesthesia was discontinued, the subjects were randomly assigned to be re-warmed either by VitalHeat, cotton blanket, or forced-air (Bair Hugger™ system, Augustine Medical). Temperature was recorded: core temperature (at the tympanic membrane) and area-weighted skin temperature and thermal flux (at 15 skin-surface sites). Vasoconstriction was determined as forearm-fingertip temperature gradient exceeding 4°C.

During the treatment period the tympanic temperature increased significantly more with forced-air warming (2.6 ± 0.6°C) compared to VitalHeat (1.3 ± 0.4°C) and cotton blanket (1.2 ± 0.4°C). Likewise, systemic heat balance increased significantly more with forced-air (forced-air 140 ± 21 kcal, VitalHeat 66 ± 19 kcal, cotton blanket 47 ± 18 kcal, p<0.001).

Therefore, VitalHeat warming was not as effective as the Bair Hugger system for rewarming of hypothermic post-anesthetic patients. Negative pressure did not increase blood flow nor facilitate peripheral heat transfer.

Comparison of forced-air warming systems with lower body blankets using a copper manikin of the human body.

Bräuer, A., et al., *Comparison of forced-air warming systems with lower body blankets using a copper manikin of the human body*. Acta Anaesthesiol Scand, 2003. 47(1): p. 58-64.

This study examined the heat transfer efficacy of six complete lower body warming systems: (1) Bair Hugger™ 505e warming unit and lower body blanket (Augustine Medical, Eden Prairie, MN); (2) Thermacare® and lower body blanket (Gaymar Industries, Orchard Park, NY); (3) WarmAir® and lower body blanket (Cincinnati Sub-Zero Products, Cincinnati, OH); (4) Warm-Gard® and lower body blanket (Luis Gibeck AB, Upplands Vasby, Sweden); (5) Warm-Gard® and reusable lower body blanket (Luis Gibeck AB); and (6) WarmTouch® and lower body blanket (Mallinckrodt Medical Inc., St. Luis, MO).

The study was conducted using a previously validated copper manikin of the human body. Heat flux and surface temperature were measured with heat flux transducers, while blanket temperature was measured with thermocouples. The blankets covered the area of approximately 0.54 m2.

Heat transfer from the blanket to the manikin depended on surface temperature; at 36 °C the heat transfer was higher (13.4 W to 18.3 W) than at of 38°C (8-11.5 W). The Thermacare system (8.3-18.3 W) delivered the highest heat transfer, while the Warm-Gard system delivered the lowest, with the single use blanket (8-13.4 W). Mean ΔT varied between 1.04°C and 2.48°C and between 0.50°C and 1.63°C for surface temperatures of 36°C and 38°C, respectively.

Forced-air warming systems tested didn't show any relevant difference in heat transfer. The authors concluded that forced-air warming systems with lower body blankets are effective in the prevention of perioperative hypothermia due to their coverage of a large body surface area.

System	h	DT at 36°C	DT at 38°C	Heat exchange (36 to 38°C)
Bair Hugger™ Model 505, LBB	26.0	1.24	0.62	8.7-17.4
Thermacare® TC3003, LBB	24.5	1.38	0.63	8.3-18.3
WarmAir® Model 134, Filt redFlo® LBB	14.4	2.15	1.08	8.4-16.7
Warm-Gard® Model 30215, LBB	12.5	1.99	1.19	8.0-13.4
Warm-Gard® Model 30215, reusable LBB	13.1	2.48	1.63	11.5-17.5
WarmTouch® Model 5800, CareDrape® LBB	30.8	1.04	0.50	8.3-17.3

Heat exchange coefficients (h), mean temperature gradients at a surface temperature of 36°C (DT at 36°C) and 38°C (DT at 38°C), and the resulting heat transfer.

The Bair Hugger patient warming system in prolonged vascular surgery: an infection risk?

Huang, J.K., et al., *The Bair Hugger patient warming system in prolonged vascular surgery: an infection risk*? Crit Care, 2003. 7(3): p. R13-6.

This study evaluated whether the use of the Bair Hugger™ forced-air patient warming system during prolonged abdominal vascular surgery would lead to increased bacterial contamination of the surgical field due to the mobilization of the patient's skin flora.

Air and wound specimens were collected during surgery in 16 patients undergoing an abdominal vascular prosthetic graft insertion procedure utilizing the Bair Hugger system. Bacterial colony counts in these samples were analyzed and the bacterial content at the end of surgery was compared to the beginning of surgery.

No increase in bacterial counts at the study sites were found and no wound or graft infections occurred. This study concluded that the Bair Hugger warming system was unlikely to affect the surgical field adversely or increase the risk of infection.

Contact a 3M Representative

Resistive-heating and forced-air warming are comparably effective.

Negishi, C., et al., *Resistive-heating and forced-air warming are comparably effective*. Anesth Analg, 2003. 96(6): p. 1683-7.

In this prospective study, 24 patients undergoing major open abdominal surgery were randomly assigned to intraoperative warming therapy with three different modalities to compare their efficacy in maintaining intraoperative patient normothermia.

The warming methods included a full-length circulating water mattress (42°C setting), a Bair Hugger™ forced-air warming system which covered the legs only (unit set on high), and a three-extremity carbon-fiber resistive heating blanket (42°C setting) which covered one arm, the chest and both legs. All patients were under combined general and continuous epidural anesthesia during procedures that lasted approximately four hours.

Core temperature (tympanic membrane) reduction in the first two hours of surgery was significantly lower in the circulation water group (1.9°C ± 0.5°C) versus the forced-air and resistive hearing groups (1.0 ± 0.6°C and 0.8 ± 0.2°C, respectively). Decreases at the end of surgery were also markedly lower for the circulating water group (2.0 ± 0.8°C, versus 0.6°C ± 1.0°C in the forced-air group and 0.5 ± 0.4°C in the resistive-heating group). The investigators concluded that resistive heating and forced-air warming were equally effective at maintaining core temperature for these procedures.

A comparative study of three warming interventions to determine the most effective in maintaining perioperative normothermia.

Ng, S.F., et al., *A comparative study of three warming interventions to determine the most effective in maintaining perioperative normothermia*. Anesth Analg, 2003. 96(1): p. 171-6.

In this prospective study, 300 patients undergoing total knee replacement surgery were randomized to receive intraoperative warming with either two cotton blankets (N=100), one reflective blanket and one cotton blanket (N=100), or Bair Hugger™ forced-air warming and one cotton blanket (N=100), to compare the efficacy of these methods in preventing inadvertent perioperative hypothermia and reducing associated negative outcomes.

Temperature measurements (tympanic) were taken before induction, on arrival in recovery, and every ten minutes until discharge from recovery. The forced-air warming group had significantly higher temperatures than the other two groups at each of these time points. Recovery room admission temperatures for the forced-air warming group were 0.577 ± 0.079°C higher than the reflective warming group and 0.510 ± 0.08°C higher than the two-cotton-blanket group (P < 0.001).

The Bair Hugger forced-air warming group also required significantly less time to reach 36.5°C in recovery (18.75 minutes for the forced-air warming group, 41.78 minutes for reflective blanket group, and 36.43 minutes for the two-cotton-blanket group). The investigators concluded that forced-air warming was most effective at maintaining patient normothermia.

Differences among forced-air warming systems with upper body blankets are small. A randomized trial for heat transfer in volunteers.

The authors investigated four forced-air warming systems in combination with upper body blankets to detect any differences in heat transfer.

Six healthy volunteers participated in this randomized cross-over study of four forced-air warming systems combined with upper body blankets: (1) Bair Hugger™ Model 505 warming unit and 520 upper body blanket, Augustine Medical; (2) ThermaCare™ TC 3003, Gaymar™ and Optisan™ upper body blanket, Brinkhaus; (3) WarmAir™ 134 and FilteredFlow™ upper body blanket, CSZ; and (4) WarmTouch™ 5800 and CareDrape™ upper body blanket, Mallinckrodt.

Heat flux transducers (HFTs) were used to measure heat transfer from the blanked to the body surface. The blanket temperature was also measured 1 cm above the HFT. After a preparation time of 60 min, the measurement time lasted 20 min.

The best heat flux (17.0±3.5 W) was observed with the use of WarmTouch blower, while the lowest heat transfer (8.1±1.1 W) was observed with the Bair Hugger unit. The remaining two systems gave intermediate heat transfer (of 14.3±2.1 W for ThermaCare and 11.3±1.0 W for the WarmAir system.

The heat loss from the covered area was estimated to be 38 W, therefore the heat balance changed by 46.1 W to 55 W by forced-air warming systems with upper body blankets. While there were significant differences in heat transfer, the authors concluded that the clinical relevance of this difference was small.

Effect of Warming on Propofol Requirement for Loss of Consciousness.

Sugino, S., et al., *Effect of Warming on Propofol Requirement for Loss of Consciousness*. Anesthesiology, 2003. 99(3): p. A-55.

It was reported that warming the hands and feet increases heat loss at these sites, thereby promoting rapid onset of physiological sleep (*Nature* 1999; 402: p.36-37). This study examined whether warming had any effect on propofol requirement for loss of consciousness.

Sixty patients with ASA physical classification of I or II scheduled for minor surgery under general anesthesia were randomized to a warming group (n = 30) or a control group (n = 30). Operating room temperature was at 23°C. Forced air warming system (Bair Hugger™ system, Augustine Medical) was used for 15 minutes, then propofol was administered intravenously as target-controlled infusion (TCI) was started. The target effect site concentration of propofol was initially set to 1.0 mug/ml and was increased by 1.0 μg/ml every 5 minutes until each patient became unconscious. Bispectral index (BIS™) values, core temperature (tympani), proximal skin temperature (thigh) and distal skin temperature (foot) were recorded at 1-minute intervals.

Loss of consciousness was determined by the following criteria: (1) loss of eyelash reflex as the first end point and (2) no response to verbal commands, such as commands to move the hands and protrude the tongue, as the second end point. When the second end point was reached, propofol infusion was discontinued, and a 5-ml sample of venous blood was immediately obtained from each patient.

Compared to control, the warming group had shorter duration of propofol infusion and reached the first and second end points for unconsciousness more quickly (P < 0.01). Consequently, the blood concentration of propofol at the second end point was significantly lower in the warming group, too (P < 0.01). The two groups did not significantly differ by the BIS™ values at both the first and second end points (P > 0.1).

This study showed that, compared to controls, warming reduced propofol requirement for loss of consciousness, but it did not affect the BIS™ values.

Efficacy of postoperative rewarming after cardiac surgery.

This prospective study randomized 50 male cardiac surgery patients to compare the efficacy of forced-air warmers and radiant heaters when rewarming after cardiac bypass graft surgery.

The patients were allocated into five groups: control (Gr. C, n=10) received standard hospital blanket, two groups of forced air warmers: WarmTouch 5700 (Gr. WT, n=10) and Bair Hugger™ system Model 500 (Gr. BH, n=10) or two groups of radiant heaters: the Aragona Thermal Ceilings CTC X radiant heater (Gr. TC, n=10) and a self-assembled radiant heater of 4 Hydrosun 500 infrared lamps (Gr. HY, n=10). Oesophageal temperature was measured. Mean skin temperature, mean body temperature and relative heat balance were calculated from oesophageal temperature, four skin temperatures and oxygen consumption (VO_2).

Compared to control, all active groups except TC showed significantly faster oesophageal warming. The mean body temperature increased 1.1 (0.7-1.7) °Ch-1 in Gr. WT, 1.3 (0.7-1.5) °Ch-1 in Gr. BH, 0.8 (0.5-1.4) °Ch-1 in Gr. TC and 0.7 (0.4-1.0) °Ch-1 in Gr. HY compared to Gr. C with 0.4 (0.2-0.7) °Ch-1. No significant difference in mean VO_2 and the maximum VO_2 between the groups was observed.

In conclusion, speed of rewarming was two- to three-fold higher when compared to control when forced-air warming was used. Radiant warming also increased speed of rewarming, albeit less than forced-air warming.

Assessment of the efficiency of warming devices during neonatal surgery.

The efficiency of different warming devices (surgical sheets covering the body and a tube-gauze on the head, forced-air warming, warming mattress) used to prevent hypothermia during neonatal surgery was evaluated in a manikin model of low-birth-weight (1,800 g) neonates.

Dry heat losses were measured from a thermal manikin, which simulated a low-birth-weight neonate of 1,800 g. The manikin's surface temperatures (35.8°C) simulated that of neonates nursed in incubators. Experimental room was kept at an ambient temperature of 30°C, as commonly found in operating rooms. The supine manikin was naked or covered with operative sheets with a 5x5 cm aperture over the abdomen. Additional warming was supplied either through a warming mattress (surface temperature, 39°C) and/or by forced-air (Bair Hugger™ system, air temperature 38°C). Covering the manikin with surgical sheets decreased the dry heat loss by 10.4 W.

Dry heat loss by manikin, when covered with surgical sheets only, was 10.4W. Forced-air warming reduced dry heat loss more than warming mattress (6.8 W vs. 2.1 W). The largest reduction in dry heat loss was achieved when both warming mattress and Bair Hugger blanket were used (7.9 W).

This study showed that forced-air warming was more effective than a warming mattress for use in preventing neonatal hypothermia during abdominal operations.

Modelling of thermal exchanges of the newborn from a thermal mannequin: Biomedical applications.

Thermal mannequins have been used to assess body heat loss by premature neonates. This study described the biomedical uses of these models from two studies. One deals with the relationship between the thermal stress, the sleeping body positions and sudden infant death syndrome, while the other offers an assessment of heating devices used in neonatal surgery.

A thermal mannequin representing a low-birth-weight neonate (body mass of 1,400 g) was designed. When the mannequin was laid in prone or supine sleeping positions in a closed incubator (air temperature of 25°C to 37°C), the heat losses did not depend on the body positions. The hypothesis that the supine sleeping position induces a thermal stress thereby increasing mortality risk, was thus discarded. The second study placed the mannequin in a supine position to simulate an operative field. Warming was conducted by using either a warming mattress alone or a convection warming device (the Bair Hugger™ system, with air temperatures between 20°C and 30°C). The Bair Hugger system was shown to be the most efficient device to rewarm the infant.

In addition, when the Bair Hugger system (air temperature 38°C) is used in conjunction with the warming mattress (39°C), the air temperature of the surgery room can be reduced from 27°C to 20°C, to improve the thermal comfort of the surgeons without affecting the thermal balance of the infant.

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Is there such a thing as laminar flow?

Kochhar T, et al., *Is there such a thing as laminar flow*? J Bone Joint Surg Br, 2004. 86-B(Supp 4): p. 408.

This independent observational study examined whether the Bair Hugger™ forced-air warming system disrupts laminar flow or contributes to displacement of dust particles into surgical wound sites in the operating room. Utilizing digital video imaging and airflow measurement techniques used in Formula 1 race car design, the investigators concluded that the Bair Hugger forced-air warming system has no effect on laminar flow or particle displacement.

Effects of a Circulating-water Garment and Forced-air Warming on Body Heat Content and Core Temperature

Taguchi, A., et al., *Effects of a circulating-water garment and forced-air warming on body heat content and core temperature*. Anesthesiology, 2004. 100(5): p. 1058-64.

This study compared effectiveness of Bair Hugger™ forced-air warming to a circulating water warming device. Nine volunteers were anesthetized on two randomly ordered days, and cooled to core temperature of near 34°C. They were then warmed for 2.5 hours with either a circulating-water garment or forced-air cover.

Cutaneous heat loss (thermal flux transducers) and metabolic heat production (oxygen consumption) were calculated from temperature measurements by intramuscular needle thermocouples, skin thermal flux transducers, and "deep" arm and foot thermometers.

Results showed that circulating-water transferred 21 ± 9 kcal/hour through the posterior skin surface after a half hour of warming, while forced air warming had no effect. Over 2.5 hours, circulating-water thus increased body heat content 56% more than forced-air. Core temperatures increased faster when circulating water warming was used resulting in higher core temperature (1.1 ± 0.7°C greater) at 2.5 hours ($P < 0.001$). Peripheral tissue heat content increased twice as much as core heat content with each device.

The results showed that circulating-water system transferred more heat than forced-air, due to posterior heating and rewarmed patients 0.4°C/hour faster than forced-air.

Evaluation of four warming procedures to minimise heat loss induced by anaesthesia and surgery in dogs.

In this prospective study, 96 dogs undergoing surgery under anesthesia were assigned to active intraoperative warming therapy with one of four different devices, or received no active warming (control), to assess the efficiency of these warming methods. Warming was done with either a pre-warmed (41°C) electrically heated pad (group 1, N=11); the same pad, supplemented by four wrapped water bottles (initially heated to 41°C) and radiant heat (group 2, N=18); a Bair Hugger™ forced-air warming system with underbody blanket set at 43°C (group 3, N=11); or by a heat/humidifier set at 41°C connected to the anesthetic breathing circuit (group 4, N=8).

Each actively warmed dog was paired with an unwarmed dog of similar breed, hair length, and surgical procedure type as control. Core temperature (rectal) was measured every 15 minutes for the first three hours after induction. Over the first, second and third hour of surgery, the mean rectal temperature of the control group decreased 1.9 ± 0.6°C, 1.4 ± 0.4°C and 1.1 ± 0.4°C, respectively. Temperature reduction at three hours for the actively warmed groups were 0.7 ± 0.7°C (group 1), 3.1 ± 1.1°C (group 2), 2.4 ± 1.1°C (group 3) and 1.0 ± 1.1°C (group 4).

Investigators concluded that the group two procedure was most efficient at preventing reduction in core temperature, followed by groups three, four and one. They noted that active warming markedly reduce intraoperative core temperature reduction, though the effectiveness of various methods differs.

Perioperative hypothermia.

This review article summarized findings from clinical trials, experimental studies and other published articles on the pathophysiology and management of perioperative hypothermia in both animals and humans. The author notes that negative consequences of inadvertent perioperative hypothermia include alterations in coagulation; cardiac, hepatic and renal function; wound healing; and humoral and cellular immunity; and that active management of intraoperative core temperature can diminish complications.

Techniques for intraoperative temperature management include continual temperature monitoring, use of forced-air warming, circulating water blankets, and warm isotonic lavage fluids.

Pre-hospital torso-warming modalities for severe hypothermia: A comparative study using a human model.

This study compared different active torso-warming modalities in a human model of severe hypothermia where shivering was inhibited by intravenous meperidine.

The subjects (N=6) were cooled in 8°C water for 30 minutes in order to achieve a core temperature of 35°C (severe hypothermia). Spontaneous torso-warming was the first modality to be tested for every participant. These results were used as a comparative control and for determination of the meperidine dose for subsequent trials. Meperidine (1.5 mg/kg) was administered during the final 10 minutes of cooling.

Subjects were then removed from the water, dried and insulated for 30 minutes. Then, 5 different warming modalities were tested for 120 minutes: 1) Bair Hugger™ forced-air warming with either a 600-W heater and commercial soft warming blanket; or 2) The Bair Hugger 600-W heater and a rigid cover; or 3) a Bair Hugger 850-W heater and rigid cover; or 4) a charcoal heater on the chest; or 5) direct body-to-body contact with a normothermic partner. Additional meperidine (to a maximum cumulative dose of 3.2 mg/kg) was administered as required to inhibit shivering.

Subjects experienced post-cooling afterdrop of approximately 1.0°C. After 30-minutes, core temperature dropped further by 0.45°C in spontaneous and body-to-body warming modalities. This post-warming afterdrop was significantly less with 600-W heater and rigid cover and the charcoal heater (0.26°C) and the least with 850-W heater and rigid cover (0.17°C). Core rewarming rates were highest using 850-W heater and rigid cover (1.45°C/hr); with charcoal heating and 600-W rigid heater (0.7°C/hr); and 600-W heater and blanket (0.57°C/hr). Body-to-body warming (0.52°C/hr) was also slightly more effective than spontaneous warming (0.36°C/hr).

The results show that external heat application in non-shivering subjects was effective in attenuating core temperature afterdrop and facilitating safe core rewarming. The effect was dependent on the amount of heat delivered and was more evident when heat was delivered to the chest. The modalities studied were practical and portable and could therefore be applied for pre-hospital use.

Prevention of perioperative hypothermia with forced-air warming systems and upper-body blankets.

This article describes evidence supporting use of forced-air warming for prevention of inadvertent perioperative hypothermia, and evidence-based best practices. The authors describe negative consequences of inadvertent hypothermia, including increased risk of surgical site infection, cardiac morbidity, prolonged hospital stay and post-operative shivering.

Citing evidence demonstrating that most body heat is lost through the skin, even during procedures with large open abdominal cavities, the authors recommend cutaneous temperature management during surgery. Specifically, they recommend placement of forced-air warming blankets on the upper body and lower extremities during abdominal surgery as a means of reducing heat loss and producing heat gain, especially in combination with fluid warming and insulation.

Rewarming of healthy volunteers after induced mild hypothermia: a healthy volunteer study.

Williams, A.B., et al., *Rewarming of healthy volunteers after induced mild hypothermia: a healthy volunteer study*. Emerg Med J, 2005. 22(3): p. 182-4.

In this randomized crossover study of eight volunteers, subject core temperatures were measured during rewarming after induced mild hypothermia (core temperature 35°C) to compare the efficacy of three different warming methods. Each subject was cooled and rewarmed three times, using a) a radiant warmer (Fisher & Paykel), b) a forced-air warming system (Bair Hugger™ system, Augustine Medical), and c) a polyester-filled blanket.

The investigators found no significant difference in rewarming rates between the three methods, and reported that endogenous heat production accounted for most rewarming. They concluded that for patients with mild hypothermia, for whom shivering is not contraindicated, the clinician's choice between these warming methods made little difference to the rate of rewarming.

Active Warming during Preanesthetic Period Reduces Hypothermia without Delay of Anesthesia in Cardiac Surgery.

Shinn, H.K., et al., *Active warming during preanesthetic period reduces hypothermia without delay of anesthesia in cardiac surgery*. Korean J Anesthesiol, 2005. 48(6): p. S5-10.

This randomized controlled study involved cardiac surgery patients and evaluated the effectiveness of active prewarming in the prevention of intraoperative hypothermia (core temperature < 35.5°C) during and after the preanesthetic period. Sixty patients were randomly assigned to the prewarming group (N=30, actively prewarmed with Bair Hugger™ forced air before anesthesia) or to the control group (N=30, no active prewarming, only cotton blankets).

Results showed that, before anesthesia, skin temperature was significantly higher in the prewarming group than in the control group. Likewise, core temperature was significantly higher in the prewarming group than in the control group at T90. Intraoperative hypothermia occurred more frequently in control than in the prewarming group (78% and 44%, respectively). Moreover, the control group was more likely to develop temperatures below 35°C compared to prewarmed subjects (58% and 17%, respectively).

Therefore, active prewarming before anesthesia reduced the incidence and degree of hypothermia in cardiac surgery patients.

Maternal and newborn outcomes related to maternal warming during cesarean delivery.

Fallis, W.M., et al., *Maternal and newborn outcomes related to maternal warming during cesarean delivery*. J Obstet Gynecol Neonatal Nurs, 2006. 35(3): p. 324-31.

This randomized control study compared two methods of maternal warming during cesarean delivery while under spinal anesthesia and their effect on maternal and newborn outcomes.

Sixty-two women were randomized to receive either a Bair Hugger™ forced-air warming blanket (n=32, intervention) or standard care - warmed cotton blankets (n=30, control).

The results showed that with the exception of perceived thermal comfort, women in the two groups were not significantly different in terms of oral temperature, incidence of shivering, and pain scores. Similarly, newborns in both groups were not significantly different in terms of any of the measured variables.

The effect of skin surface warming during anesthesia preparation on preventing redistribution hypothermia in the early operative period of off-pump coronary artery bypass surgery.

Because pre-warming for such a long time (at least 1-2 hours) is impractical in clinical practice, this study evaluated the efficacy of active warming during the preanesthetic period on the prevention of redistribution hypothermia in the early operative period of off-pump cardiac bypass (OPCAB) surgery.

In this randomized study 40 patients undergoing OPCAB were randomly assigned to control or pre-warming groups. The patients in control group (n=20) received warm mattresses and cotton blankets, and patients in the pre-warming group (n=20) were actively warmed with a Bair Hugger™ forced-air warming device before the induction of anesthesia (prewarming).

Active warming duration was 49.7 ± 9.9 minutes. At pre-induction period, there were no statistically significant differences in skin temperature, core temperature and hemodynamic variables between the two groups. However, at T30, T60, and T90 core temperature was statistically higher in pre-warming group than that in control group. At T90, only 5% of pre-warmed patients (compared to 35% of control patients) had core temperature below 35°C (P=0.02).

The results showed that active warming using a forced air blanket system reduced the incidence and degree of redistribution hypothermia in patients undergoing OPCAB.

Comparison of forced-air warming and electric heating pad for maintenance of body temperature during total knee replacement.

This is a report from a randomized controlled trial to compare the efficacy of forced-air warming (Bair Hugger™ Augustine Medical model 500/OR, Prairie, MN) with that of an electric heating pad (Operatherm 202, KanMed, Sweden).

A total of 60 patients undergoing total knee replacement surgery were monitored for the maintenance of intraoperative core body temperature. The results showed that there were no differences between the two groups. The heating pad was as effective as forced-air warming for the maintenance of body temperature.

Pathophysiology and management of perioperative hypothermia.

This was an observational study of 60 consecutive patients with extensive burns. Long-lasting dressings in burn patients--when the whole body is not covered and protected--can be performed safely only in conditions excluding heat loss and core temperature drop.

This paper is a review of pathophysiology and management of perioperative hypothermia. The premise was that the ideal re-warming method should be safe and enable fast, reliable and predictable warming or re-warming.

The authors observed that active warming with forced-air warmers (Warm Touch 5700 and the Bair Hugger™ system Model 500) or radiative heaters (IR-A: Hydrosun 500, IR-C radiation: CTC X, MTC) was more effective than the use of standard, passive insulation hospital blankets or convectional heaters. The forced-air warmers were considered to be more useful in cardiovascular surgery hypothermia management, and radiative heaters were useful in burn management.

Prevention of perioperative hypothermia in plastic surgery.

While inadvertent perioperative hypothermia has received serious attention in many surgical specialties, few discussions of hypothermia have been published in the plastic surgery literature. Measures for preventing hypothermia are emphasized in this article, with the focus on the one most effective modality as shown in prospective and controlled clinical studies.

Prewarming of patients in the preoperative area with Bair Hugger™ forced-air heating systems is the most important step in maintaining normothermia, and should be followed by intraoperative warming with forced-air and fluid warming as well. There are other strategies, such as maintaining an ambient operating room temperature of approximately 73°F (22.8°C) or covering as much of the body surface as possible.

Another important part of the thermal management process is monitoring of patient's core body temperature throughout the perioperative period. Prevention of perioperative hypothermia is neither difficult nor expensive. Proper preventive measures can reduce the risk of complications and adverse outcomes, and eliminate hours of needless pain and misery for the patients.

Temperature management during off-pump coronary artery bypass graft surgery: a randomized clinical trial on the efficacy of a circulating water system versus a forced-air system.

The authors compared a new temperature management system specifically designed for cardiac surgery (Allon®, ThermoWrapping Thermoregulation System; MTRE Advanced Technologies Ltd, Or Akiva, Israel) using a circulating-water against a conventional Bair Hugger™ forced-air warming system.

A total of 31 patients undergoing off-pump coronary artery bypass graft (OPCAB) surgery were randomized into two study groups. One group (study) with 15 patients received the Allon System, while the other group (control) with 16 patients used the Bair Hugger system.

Results showed that patients in the study group had higher temperatures than the control group at all time points. The difference reached a statistical significance after 2 hours of surgery and fewer patients from the study group suffered perioperative hypothermia.

Efficacy of forced-air warming systems with full body blankets.

Brauer, A., et al., *Efficacy of forced-air warming systems with full body blankets: [Efficacite des systemes de chauffage a air pulse avec des couvertures a champ complet]*. Can J Anaesth, 2007. 54(1): p. 34-41.

This manikin study was conducted to determine the heat transfer efficacy of 11 forced-air warming systems with full body blankets. The following systems were tested: 1) Bair Hugger™ system Model 505; 2) Bair Hugger system Model 750; 3) Life-Air 1000 S; 4) Snuggle Warm; 5) Thermacare; 6) Thermacare with reusable Optisan blanket; 7) WarmAir; 8) Warm-Gard; 9) Warm-Gard and reusable blanket; 10) WarmTouch; and 11) WarmTouch and reusable blanket. Heat flux per unit area and surface temperature were measured with 16 heat flux transducers. The blanket temperature was measured using 16 thermocouples.

The authors observed heat transfers of 30.7 W to 77.3 W for surface temperatures of 32°C, and between -8.8 W to 29.6 W for surface temperatures of 38°C. Results showed that there were clinically relevant differences among the tested forced-air warming systems with full body blankets. Several systems were unable to transfer heat to the manikin at a surface temperature of 38°C.

System	h	ΔT (°C) at 32°C	34°C	36°C	38°C	Heat exchange (W) at 32°C	34°C	36°C	38°C
Bair Hugger™ 505, FBB	21.9	1.40	0.91	0.43	-0.06	30.7	19.9	11.4	-1.6
Bair Hugger™ 750, FBB	28.0	2.76	2.09	1.31	0.53	77.3	58.5	44.4	18.0
Life-Air 1000 S, FBB	26.4	1.76	1.17	0.58	-0.02	46.5	30.9	18.5	-0.6
Snuggle Warm® SW-3000, FBB	32.2	1.93	1.42	0.91	0.40	62.1	45.7	35.5	15.6
Thermacare®, FBB	23.6	1.97	1.40	0.83	0.26	46.5	33.0	23.7	7.4
Thermacare®, Optisan® FBB	17.1	2.79	2.00	1.22	1.43	47.7	34.2	25.2	8.9
WarmAir®, FiltredFlo™ FBB	13.4	2.61	1.83	1.05	0.27	35.0	24.5	17.0	4.4
Warm-Gard®, FBB	15.4	3.18	2.65	2.12	1.59	49.0	40.8	39.5	29.6
Warm-Gard®, reusable FBB	15.3	2.50	1.83	1.16	0.49	38.3	28.0	21.5	91.1
WarmTouch™, CareDrape™ FBB	28.1	1.24	0.74	0.24	-0.26	34.8	20.8	8.2	-8.8
WarmTouch™, MultiCover™ FBB	14.5	3.18	2.46	1.74	1.02	46.1	35.7	30.5	17.9

Heat exchange coefficients (h), mean temperature gradients at a calculated surface temperature of 32°C (ΔT at 32°C), 34°C (ΔT at 34°C), 36°C (ΔT at 36°C) and 38°C (ΔT at 38°C) and the resulting heat exchange between the full body blanket and the manikin

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Intraoperative forced air-warming during cesarean delivery under spinal anesthesia does not prevent maternal hypothermia.

This is a randomized study of 30 patients undergoing cesarean delivery with spinal anesthesia. Patients were assigned to the Bair Hugger™ forced air-warming group or the control group (identical cover applied with the forced air-warming unit switched off). A blinded investigator assessed oral temperature, shivering, and thermal comfort scores at 15-minute intervals until discharge from the postanesthetic care unit. Umbilical cord blood gases and Apgar scores were also measured after delivery.

Since all measured parameters did not significantly differ between the two groups in this small study, authors concluded that forced air-warming does not prevent hypothermia or shivering in women undergoing elective cesarean delivery with spinal anesthesia.

Relation between general and regional anesthesia, upper- and lower-body warming: what strategies in pediatric anesthesia?

In this editorial, the author describes factors that contribute to inadvertent perioperative hypothermia (IPH), the development phases and negative consequences of IPH, and interventions for IPH prevention and treatment, especially for pediatric patients.

Interventions noted include forced-air warming, circulating water mattresses, and whole-body circulating water garments. The author cites evidence that the effectiveness of cutaneous warming is related to the quantity of patient skin surface reached. Forced-air warming of the extremities is described as more effective than warming with a circulating water mattresses, though less effective than whole-body garments, which reach a higher percentage of body surface area.It is reported that evidence supporting the superiority of either upper- or lower-body forced-air warming is mixed.

The author suggests that in clinical practice, forced-air warming using whole-body blankets is particularly effective, especially for neonatal patients.

Meperidine and skin surface warming additively reduce the shivering threshold: a volunteer study.

Kimberger, O., et al., *Meperidine and skin surface warming additively reduce the shivering threshold: a volunteer study*. Crit Care, 2007. 11(1): p. R29.

In this observational study, the core temperature of eight healthy volunteers was reduced to hypothermic levels to test whether a combination of meperidine and cutaneous warming would reduce the threshold for shivering to 34°C with no significant sedative effect or respiratory depression. On each of four separate study days, the core temperatures of each volunteer was lowered to 34°C via injection of cold ringer lactate (4°C), and subsequent rewarming was conducted with one of the following methods: a) control; b) cutaneous warming (Bair Hugger™ forced-air combined with warming blanket), c) meperidine (target plasma level: 0.9 mug/ml), and, d) cutaneous warming and meperidine.

The shivering threshold for control was 35.5 ± 0.2°C. Thresholds for groups b, c, and d were: 34.9 ± 0.5°C (p = 0.01), 34.2 ± 0.3°C (p <0.01), and 33.8 ± 0.2°C (p < 0.01), respectively. Combined meperidine and cutaneous warming produced no synergistic or antagonistic effects (p = 0.59). Meperidine alone produced only very mild sedation. Investigators concluded that a combination of meperidine and cutaneous warming lowered the shivering threshold to 33.8 ± 0.2°C with only a very mild sedative effect and no negative respiratory consequences.

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A randomized, controlled trial of the electric heating pad vs. forced-air warming for preventing hypothermia during laparotomy.

This study compared two modalities of maintenance of intraoperative body temperature for patients undergoing laparotomy under general anesthesia. Following randomization, a total of 60 patients received upper body forced-air warming (Bair Hugger™ system, Augustine Medical model 500/OR, Eden Prairie, MN) or an electric heating pad (Operatherm 202, KanMed, Bromma, Sweden).

Final mean temperature with forced-air warming was 36.2 (0.4)°C, and with the heating pad it was 35.5 (1.0)°C (p < 0.01). The conclusion was that the Bair Hugger upper body forced-air warming was more effective than the heating pad for maintenance of body temperature during laparotomy.

Hypothermia during laparotomy can be prevented by locally applied warm water and pulsating negative pressure.

The authors compared a new method of applying heat and pulsating negative pressure to the skin with conventional forced-air warming for preventing perioperative hypothermia in order to test their hypothesis that pulsating negative pressure would increase skin blood flow and thus heat transfer.

Twenty patients were randomly allocated to either standard method (SM) of forced-air warming, 43°C (Bair Hugger™ system) on the thoracic and upper arm surface or to the new method (NM). NM involved warm water and pulsating negative pressure treatment applied in a transparent acrylic cylinder (50 x 16 cm) on one arm. Pulsating pressure between 0 and -40 mm Hg was generated in the air pocket inside the cylinder. The air pocket inside the device was created by water 42.5°C, which circulated through the cylinder.

In both groups, warming started after induction of general anaesthesia. The two methods performed similarly during the first 60 minutes, with a mean 0.7°C decrease in core temperature. The tympanic temperature curve in NM group then increased and returned to baseline (37°C) by 120 minutes. The temperature of SM group increased more slowly, reaching 36°C by 120 minutes ($P < 0.05$). The authors concluded that pulsating negative pressure was significantly better at treating hypothermia during laparotomy than forced-air warming.

A model to predict patient temperature during cardiac surgery.

This article describes a new computer model of patient heat transfer during cardiac surgery that provides information on the varying effects of different patient warming methods on reducing post-cardiopulmonary bypass core temperature reduction ("afterdrop"). The authors report that the model was validated through comparisons of model results to actual measurement results during three surgical procedures.

In a subsequent parameter study utilizing the model, the authors report that the Bair Hugger™ forced-air warming system was more beneficial than increased environmental temperature or use of a circulating water mattress in reducing afterdrop.

Contact a 3M Representative

Comparison of cutaneous heat transfer using two different warm blankets in healthy volunteers.

Taniguchi, Y., et al., *Comparison of cutaneous heat transfer using two different warm blankets in healthy volunteers*, in Anesthesiology. 2007. p. A1269.

In this observational study, six healthy volunteers cooled with infusions of cold IV fluid to induce shivering were randomly assigned to rewarming with either of two convective warming systems (Bair Hugger™ forced-air warming system or Eppendorf™ forced-air warming system) to compare the efficacy of these systems in restoring normothermia. Upper-body blankets were used with both systems.

Core temperature (tympanic membrane) before rewarming was 35.0 ± 0.47°C for the Bair Hugger volunteers and 35.0 ± 0.89°C for the Eppendorf volunteers. Rewarming rates were comparable (1.2 ± 0.32°C/hour and 1.3 ± 0.41°C/hour, respectively). The investigators concluded that there was no significant difference in warming effectiveness between the two systems.

Efficacy of an Underbody Forced-Air Warming Blanket for the Prevention of Intraoperative Hypothermia.

Tominaga, A., et al., *Efficacy of an underbody forced-air warming blanket for the prevention of intraoperative hypothermia*, in Anesthesiology. 2007. p. A91.

Forced-air systems that use conventional blankets cannot prevent the initial decrease of core temperature during surgery, as these blankets cover the patient only partially. The authors evaluated the efficacy of preventing hypothermia by a new type of forced-air warming blanket (Bair Hugger™ system, Model 635 Full Access Blanket – Arizant Healthcare), which is used by placing it under the body of patients.

Twenty patients undergoing elective upper abdominal surgery were randomized into two groups; (1) the forced-air warming (43ºC) group using underbody blanket (underbody blanket group), and (2) circulating water mattress (43ºC) group (control group). After the induction of anesthesia, esophageal and bladder temperatures were taken at 15-minute intervals for 120-minutes following induction. Data was presented as mean + SD. Statistical analysis was performed using ANOVA and post hoc Bonferroni/Dunn or Scheffe's F test.

The results showed that esophageal temperature did not change significantly throughout surgery in the "underbody" blanket group, while it decreased significantly in the control group. The maximum decrease of the esophageal temperature was 0.24 ± 0.30ºC and 0.91 ± 0.44 ºC in the "underbody" blanket and control group, respectively.

The authors demonstrated that the Bair Hugger forced-air warming system using the underbody blanket was more effective in preventing hypothermia during upper abdominal surgery. This study showed that this device could also prevent the initial temperature decrease caused by redistribution.

Compared with most frequently used upper body blankets (that cover the upper extremities from above), the underbody blanket can warm larger body surface areas (not only upper and lower extremities, but also the lateral sides of the trunk), which facilitates the maintenance of normothermia.

Contact a 3M Representative

New circulating-water devices warm more quickly than forced-air in volunteers.

Wadhwa, A., et al., *New circulating-water devices warm more quickly than forced-air in volunteers*. Anesth Analg, 2007. 105(6): p. 1681-7.

This study compared two circulating-water systems with a Bair Hugger™ forced-air system during simulation of upper abdominal or chest surgery in volunteers.

Seven healthy volunteers participated in this study over three separate days. Each day, they were anesthetized and cooled to a core temperature near 34°C, which was maintained for 45-60 minutes. They were then rewarmed with one of three warming systems until distal esophageal core temperature reached 36°C or anesthesia had lasted 8 hours.

The warming systems were 1) energy transfer pads (two split torso pads and two universal pads; Kimberly Clark, Roswell, GA); 2) circulating-water garment (Allon® MTRE 3365 for cardiac surgery, Akiva, Israel); and 3) lower body forced-air warming (Bair Hugger system Model 525 blanket, Model 750 blower, Eden Prairie, MN). Data were presented as mean ± SD.

The rate of increase of core temperature from 34°C to 36°C was 1.2 ± 0.2°C/hour with the Kimberly Clark system, 0.9 ± 0.2°C/hour with the Allon system, and 0.6 ± 0.1°C/hour with the Bair Hugger system (P = 0.002).

Thus, the warming rate with the Kimberly Clark system was 25% faster than with the Allon system and twice as fast as with the Bair Hugger system. This study demonstrated that both circulating-water systems warmed hypothermic volunteers significantly more quickly than the forced-air system.

Randomized clinical trial of perioperative systemic warming in major elective abdominal surgery.

In this prospective study, 103 patients undergoing elective major abdominal surgery with intraoperative warming therapy were placed on a conductive carbon warming mattress 2 hours before being transferred to the operating theatre. All patients remained on the mattress before, during and after surgery. The study was designed to investigate the effect of additional warming on post-operative morbidity.

In the warmed group (N=47), the mattress was turned on 2 hours before surgery and kept at 40°C throughout surgery. In the control group (N=56), the mattresses were switched off, however the patients were warmed using the Bair Hugger™ forced-air warming system set at 40°C and also received warmed intravenous fluids.

Patients who received additional warming experienced less blood loss than patients who received no additional warming (median 200, range 5-1000 ml versus median 400, range 50-2300 ml, P=0.011). Complication rates were also reduced for patients who received additional warming (32% versus 54%, P = 0.027).

The investigators concluded that perioperative systemic warming, in addition to standard forced-warm air intraoperative warming, resulted in a significant reduction in blood loss and other complications, contributed minimal cost, and diminished patient discomfort.

Maximizing patient thermoregulation in US Army forward surgical teams.

Blackbourne, L.H., et al., *Maximizing patient thermoregulation in US Army forward surgical teams*. US Army Med Dep J, 2008: p. 60-6.

In this article, the authors describe the importance of maintaining normothermia among emergency and trauma patients entering U.S. Army forward surgical teams (FSTs), and recommend approaches to preventing or mitigating inadvertent hypothermia. Reported benefits of setting minimal thermoregulation systems for FSTs include decreased morbidity and mortality, and decreased blood and fluid requirements, for wounded patients.

The authors recommend as standard thermoregulatory equipment for Level IIB FSAs: Bair Hugger™ forced-air warming systems, the Belmont FMS-2000 fluid warmer, wool blankets, reflective blankets, an environmental control unit, and the Enthermic Medical Systems fluid warmer.

Effect of prewarming on post-induction core temperature and the incidence of inadvertent perioperative hypothermia in patients undergoing general anaesthesia.

This study tested the efficiency of a preoperative forced-air warming system (Bair Paws™ system) in preventing perioperative hypothermia.

Sixty-eight adult patients undergoing spinal surgery under general anaesthesia were randomized to receive either standard care (N=37) or prewarming for 60 minutes, at 38°C (N=31), using the Bair Paws system. All patients received a Bair Paws forced-air warming gown and were connected to a Bair Hugger™ forced-air warming unit intraoperatively.

The results showed that there was a 0.3 °C smaller decrease in mean core temperature in the prewarmed group at 40, 60, and 80 minutes post-induction (P≤0.05). Temperature was maintained above the hypothermic threshold of 36 °C in 21 (68%) patients in the prewarmed group, compared with 16 (43%) patients in the control group (P<0.05).

Therefore, preoperative warming using the Bair Paws system led to smaller decreases in core temperature intraoperatively and less perioperative hypothermia in patients undergoing spinal surgery under general anaesthesia.

Cardiac surgery fast-track treatment in a postanesthetic care unit: six-month results of the Leipzig fast-track concept.

Ender, J., et al., *Cardiac surgery fast-track treatment in a postanesthetic care unit: six-month results of the Leipzig fast-track concept*. Anesthesiology, 2008. 109(1): p. 61-6.

The authors compared a new fast-track concept developed at their center, which included a direct admission to the postanesthetic care unit, to standard perioperative management. A historical control was used for the latter.

All fast-track patients treated within the first 6 months of implementation of the new concept (N=421) were matched 1:1 via propensity scores to a historical control group of patients who underwent cardiac surgery prior to fast-track implementation. The two groups of patients had a similar age (64 ± 13 vs. 64 ± 12 years for fast-track vs. control, P = 0.45) and European System for Cardiac Operative Risk Evaluation–predicted risk of mortality (4.8 ± 6.1% vs. 4.6 ± 5.1%, P = 0.97). Fast-track patients had significantly shorter times to extubation (75 minutes [45–110] vs. 900 minutes [600–1140]), as well as shorter lengths of stay in the postanesthetic or intensive care unit (4 h [3.0 –5] vs. 20 hours [16 –25]), intermediate care unit (21 hours [17–39] vs. 26 hours [19–49]), and hospital (10 days [8 –12] vs. 11 days [9 –14]) (expressed as median and interquartile range, all P < 0.01). Fast-track patients also had a lower risk of postoperative low cardiac output syndrome (0.5% vs. 2.9%, P < 0.05) and mortality (0.5% vs. 3.3%, P < 0.01).

This study has shown that the Leipzig fast-track protocol was a safe and effective method to manage cardiac surgery patients after a variety of operations.

Comparison of three warming devices for the prevention of core hypothermia and post-anaesthesia shivering.

Ihn, C.H., et al., *Comparison of three warming devices for the prevention of core hypothermia and post-anaesthesia shivering*. J Int Med Res, 2008. 36(5): p. 923-31.

This is a prospective randomized double-blind study, which allocated patients undergoing total abdominal hysterectomy into 3 groups with 30 patients each (a total of 90 patients) to compare the efficacy of different warming devices in preventing a decrease in core temperature during anaesthesia and post-anaesthesia shivering (PAS) . The three groups included Bair Hugger™ forced air warming with a surgical access blanket, Bair Hugger forced air warming combined with an upper body blanket, and a circulating water mattress.

Core temperature was measured 15, 30, 45, 60, 90 and 120 minutes after induction of anaesthesia. PAS was evaluated every 5 minutes after emergence from anaesthesia over a period of 1 hour. The core temperature fell in all three groups compared with the baseline, but forced air warming using a surgical access blanket was more effective than the other warming methods in ameliorating the temperature decrease. The forced air warming with a surgical access blanket was also superior to the circulating water mattress in reducing PAS.

The effects of warming methods on temperature, cardiac function and cytokines in plateletpheresis donors.

In this prospective study, 50 plateletpheresis donors were randomly assigned to active warming with the Bair Hugger™ system (N=25) or a non-warmed control group (N=25) to assess the effect of warming on donor temperature (tympanic), cardiac measurements, and cytokines.

The control group experienced lower temperatures (P=0.014), and significantly decreaseed diastolic blood pressure (P=0.010) during apheresis. With regard to cardiac function, there was a higher, but statistically insignificant, frequency of abnormal beats for the control group. The warming group saw no change in IL-2 or TNF-alpha. The control experienced significant decreases in IL-2 or TNF-alpha following plateletpheresis.

The investigators concluded that the warming approach used in the study could maintain donor normothermia and may help preserve hemodynamic and cytokine balance in this population.

Resistive polymer versus forced-air warming: comparable heat transfer and core rewarming rates in volunteers.

This study evaluated the efficacy to preserve perioperative normothermia by using a Bair Hugger™ forced-air warming system compared to the newly-developed resistive polymer system.

Eight healthy volunteers participated, each on two separate study days. All volunteers were unanesthetized and were cooled to a core temperature (tympanic membrane) of 34°C by application of forced-air at 10°C and a circulating-water mattress at 4°C. Meperidine and buspirone were administered to prevent shivering. Then, the volunteers were randomized to receive rewarming (until their core temperatures reached 36°C) with one of the following active warming systems: (1) forced-air warming (Bair Hugger™ Model 300 blanket, Model 750 warming unit, Arizant, Eden Prairie, MN); or (2) polymer fiber resistive warming (HotDog whole body blanket, HotDog standard controller, Augustine Biomedical, Eden Prairie, MN). The alternate system was used on the second study day. Metabolic heat production, cutaneous heat loss, and core temperature were measured.

Metabolic heat production and cutaneous heat loss were similar with each system. After a 30-minute delay, core temperature increased nearly linearly by 0.98 (95% confidence interval 0.91-1.04)°C/hour with forced-air and by 0.92 (0.85-1.00)°C/hour with resistive heating ($P = 0.4$).

This study authors conclude that heating efficacy and core rewarming rates were similar for the two types of warming devices.

Thermoregulatory management for mild therapeutic hypothermia.

Kimberger, O. and A. Kurz, *Thermoregulatory management for mild therapeutic hypothermia*. Best Practice & Research Clinical Anaesthesiology, 2008. 22(4): p. 729-744.

Mild therapeutic hypothermia has a neuroprotective effect and is utilized for treatment after cerebral ischemic hypoxic injury. It has been shown that mild therapeutic hypothermia leads to improved outcome after out-of-hospital cardiac arrest, and has a beneficial effect on patient outcome after traumatic brain injury, cerebrovascular damage, and neonatal asphyxia.

This review article explored numerous different methods for the induction of mild therapeutic hypothermia, reviewed thermoregulatory management during maintenance, and discussed associated risks and complications.

Wet forced-air warming blankets are ineffective at maintaining normothermia.

Lin, E.P., K. Smith, and R.D. Valley, *Wet forced-air warming blankets are ineffective at maintaining normothermia*. Paediatr Anaesth, 2008. 18(7): p. 642-4.

This study used a simple model to show that forced-air warming blankets become ineffective if they get wet. Temperature sensor probes were inserted into three 1-liter fluid bags. Group C bags served as the control. Groups D (dry) and W (wet) bags were placed on Bair Hugger™ pediatric underbody blankets (Model 555 blanket, Arizant Healthcare, Inc., Eden Prairie, MN, USA). The warming blanket for Group W bags was subsequently wet with irrigation fluid. Temperature was recorded every 5 minutes and the model was repeated twice for a total of three cycles.

Starting temperatures for each model were within a 0.3°C range. Group C demonstrated a steady decline in temperature. Group D maintained and slightly increased in temperature during the observation period, while Group W exhibited a decrease in temperature at a rate similar to Group C. These results were significant at $P < 0.005$.

The authors have demonstrated that wet forced-air warming blankets were ineffective at maintaining normothermia; once wet, the warming blanket led to cooling similar to the control group.

Contact a 3M Representative

Improvements in forced-air warming systems might prevent intraoperative redistribution hypothermia.

Ouichi, T., et al., *Improvements in forced-air warming systems might prevent intraoperative redistribution hypothermia*. Anesthesiology, 2008. 109: p. A918.

In this prospective study, 30 patients undergoing elective upper abdominal surgery were randomized to receive intraoperative warming therapy with one of three methods to compare their effectiveness in preventing inadvertent perioperative hypothermia.

The three warming methods were: a) Bair Hugger™ forced-air warming therapy using a Model 635 underbody blanket (Arizant Healthcare); b) Bair Hugger forced-air warming therapy using a Model 522 upper-body blanket (Arizant Healthcare); or a circulating water mattress (control). All three systems were set at 43°C. Esophageal and bladder temperatures were recorded every 15 minutes after induction. All patients received combined thoracic epidural and sevoflurane anesthesia.

Both forced-air warming groups maintained esophageal temperatures throughout the procedure, while the temperature dropped significantly in the circulating water group. The maximum decrease in esophageal temperature for group A was 0.27 ± 0.30°C, versus 0.11 ± 0.26°C for group B and 0.91 ± 0.44°C for group C.

The investigators concluded that the Bair Hugger forced-air warming methods were equally effective, and more effective than the circulating water mattress, at maintaining patient normothermia during upper abdominal surgery.

A comparison of forced-air warming and resistive heating.

Perl, T., et al., *Comparison of forced-air warming and resistive heating*. Minerva Anestesiol, 2008. 74(12): p. 687-90.

In this prospective study, six healthy volunteers were randomized to receive warming from either a forced-air warming system (Bair Hugger™ therapy with Model 505 unit and Model 522 blankets) or a resistive heating system (Geratherm Medical AG) to compare the warming effectiveness of the two systems. Heat transfer was evaluated using 11 calibrated heat flux transducers on the upper body, and blanket and skin temperatures were also measured.

There was no significant difference in skin temperature between the two groups (37.3 ± 0.2°C for forced-air versus 37.8 ± 0.2°C for resistive heating), but the resistive heating group experienced significantly higher blanket temperature (40.3 ± 0.6°C vs 38.1 ± 0.4°C, P=0.002) and heat transfer (13.2 ±3.6 W vs 7.8 ± 1.9 W, P=0.048).

The investigators concluded the resistive heating approach produced significantly greater heat transfer than forced-air warming.

Impact of Perioperative Warming on Maintenance of Normothermia and Outcome after Colorectal Surgery.

Yilmaz, M., et al., *Impact of perioperative warming on maintenance of normothermia and outcome after colorectal surgery*, in Anesthesiology. 2008. p. A880

The goal of this study was to determine the incidence of hypothermia (temperature < 36°C) in the post-anesthesia recovery room (primary outcome) and the rate of complications and duration of hospital stay (secondary outcomes) in patients undergoing colorectal surgery, who were randomized to either standard intraoperative warming only or preoperative and intraoperative warming.

Eighty-two patients were assigned intraoperative warming (Phase 1), which consisted of a Bair Hugger™ forced air warming and the use of fluid warming. Fifty-nine patients were assigned to Phase 2 (preoperative & intraoperative warming), where the warming protocol consisted of a forced air warming gown (temperature self controlled) and a fluid warmer started in the pre-operative holding area. The operating room temperature was maintained at 21°C during induction and awakening, and lithotomy forced air warmer was used if the surgery was to be performed in this position.

The results showed that recovery room admission was achieved in 95% of Phase 2 subjects compared to 43% during Phase 1 (P<0.01). Temperatures at entry to the OR, incision, end of case and entry to the recovery area were higher in the group warmed preoperatively. Postoperative infections were reduced by 12.3% (95% CI 0.1% to 23.0%) in phase 2 compared to phase 1 (P=0.09, trend). There was no difference in the need for blood transfusions between the two groups. The average length of stay was 8 ± 5 days during phase 1 compared to 7 ± 3 days in phase 2 (P=0.17).

This study showed that active warming administered preoperatively was more effective in achieving normothermic admission temperature to the post-anesthesia recovery room than when warming was administered only intra-operatively. The group warmed preoperatively showed a tendency towards a decreased incidence of infections and shorter hospital stay.

Mild Perioperative Hypothermia.

Sessler DI, Kurz A, *Mild Perioperative Hypothermia*. Anesthesiology News, Oct 2008: p. 17-28

This review article provides a comprehensive summary of evidence surrounding the causes and negative consequences of inadvertent perioperative hypothermia, as well as prevention and treatment options and recommendations for clinicians.

The authors note that inadvertent hypothermia is common among patients under general or regional anesthesia, and results from both anesthesia-induced impairment of the thermoregulatory system and cold operating room environments. Negative consequences associated with inadvertent perioperative hypothermia include increased risk of surgical site infection, duration of hospitalization, intraoperative transfusion requirement and blood loss, morbid cardiac events, delayed post-operative recovery, and post-operative shivering.

The authors report that passive warming with insulators (e.g. cotton blankets) and warming with circulating water mattresses are nearly ineffective, whereas the best forced-air warming systems are usually capable of maintaining perioperative normothermia even during major surgical procedures. The authors recommend that patient temperature be measured during both general and regional anesthesia procedures, with a goal of maintaining patient temperature above 36°C.

Comparison of two convective warming systems during major abdominal and orthopedic surgery.

Wagner, K., et al., *Comparison of two convective warming systems during major abdominal and orthopedic surgery*. Can J Anaesth, 2008. 55(6): p. 358-63.

Authors evaluated the use of the WarmAir convective warming system (WarmAir, sound pressure level 49 dba, air flow 35 cfm) compared to Bair Hugger™ system (Model 750, sound pressure level 55 dba, air flow 48 cfm) with regards to temperature outcome.

In this study, patients undergoing general anesthesia for major abdominal and orthopedic surgery were randomized to receive either a WarmAir (n=89) upper body convective blanket warming or Bair Hugger (n=95) upper body convective warming blanket. Distal esophageal or nasopharyngeal temperature was measured intraoperatively. Sublingual temperature was measured preoperatively.

In the WarmAir group, preoperative, lowest intraoperative, end of surgery, and postanesthesia care unit admission temperatures were (means ± SD); 36.3 ± 0.5°C, 35.4 ± 1.1°C, 36.4 ± 0.7°C, and 36.4 ± 0.6°C, respectively. Corresponding temperatures in the Bair Hugger group were; 36.3 ± 0.6°C, 35.6 ± 1.0°C, 36.5 ± 0.6°C, and 36.4 ± 0.5°C, respectively. Results showed that both systems were effective and that choice of system depends on other factors such as ergonomics or cost.

Forced-air warming: technology, physical background and practical aspects.

Brauer, A. and M. Quintel, *Forced-air warming: technology, physical background and practical aspects*. Curr Opin Anaesthesiol, 2009.

This is a review of the studies of forced air warming devices available on the market.

Heat flow produced by power units depends on the air temperature at the nozzle and the airflow. The efficacy of a forced-air warming systems is mainly determined by the design of the blankets. A good forced-air warming blanket can easily be determined by measuring the temperature difference between the highest and lowest temperature of the blanket. This difference should be as low as possible.

Patients must be prewarmed for 30 – 60 minutes even if a forced-air warming system is used during the operation. During the operation, the largest blanket possible should be used. Forced-air warming is a well tolerated and effective method for most surgical procedures.

Contact a 3M Representative

What determines the efficacy of forced-air warming systems? A manikin evaluation with upper body blankets.

Brauer, A., et al., *What determines the efficacy of forced-air warming systems? A manikin evaluation with upper body blankets*. Anesth Analg, 2009. 108(1): p. 192-8.

This is a manikin study with heat flux transducers using five forced-air warming systems to determine the factors that were responsible for heat transfer from the blanket to the manikin.

There was no relation between the air flow and air temperature at the nozzle of the power unit with the resulting heat transfer. All blankets performed best at high air flows (above 19 L/s). Authors concluded that the efficacy of forced air warming systems primarily depended on the blanket.

An optimization of blanket design by optimizing the mean temperature gradient between the blanket and the manikin (or any other surface) with a very homogeneous temperature distribution in the blanket would enable the manufacturers to develop better forced-air warming systems.

Resistive-Heating or Forced-Air Warming for the Prevention of Redistribution Hypothermia.

In this prospective study, 27 patients undergoing laparoscopic colorectal surgery were randomized into one of three warming groups to evaluate the effectiveness of the approaches in preventing inadvertent perioperative hypothermia. Patients either received a) 30 minutes of warming before anesthesia (pre-warming) with a carbon-fiber total body resistive-heating device; b) 30 minutes of prewarming with an over-the-body Bair Hugger™ forced-air warming system (shoulders, ankles and feet were exposed); or c) control (no prewarming). The resistive-heating and forced-air systems were set at 42°C.

Upon induction of anesthesia, all patients were warmed with the same type of lithotomy blanket. Temperature measurements were taken via tympanic and esophageal devices. At 50 minutes after induction of anesthesia, mean esophageal temperature in the control group was 35.9 ± 0.3°C, versus 36.5 ± 0.4°C for the resistive warming group and 36.2 ± 0.3°C for the forced-air warming groups.

Differences between the two active warming groups were not statistically significant. The authors concluded that prewarming should be considered to reduce risk of post-operative hypothermia.

Anesthesia management for transapical transcatheter aortic valve implantation: a case series

This is an observational study of 100 patients with severe aortic stenosis with the goal to review the management of anesthesia. The patients were treated following a fast-track protocol. Eighty-one patients were treated completely off pump. The first 10 patients in the study were intentionally placed on cardiopulmonary bypass, and 9 patients required cardiopulmonary bypass due to hemodynamic deterioration.

Authors concluded that the design of anesthetic plan and understanding of surgical procedure were required to have successful outcomes in surgery of high risk patients.

Contact a 3M Representative

Active warming systems to maintain perioperative normothermia in hip replacement surgery: a therapeutic aid or a vector of infection?

Some reports in the literature have suggested that the use of devices like the Bair Hugger™ system can increase the risk of nosocomial infections, particularly surgical wound infections.

The aim of this study was to assess the risk of contamination of the surgical site associated with the use of the Bair Hugger blanket during hip replacement surgery. Authors measured the level of bacterial contamination of the air in the operating theatre with and without the use of the Bair Hugger, during the course of 30 hip implants performed in patients.

Statistical analysis of the data showed that the Bair Hugger system did not pose a real risk for nosocomial infections. In addition, monitoring patients over the six months following the operation allowed authors to exclude a later manifestation of a nosocomial infection.

Temperature control in conventional abdominal surgery: comparison between conductive and the association of conductive and convective warming.

The objective of this randomized study was to compare two methods of intraoperative warming (convective and conductive warming) used in abdominal surgery and their efficacy in preventing perioperative hypothermia.

The study randomized 43 patients undergoing xyphopubic laparotomy, ages 18 to 88 years, to receive either conductive (COND, N=24) or conductive and convective (COND + CONV, N=19) warming. Conductive warming consisted of a circulating water mattress at 37°C on the back, while convective warming included a forced-warm air blanket (Bair Hugger™ therapy) at 42°C, over the thorax and upper limbs. Both groups were similar in most analyzed parameters (age, gender, weight, temperature 1 hour post induction (M1), temperature at admission (M(a-REC)) and discharge (M(d-REC)) from the post-anesthetic recovery room (PARR). However, the parameters differed at M2, M3, M4, end of surgery (Mes), and on anesthetic induction (Mea).

The results showed that the decrease in patients' temperature occurred at 2 h post-anesthesia in the COND group and only at 4 hours post-anesthesia in the COND + CONV group. The COND group patients presented with hypothermia upon admission and discharge from PARR. While warming methods reduced hypothermia, the complaints of cold and tremor were not reduced.

Forced-air warming effectively prevents midazolam-induced core hypothermia in volunteers.

Midozalom is used to induce hypothermia and the authors tested the hypothesis that forced-air warming could prevent this midozalom effect.

The study included 6 male volunteers who participated in a 3-day study. On the first day, the volunteers received only 30 minutes of forced-air warming (Bair Hugger™ system). On the second day, they were vasoconstricted and 75µg/kg of midozalom was administered intramuscularly, then the patients were covered with blankets. The treatment on the third day was the same, except for the blankets, which were substituted with forced-air warming.

Surface temperature was measured by four adhesive skin-surface probes with thermocouplers (chest, upper arm, lateral calf and thigh) and was used for calculation of mean skin and body temperature. Core temperature was measured by tympanic temperature.

Results showed that midozalom significantly decreased core body temperature in a time-dependent manner. Although forced-air warming did not prevent transient decrease in core temperature induced by midozalom, the temperature increased thereafter to the control level, leading to conclusion that forced-air warming could effectively prevent midozalom-induced hypothermia.

Predicting the efficacy of convection warming in anaesthetized children.

This study analyzed the factors purported to influence children's heating rates, with the goal of describing the most effective usage of the convection warming technique, and to better understand its physiology in children receiving anesthesia in surgeries lasting longer than 90 minutes.

Children were warmed by the Bair Hugger™ system and authors analyzed the relationship between characteristics and various thermal measures. A thermodynamic model was also evaluated. A total of 39 children (age ranging from 2 days to 12.5 years) were included in this study.

The result showed a number of significant correlations between different factors (e.g. height and weight) and heating efficacy. Neither the morphological characteristics nor the author's model could predict an individual's T (core) behaviour. To minimize the risk of hyperthermia, authors recommended a continuous measurement of T (core) during convection heating. The device air temperature should be turned to medium (38 °C) as T (core) approaches 37 °C.

Induced systemic hypothermia, using the coolgard system (Alsius®), for combined surgical and endovascular management of a giant cerebral aneurysm.

The most robust neuroprotection is provided by the application of moderate hypothermia (32°C core temperature). In this case study, the authors used Coolgard System (Alsius®) to induce systemic hypothermia during combined surgical and endovascular management of a giant aneurysm.

A 57-year-old female was scheduled for elective surgical clipping of a medial cerebral artery giant aneurysm (3.4 vs 9 cm diameter) under anesthesia. Coolgard was installed at 32°C as "end" temperature with "maximal cooling" setting. Starting body core temperature varied from 34.6°C for esophageal, to 35.6°C for rectal, and 35.7°C for bladder temperature. At 1 hour and 6 minutes after the start of hypothermia induction, the aimed core temperature of 32°C was obtained. The surgical procedure lasted 3 hours and 4 minutes, with core temperature between 31.9 - 32.1°C.

Coolgard was installed at 35°C "end" temperature with maximal rewarming set at 0.65°C per hour, after surgery. At 3 hours and 48 minutes, body core temperature reached 35°C, and Coolgard system was stopped. Warming continued and the Bair Hugger™ system was installed when patient was transferred to ICU.

The core body temperature increased to 36-36.5°C and the patient was awakened without any deficit (11.30 hours after ICU admission). Most importantly, the entire rewarming process occurred at the desired slow rate, without any postoperative complication.

Prospective, Randomized and Controlled Trial Using Parallel Design to Evaluate the Efficacy of Forced-Air Warming Bair Hugger Full Access Underbody Blanket in Maintaining Body Temperature as Compared to Circulating Water Warming Mattress and Forced-Air Warming Bair Hugger Cath Lab (U-Shape) Blanket in Coronary Artery Bypass Graft (CABG) Surgery.

This randomized clinical trial compared the efficacy of a Bair Hugger™ underbody blanket (Model 635) in maintaining body temperature in CABG surgery and compared it to water warming (Blanketrol II Hyper-hypothermia Model 222B) and Bair Hugger U-shaped (Model 560) blankets.

Forty surgery patients were randomly assigned to either experimental (Bair Hugger Underbody Blanket) or control group (water warming and Bair Hugger U-shaped blankets). Baseline core temperature was taken at intubation (via esophagus, skin and rectal route). The rate of temperature change was calculated from the temperature taken at "off-bypass" to the time of readiness to transfer from operating table to the surgical bed to CTSICU bed.

The results showed that the use of a Bair Hugger underbody blanket was comparable to the use of two devices (water warming and Bair Hugger U-shaped blankets). The authors thus recommended the use of a Bair Hugger underbody blanket due to ease of use, time-savings, and significant cost-savings.

Contact a 3M Representative

Pre-operative forced-air warming as a method of anxiolysis.

This randomized, controlled, blinded study tested a hypothesis that pre-operative forced-air warming was as effective for anxiolysis as intravenous midozalom.

A total of 120 patients were randomly assigned to one of the following groups: cotton blanket and saline (n=30), midozalom and cotton blanket (n=30), Bair Hugger™ forced-air warming system and saline (n=30), or Bair Hugger forced-air system and midozalom (n=30). Patients completed visual analogue scales for anxiety and thermal comfort, as well as State-Trait Anxiety Inventory, at baseline and after twenty minutes of treatment. The estimated effect of midozalom on anxiety visual analogue scores (score: -10, 95% CI -3 to -18, p = 0.007) and state anxiety scores (score: -5, 95% CI -7 to -4, p = 0.03). Warming appeared to have no influence on visual analogue scores for anxiety (p = 0.50) nor state anxiety (p = 0.33).

Warming did have an estimated effect on thermal comfort (score: +23, 95% CI 19-27, p < 0.0001). No interaction between midazolam and warming was observed. Thus, pre-operative warming was not equivalent to midazolam for anxiolysis.

Randomized non-inferiority trial of the vitalHEAT™ Temperature Management System versus the Bair Hugger™ warmer during total knee arthroplasty.

Trentman, T.L., et al., *Randomized non-inferiority trial of the vitalHEAT temperature management system vs the Bair Hugger warmer during total knee arthroplasty*. Can J Anaesth, 2009. 56(12): p. 914-20.

In this study, a total of 55 patients were randomized to test the hypothesis that the vitalHEAT™ system is non-inferior to the Bair Hugger™ system during unilateral total knee arthroplasty. One group of patients (n=30) received vitalHEAT system, and the other group (n=25) had received the Bair Hugger system.

The results showed that, in terms of the primary outcome (sublingual temperature measured within 10 minutes interval in recovery room), vitalHEAT system underperformed compared to the Bair Hugger system. Likewise, for the secondary outcomes (i.e. intraoperative esophageal temperatures), vitalHEAT did not perform on the level of the Bair Hugger system.

This study showed that during total knee arthroplasty, the Bair Hugger system outperformed the vitalHEAT system.

Preventing hypothermia: comparison of current devices used by the U.S. Army in an in vitro warmed fluid model.

This study compared several active and passive warming devices and evaluated whether an in vitro fluid bag torso model they developed was sensitive enough to detect heat loss when using these warming devices. Active devices included Hypothermia Prevention Management Kit [HPMK], Ready-Heat, and the Bair Hugger™ system.

Passive hypothermia prevention products included wool blankets, Blizzard blankets, human remains pouch, and Hot Pocket. The fluid model was warmed to 37°C before testing and both groups of devices evaluated versus a control (no warming). Assessment included taking core temperature every 5 minutes for 2 hours total.

Results showed that active warming devices performed better than passive ones. Of all warming methods testing, HPMK yielded significantly better results (higher temperature at 2 hours, $p < 0.05$). Active heated devices never reach temperature of 44°C that could damage human tissue.

Only two passive warming products (Blizzard blanket or the Hot Pocket) performed the same as two active warming devices (other than HPMK) at 2 hours at room temperature. Model of in vitro fluid bag "torso" was sensitive to detect heat loss for both group of products. The applicability of these data in field conditions requires further studies.

Energy efficiency comparison of forced-air versus resistance heating devices for perioperative hypothermia management.

Hypothermia (core body temperature below 36°C) in the operating room may ensue due to the cold environment, low metabolic heat generation in a surgical patient, and exposure of afflicted body parts, which are not covered.

Two distinct, most frequently used approaches to patient warming include convective air warming and direct-contact heat induction. These two approaches are associated with different energy efficiencies, which were analyzed here. Representative devices from the two categories were analyzed experimentally to determine their energy utilization efficiency. Air conditioning devices are used to maintain the operating room temperature, thus any energy escaping from the warming devices must be extracted. This portion of energy from the devices was calculated from the known efficiency of air conditioners.

The most efficient of all the investigated devices was the Augustine WC01 direct-contact conduction model. Among the two convective warming devices, the Bair Hugger™ system was superior to the Mallinckrodt 5100. The Bair Hugger convective warming device was also more efficient than the Stihler direct-contact conduction device.

The conclusion was that the energy efficiency depended more on the specifics of the device within a category, than on the category itself.

Active warming systems to maintain perioperative normothermia in hip replacement surgery.

Comment on:
Active warming systems to maintain perioperative normothermia in hip replacement surgery: a therapeutic aid or a vector of infection? [J Hosp Infect. 2009]

This letter was written to the editor from the U.S. National Institutes of Health (NIH) in support of the conclusions of Moretti that the Bair Hugger™ system poses no risk for hospital-acquired infections.

Memarzadeh shares the outcomes of computational fluid dynamics and a particle tracking methodology used to analyze laminar flow disruption and airflow patterns. The NIH determined that particles are cleaned away from the patient by airflow from the laminar diffuser no matter if the forced-air warmer is on or off, with zero percent deposition on the patient from contaminant sources.

The analysis reconfirms previous research by Moretti, et al. that states Bair Hugger forced-air warming does not elevate the threat of surgical wound infection.

Contact a 3M Representative

Resistive-Polymer Versus Forced-Air Warming: Comparable Efficacy in Orthopedic Patients

This randomized study compared the efficacy of two patient warming methods used to maintain normothermia, forced air warming (FA) and resistive-polymer system (RP). Eight orthopedic surgery patients were allocated to receive either FA (Bair Hugger™ warming upper body blanket (Model #522) and warming unit (Model #750), Arizant, Eden Prairie, MN) or RP (Hot Dog™ Multi-Position Blanket and Hot Dog controller, Augustine Biomedical, Eden Prairie, MN) system warming. Continuous temperature recording (core, skin and room temperature) was performed.

No significant difference was observed between the two warming methods in core or in skin temperature. The environment close to the patients was significantly warmer when FA warming was used (24.4 ± 5.2°C for FA vs 22.6 ± 1.9 °C for RP at 30 minutes; P(AUC) <0.01). After initial decline, the rise in core temperature was comparable between the two warming methods (FA: 0.33 ± 0.34°C/hour; RP: 0.29 ± 0.35 °C/hour; P = 0.6). Thus, RP was as efficient as FA for patient warming in orthopedic surgery.

Forced-air warming blowers: An evaluation of filtration adequacy and airborne contamination emissions in the operating room.

Forced air warming units are in use near the operative site and are equipped with a 0.2-μm intake filter to prevent microbial dispersal and contamination posing a risk for surgical site infection. The study compared five model 200708C filters removed from the equipment currently used in the hospitals with five new filters, model 200708D, for Bair Hugger™ warming unit (Model 505, Arizant Healthcare, Eden Prairie, MN). Filter efficiencies were tested on 52 forced-air warming devices by using mono-disperse sodium chloride aerosol.

Results showed that design changes made a difference in retention efficiency. The new filter has a thinner filtration media and substantially lower retention efficiency (61.3% compared to 93.8% for the current filter). Since microorganisms were detected in the air path surfaces for 92.3% of warming units and 58% of evaluated warming units were generating end emitting contaminants, introduction of a new filter was a concern.

A Randomized Comparison of Intraoperative PerfecTemp and Forced-Air Warming During Open Abdominal Surgery.

Egan, C., et al., *A Randomized Comparison of Intraoperative PerfecTemp and Forced-Air Warming During Open Abdominal Surgery*. Anesth Analg, 2011. 113(5): p. 1076-1081.

A randomized study was undertaken to address the hypothesis that the PerfecTemp underbody warming system is non-inferior to a Bair Hugger™ upper body forced-air warming blanket in abdominal surgery patients in maintaining the core body temperature.

There were 36 patients in resistive heating group (PerfecTemp) and 34 in the forced-air warming group. Time-weighted average intraoperative temperature was the primary outcome comparing the two warming systems and 0.5°C was used as a buffer. The results showed non-inferiority of PerfecTemp system, with a mean difference of -0.12°C [95% confidence interval (CI) -0.37 to 0.14]. At the end of surgery, the respective averaged core temperatures in resistive warming and forced-air warming patients were 36.3°C [95% CI 36 to 36.5] and 36.6°C [95% CI 36.4 to 36.8], with the mean difference of -0.34°C [95% CI -0.69 to 0.01].

The study showed that underbody resistive heating may be an alternative to forced-air warming.

An evaluation of underbody forced-air and resistive heating during hypothermic, on-pump cardiac surgery.

This randomised controlled trial was conducted on 129 patients having cardiac surgery with cardiopulmonary bypass. Authors used Bair Hugger™ forced air warming (Arizant Healthcare Inc, Eden Prairie, MN, USA) for one group of patients and compared it to an underbody heating mattress (Inditherm® Patient Warming System, Rotherham, UK) and passive insulation.

External warming was used throughout the surgery, while the separation from the cardiopulmonary bypass was peformed at a core temperature of 35°C. Results showed that both active warming groups of patients had significantly greater temperature-vs-time slopes than the passive insulation group with no difference between forced air and resistive warming, before bypass.

Following bypass, rewarming of patients with the Bair Hugger forced air system was significantly greater compared to the two remaining warming methods, although the absolute temperature differences among the groups were small.

Preprocedure warming maintains normothermia throughout the perioperative period: a quality improvement project.

Preventing unplanned perioperative hypothermia (when core temperature is lower than 36°C) instigated research on patient prewarming. The concept behind this was that preprocedure warming would maintain perioperative normothermia.

Authors conducted a retrospective chart review of 148 patients who received standard preprocedure care and patients who were warmed with a warming gown for one hour before surgery and compared their temperature in the PACU.

Percentage of hypothermic patients received in PACU dropped from about 50% to 12% when prewarming procedure was implemented. The manuscript also discussed preprocedure warming, postprocedure hypothermia, and complications associated with hypothermia.

Comparing ambient, air-convection, and fluid-convection heating techniques in treating hypothermic burn patients, a clinical RCT.

Kjellman, B.M., et al., *Comparing ambient, air-convection, and fluid-convection heating techniques in treating hypothermic burn patients, a clinical RCT*. Ann Surg Innov Res, 2011. 5(1): p. 1-8.

Authors compared standard heating methods with newly developed devices Allon® 2001 Thermowrap (a temperature regulating water-mattress), and Warmcloud (a temperature regulating air-mattress) to identify the best method for preventing hypothermia in burn patients. Their prior experience with the standard technique (Bair Hugger™ system + radiator ceiling + bed warmer + Hotline®) had many drawbacks for the burned patients.

This prospective, randomized, comparative study, included 10 consecutive burn patients (> 20% total burned surface area and a core temperature < 36.0°C). Authors used three heating methods in 6 hour cycles (2 hours for each method). Core temperature was measured with bladder thermistor. Results showed that the Allon 2001 Thermowrap outperformed other warming methods by achieving mean core temperature increase of 1.4 (SD 0.6)°C (range 0.6-2.6°C) compared to 0.2 (0.6)°C (range -1.2 to 1.5°C) and 0.3 (0.4)°C (range -0.4 to 0.9°C) for conventional and Warmcloud warming methods, respectively.

In addition to superior effectiveness, Allon 2001 Thermowrap was perceived as more comfortable and straightforward compared to other warming methods tested.

Effectiveness of strategies for the management and/or prevention of hypothermia within the adult perioperative environment.

This is a comprehensive, systematic review of the effectiveness of different methods to treat and/or prevent perioperative hypothermia. Reviewers analyzed papers including adult (>18 years) surgery patients (any type) and including prospective studies with a clear description of randomization and/or use of control group and where core temperature was an outcome. Types of warming devices ranged from any type of linen or cover, aluminum foil wraps, Bair Hugger™ forced-air warming and other convective devices, radiant warming devices, and fluid warming devices.

This review included 19 studies with a total of 1,451 surgery patients. Numerous positive associations were observed. For example, forced-air warming prevented maternal and fetal hypothermia in pregnant women scheduled for caesarean delivery under regional anaesthesia. Similarly, the use of intravenous and irrigating fluids warmed to 38–40°C by different fluid warming devices led to a higher post-operative core temperature.

Forced air warming was effective in reducing the risk of post-operative infections and cardiac complications. Passive warming with reflective heating blankets or elastic bandages wrapped around the legs was found to be ineffective.

The authors concluded that forced-air warming carried significant benefits. Combination approaches, such as using warmed fluids in addition to forced-air warming were even more beneficial, in particular in vulnerable patient populations. It is recommended that active warming commence preoperatively with monitoring throughout the intraoperative period.

Contact a 3M Representative

Intra-operative rewarming with Hot Dog® resistive heating and forced-air heating: a trial of lower-body warming.

Authors evaluated 28 patients with major maxillary tumor surgery to test the hypothesis that two intra-operative warming systems were similar. They used Hot Dog® (Augustine Biomedical) resistive heating and compared it to the Bair Hugger™ system (Arizant) forced-air heating systems.

In the process of monitoring, patients became hypothermic with core temperature decline to about 35°C. They were then randomly assigned to lower body rewarming with Hot Dog® or Bair Hugger system and each system set to "high".

Authors observed rewarming rate for both active heating groups in the interval of core temperature rising from 35 to 37°C. Forced air warming increased core temperature at twice the rate compared to resistive heating. Resistive heating warmed at half the rate of forced air warming (p < 0.001).

Forced-air Warming and Ultra-clean Ventilation Do Not Mix

McGovern PD, et al., *Forced-air warming and ultra-clean ventilation do not mix: An investigation of theatre ventilation, patient warming and joint replacement infection in orthopaedics*. J Bone Joint Surg Br, 2011. 93-B(11): p. 1537-1544.

The authors conducted both visualization and retrospective studies to investigate the capacity of patient warming devices to disrupt the ultra-clean laminar airflow system. The paper compared the effects of two patient warming technologies -- forced-air (the Bair Hugger™ system) and conductive fabric (the HotDog® system) -- on operating theatre ventilation during simulated hip replacement and lumbar spinal procedures using a mannequin as a patient.

For the visualization study, the authors used soap bubbles to observe airflow resulting from the use of the warming technologies. The paper reports that forced-air warming generated convection currents that mobilized floor air into the surgical site area, but notes that the effects of lighting, drapes and personnel all create localized disturbances and likely play a role in the formation of convection currents.

For the retrospective arm of the study, infection data were reviewed to determine whether joint infection rates were associated with the type of patient warming device that was used. A significant increase in deep joint infection, as demonstrated by an elevated infection odds ratio (3.8, $p = 0.024$), was identified during a period when forced-air warming was used compared to a period when conductive fabric warming was used.

Authors indicate that the study does not establish a causal basis for the associated relationship between the method of patient warming used and infection rates. In addition, the authors indicate that the data is observational and may be confounded by other infection control measures instituted by the hospital.

Forced-Air Warming Does Not Worsen Air Quality in Laminar Flow Operating Rooms

Sessler, D.I., R.N. Olmsted, and R. Kuelpmann, *Forced-air warming does not worsen air quality in laminar flow operating rooms*. Anesthesia & Analgesia, 2011. 113(6): p. 1416-1421.

Theoretically, laminar flow can be disturbed by warm air produced through the use of forced-air devices. This study tested the hypothesis that laminar flow stays within standards during the use of Bair Hugger™ forced-air warming. The air quality was evaluated in two laminar flow operating rooms by including volunteer patients and heated manikin "surgeons". Results from the measurement of background particle counts in the vicinity of the potential surgical incision were confirmed by using smoke as a visual tracer.

There were no statistically significant or clinically important differences with a forced-air blower set to off, ambient air, and high temperature and all values remained well within the DIN standard requirements. Normal and effective function of the laminar flow process was maintained during the use of a forced air warming system.

In conclusion, Bair Hugger forced-air warming does not reduce operating room air quality during laminar flow ventilation and presents an appropriate intraoperative warming method.

Dynamics of thermoregulatory responses after cardiac surgery.

A preliminary study was conducted in cardiac surgery patients to examine the relationship between responses in skin and core temperature to the turning off of the Bair Hugger™ warming blanket on one side and length of stay (LOS) on the other. No relationship was found, however, it was observed in 9 patients with LOS of less than 7 days, that the dynamics of thermoregulation may contain useful information pertinent to the outcome of patients after cardiac surgery.

Thus further investigation would be needed to assess the value of dynamic features as indicators of patients' health status after cardiac surgery.

Contact a 3M Representative

The effects of active warming on patient temperature and pain after total knee arthroplasty.

Hypothermia may affect the patient's experience of postoperative pain after TKA (Total Knee Arthroplasty), a surgical procedure that places patients at risk for both hypothermia and post-operative pain. The aim of this study was to examine the effectiveness of whether perioperative warming can reduce both symptoms.

This randomized study included 30 patients in two groups. One group was prewarmed with standard cotton blankets (n=15) and the other group with patient controlled Bair Paws™ forced air warming gowns (n=15). Authors evaluated how the optimization of body temperature was related to postoperative pain after TKA.

Compared to patients who received standard blankets, the patients who received warming gowns had significantly higher post-operative temperatures (P < 0.001) and used less opioids (P = 0.05) after surgery. These patients also reported more satisfaction (P = 0.004).). The pain scores they reported were not significantly different compared to patients who used standard blankets during surgery.

Based on these findings, the authors encourage the use of effective patient warming methods for all patients and especially the elderly and in surgeries considered to be painful (such as TKA). The study results suggest that the use of forced air warming gowns may reduce the amount of opioids needed for treatment of postoperative pain and improve patient satisfaction.

Effect of forced-air warming on the performance of operating theatre laminar flow ventilation.

Dasari, K.B., M. Albrecht, and M. Harper, *Effect of forced-air warming on the performance of operating theatre laminar flow ventilation*. Anaesthesia, 2012. 67(3): p. 244-249.

The study investigated whether the floor-to-ceiling temperatures around a draped manikin in a laminar flow theatre differed when employing different types of warming devices. They hypothesized that forced-air warming exhaust may disrupt operating room airflow by the formation of convection currents.

In this study three types of warming devices were used: a forced-air warming blanket (Bair Hugger™ system); an over-body conductive blanket (Hot Dog®); and an under-body resistive mattress (Inditherm®).

Air temperature did not differ significantly between the three devices at floor (p=0.339), knee (p=0.799) and head height levels (p=0.573). However, mean (SD) temperatures were significantly higher over the surgical site when a forced-air warming blanket was used, compared to those measured with the conductive blanket (+2.73 (0.7) °C; p<0.001) or resistive mattress (+3.63 (0.7) °C; p<0.001).

The study concluded that forced-air warming generated convection current activity in the vicinity of the surgical site. Potential airflow disruption caused by the convection currents presents a clinical concern. These may interfere with the removal of airborne contaminants from the surgical site by the ventilation system.

Nice and warm: Did NICE guidance on perioperative hypothermia make any difference?

The paper presents the result of annual audits performed in the period from 2008-2010 to assess the hospital compliance with NICE (National Institute for Clinical Excellence) guidance on inadvertent perioperative hypothermia.

The audits assess the first 100 consecutive patients enrolled in September of each year. After the first audit (2008), poor adherence to the guidelines was documented. Therefore, the hospital developed a local implementation program to improve results for 2009. Sustained education and having a separate Pre-Operative Preparation Area (POPPA) led to further improved compliance in 2010.

One of the program measures was to use an inexpensive device (Clinitrend™) to continuously monitor patient's temperature throughout surgery. Other measures to prevent perioperative hypothermia included the use of Bair Hugger™ system, warmed fluids, and other active warming devices, as well as blankets. All of these measures were incorporated in the procedures. In addition, the Pre-operative preparation Area (POPPA) was implemented and staff awareness, training, and distribution of audit results each year helped in improving the compliance.

Impact of equipment with fans in the operating room.

Smooth and non-turbulent airflow in the operating room (OR)) can protect patients from acquiring air-borne pathogens. This project undertook an investigation to determine how OR equipment can influence airflow when they are used in the vicinity of an OR table.

Authors tested the following equipment: anesthesia station, a forced-air patient warming unit (Bair Hugger™ system), electrosurgical unit, arthroscopic machine, Pyxis Anesthesia System, high intensity light source, and two additional personal computers (one at the Picture Archiving and Communication System Station and one at the charting station). They utilized a simulated patient on the OR table and used smoke visualization testing.

Results showed that all but one piece of equipment had no effect on the non-turbulent airflow over the OR table. The operation of the high intensity light source was found to cause turbulence in the airflow. That effect was minimized with corrective placement.

During normal use, the fans within small computer stations, forced-air warming blankets, electrosurgical units, and arthroscopic equipment have no impact on non-turbulent/ unidirectional airflow.

Comparison of peri-operative core temperature in obese and non-obese patients.

Fernandes, L.A., et al., *Comparison of peri-operative core temperature in obese and non-obese patients*. Anaesthesia, 2012. 67(12): p. 1364-1369.

The study was initiated to compare peri-operative core temperatures and occurance of hypothermia in obese (n=10) versus non-obese women (n=10) undergoing abdominal surgery. The female patients were assigned to a group according to body mass index.

Patients in both groups received forced-air warming (Bair Hugger™ system) on their lower limbs. Mean intraoperative core temperatures in each group were compared at the end of surgery and were significantly (P<0.001) higher in the obese group than in non-obese group (36.7 (0.5) °C and 36.0 (0.6) °C, respectively). Mean recovery-room temperatures with standard deviations (SD) were 36.2 (0.4) vs 35.6 (0.5) °C, respectively (P < 0.001). Likewise, the obese group had a lower incidence of intraoperative hypothermia compared to non-obese group (10% and 60%, respectively, P=0.019).

In conclusion, obese women undergoing abdominal surgery using forced-air warming had higher peri-operative core temperatures and experienced less hypothermia, compared to non-obese women.

Do forced air patient-warming devices disrupt unidirectional downward airflow?

The study measured and compared the temperature and number of particles over the surgical site in an operating room set up for a routine lower-limb arthroplasty procedure while using three different warming devices. A single volunteer was used in evaluation. The study compared measurements from forced-air warming, radiant warming and no warming.

Forced air warming could theoretically disrupt the unidirectional airflow in the operating room and thereby potentially increase the risk of infection.

The results showed that the use of forced-air caused a significant mean increase in the temperature ($1.1°C$ vs $0.4°C$, $p < 0.0001$) and number of particles (1038.2 vs 274.8, $p = 0.0087$) over the surgical site when compared with radiant warming. The authors theorized that the rise in the number of particles may pose a potential concern, as particles are required for bacteria transport.

The Effects of Intraoperative Hypothermia on Surgical Site Infection: An Analysis of 524 Trauma Laparotomies.

The primary objective of this retrospective study was to determine whether intraoperative hypothermia predisposes patients to postoperative surgical site infections (SSI) after trauma laparotomy. The effects of intraoperative hypothermia on SSI remain unstudied in trauma even though intraoperative normothermia is an important quality performance measure for patients undergoing colorectal surgery.

Authors reviewed all patients in the period from July 2003 to June 2008, who survived 4 days or more after urgent trauma laparotomy at a level I trauma center. The total number studied was 524 patients. The evaluation consisted of patient characteristics, preoperative and intraoperative care focusing on SSI risk factors, and depth and duration of intraoperative hypothermia. The primary outcome measure was the diagnosis of SSI within 30 days of surgery. Cut-point analysis of the entire range of lowest intraoperative temperature measurements established the temperature nadir that best predicted SSI development.

Results shows that the mean intraoperative temperature nadir of the study population (n = 524) was 35.2 ± 1.1°C and 30.5% had at least one temperature measurement less than 35°C. Lower mean intraoperative temperature nadir (P = 0.009) and a greater number of intraoperative temperature measurements <35°C (P < 0.001) were present with patients who developed SSI (36.1%). Intraoperative temperature of 35°C as the nadir temperature was determined by cut-point analysis as most predictive parameters of SSI development. Multivariate analysis determined that a single intraoperative temperature measurement less than 35°C independently increased the infection risk 221% per degree below 35°C (OR: 2.21; 95% CI: 1.24–3.92, P = 0.007).

Results suggest that intraoperative normothermia should be strictly maintained in patients undergoing operative trauma procedures.

Interference with BIS™ values from a forced-air device.

This letter to the editor is a case report of potential interference of Bair Hugger™ intraoperative warming with the function of Bispectral Index (BIS) used as a measure of the patient's hypnotic state during anesthesia.

The patient was a 50-year old, morbidly obese woman undergoing laparoscopic surgery for hysterectomy. Intraoperative core temperature was maintained with upper body forced-air warming (Bair Hugger). Midway through surgery, hypertension resistant to boluses of propofol was noted. In addition significant facial EMG activity was noted, but no artifacts on EEG trace were observed. BIS value was 90-95. As this was inconsistent with clinical presentation, it was hypothesized that these values were due to mechanical interference of forced-air warming with BIS.

A towel was placed between the plastic flap and BIS monitor, which led to immediate decrease in EMG activity and to BIS value dropping to 25-30, requiring immediate decrease in anesthetic (sevoflurane) concentration. The surgery continued uneventfully. In the post-anesthesia care unit, the patient was interviewed and denied any intraoperative recall. Interference from forced-air warming was reported previously with other BIS models, but this was the first report of interference with the latest BIS model A-2000 XP.

Such interference may lead to inadvertent anesthetic overdose, thus the authors call for caution in interpreting BIS values when they are not consistent with clinical judgement.

Effectiveness of an Underbody Forced Warm-Air Blanket during Coronary Artery Bypass Surgery in the Prevention of Postoperative Hypothermia: A Prospective Controlled Randomized Clinical Trial.

This randomized study involved 60 low-risk cardiac surgery patients assigned into two groups. One group received standard thermal care management (control group n = 30) and the other group received the Bair Hugger™ underbody forced-air warming system in addition to the standard thermal care (intervention group n = 30). The authors evaluated whether underbody forced air blankets can prevent postoperative hypothermia if they are used during coronary artery bypass graft surgery.

Results support the hypothesis that forced-air warming blankets prevent postoperative hypothermia for the patients undergoing normothermic coronary artery bypass surgery. In the intervention group, 27 patients (90%) arrived in the ICU with a bladder temperature of 36°C, compared to only 14 patients (46.7%) in the control group. The peripheral temperature in the intervention group was also significantly higher than in control group.

A Bair Hugger full underbody forced-air warming blanket was effective in preventing hypothermia in this patient population.

Forced-air warming and surgical site infections.

ECRI, *Forced-air warming and surgical site infections*. Health Devices, 2013(April): p. 122-125.

This review of literature was conducted to evaluate whether Bair Hugger™ forced-air warming (FAW) may increase the rate of surgical site infections (SSI) compared to other warming methods.

Maintaining normothermia in surgery patients has been reported to significantly lower the risk of postoperative surgical wound infections (Kurz et al. 1996, Melling et al. 2001). The objective of this guidance report was to determine whether FAW practice showed an increase in SSI.

The review found insufficient evidence to support a change in practice. The studies included in the review included humans, compared FAW with another means of maintaining body temperature, studies were randomized controlled or nonrandomized comparison studies with at least two arms, had no less than 10 patients in each arm, had documented temperature data, reported the infections that occurred during the follow up period of at least 30 days, and were published in English as full articles in peer-reviewed journals.

Out of 180 potential studies identified, numerous studies were eliminated for not meeting enough of these criteria. Studies which were not clinical, did not include human surgical patients, studies that looked at OR contaminations or increased particle counts, but did not use SSI were example of excluded studies. While no studies met all inclusion criteria, four studies were evaluated in depth and came close to meeting the criterion of examining SSI.

Based on this focused systematic review of the published literature, ECRI states there is insufficient evidence to establish that the use of FAW systems leads to an increase in SSIs compared to other warming methods. Based on this review, the ECRI Institute's recommendation was not to discontinue the use of FAW during surgery.

The Institute will continue to monitor this topic in published literature and update this recommendation, if warranted.

Comparison of two forced-air warming devices for the prevention of hypothermia during abdominal surgery in the Lloyd-Davies position.

Crivits, M., et al., *Comparison of two forced-air warming devices for the prevention of hypothermia during abdominal surgery in the Lloyd-Davies position*. 1AP6-1. Eur J Anaesthesiol, 2013. 30: p. 21.

This study compared two forced-air warming devices in a surgical population with restricted body surface area available for warming. This is the case for the Lloyd-Davies position when used during surgery. The present study was designed to evaluate the effectiveness of an underbody forced-air warming mattress in patients undergoing surgery in Lloyd Davies position, in comparison with the upper body forced-air warming blanket.

The study randomized 44 patients to two treatment groups: group A: Mistral-Air® forced air warming underbody, and group B: Bair Hugger™ upper body warming blanket. An esophageal probe was used to monitor core temperature and the temperature was recorded every 15 minutes.

Result showed that temperatures were higher in the group using the underbody forced air mattress compared to the upper body warming blanket at T30, T45 and T60. The forced air underbody blanket seems to provide better early temperature maintenance than the upper body blanket.

High incidence of postoperative hypothermia in total knee and total hip arthroplasty: a prospective observational study.

Hypothermia has been shown to increase cardiac mortality, the incidence of postoperative infections, and the length of hospitalization following general surgery. This study assesses the incidence of hypothermia during primary total hip and total knee arthroplasty (THA and TKA).

In this prospective observational study, the incidence of hypothermia was measured among 672 patients (415 underwent THA and 257 TKA). The incidence of hypothermia for THA and TKA was 26.3% and 28.0%, respectively, with over a quarter of patients exposed to hypothermia.

This study highlights the requirement for interventions to prevent perioperative hypothermia.

Body temperature monitoring in anesthetized beagle dogs, to establish acceptable conditions for conduct of pharmacokinetics or safety assessments of thermo-sensitive compounds.

In this study investigators examined whether the body temperature of beagle dogs (two males and two females) could be maintained during a 2 hour surgery under general anesthesia and up to 4 hours post-surgery. The goal was to maintain core temperature within the 36.5 to 37.5°C range. The temperatures were monitored throughout this time by using rectal thermometer and oximeter thermometer placed in the esophagus. Heating devices were used (e.g., Bair Hugger™ system and/or heating pumps) to prevent fluctuations outside of the targeted range.

Temperature of the animals returned to pre-anesthesia levels within 1.5 to 2 hours after the anesthesia was completed. The authors proposed that dogs may be good preclinical models for assessment of thermo-sensitive compounds.

Contact a 3M Representative

Evaluation of bacterial contamination on surgical drapes following use of the Bair Hugger™ forced-air warming system.

This pilot study was conducted on small animals, which included 100 patients undergoing clean surgical procedures to determine the rate of bacterial contamination on surgical drapes. Patients were allocated to two groups: control group, and the group receiving intra-operative warming with the Bair Hugger™ forced-air warming system.

Contamination of the surgical drapes was determined by swabbing with aerobic culturettes at the beginning and end of surgery and culturing the samples on Trypticase soy agar.

The results showed that 6.1% of drapes were contaminated (in 6/98 cases). Contamination of drapes in the two groups (Bair Hugger vs control) did not differ significantly (P = 0.47).

Forced-air warming design: Evaluation of intake filtration, internal microbial buildup, and airborne-contamination emissions.

Reed, M., et al., *Forced air warming design: Evaluation of intake filtration, internal microbial buildup, and airborne-contamination emissions*. AANA Journal, 2013. 81(4): p. 275-80.

Authors sampled 23 forced-air warming devices (Bair Hugger™ model 750, Arizant Healthcare) and rated the intake filtration efficiency. Filtration measures are important for preventing the internal microbial buildup and airborne contamination emissions.

Using swabbing and particle counting, authors concluded that the intake filter had 63.8% efficiency. Microorganisms were detected within 100% of sampled blowers and 96% of forced air warming blowers emitted significant level of airborne contaminants.

While the authors concluded that there may be a need to upgrade filters to the high efficiency particulate air filtration (99.97% efficient), they noted that for this article the warming units were sampled without the blanket attached and recognized that the blanket may act as a low-efficiency microbial filter.

Contact a 3M Representative

Air warming during CABG: simple method to prevent microcirculation disturbances.

Perioperative hypothermia is strongly associated with cardiac surgery. In this study authors compared different warming systems on 50 CABG patients randomized into 2 groups. Group 1 (n=30) used an underbody water warming system (HICO-AQUATHERM 660®, Hirtz, Germany). Group 2 (n = 20) received an underbody warm-air blanket (Bair Hugger™ system, 3M, USA). Patients started with warming upon admission to the OR and continued until the end of surgery. Both central temperature (tC) and peripheral temperature (tP) were monitored.

Results showed that in different phases of surgery there were differences in temperature of patients assigned to the different groups. After admission, the temperature did not differ between the groups. Before CPB, both tC and tP were higher in Group 2. After 40 minutes tC in group 1 rose up to tC of Group 2, but tP was still greater in Group 2. At the end of surgery temperatures were higher in Group 2.

The authors concluded that Bair Hugger forced air warming blankets were more effective than the water warming system during CABG. Forced-air warming also resulted in better peripheral microcirculation helping to avoid temperature vasoconstriction.

Steroids control paradoxical worsening of Mycobacterium ulcerans infection following initiation of antibiotic therapy.

This is a case report for a 19 year old patient with a non-healing ulcer on the right knee for a period of 3 months. Different therapies were used to treat the ulcer. During one period of treatment there was rapid deterioration in the clinical condition, with fevers, sweats, anorexia and a recurrence of lower limb oedema and pain.

At one point during therapy, heat treatment with the Bair Hugger™ system (3M Arizant Healthcare) was used to maintain skin temperature at 39°C. After stopping deterioration in patient's condition, the patient completed a 3-month course of antimycobacterial antibiotics, at which time there was no sign of ongoing infection.

Forced-air patient warming blankets disrupt unidirectional airflow.

Legg, A. and A. Hamer, *Forced-air patient warming blankets disrupt unidirectional airflow*. Bone Joint J, 2013. 95(3): p. 407-410.

This non-human study was a test of the theory that Bair Hugger™ forced-air warming blankets may increase the number of airborne particles over the surgical site, due to the increase in temperature they cause. This mannequin study simulated total knee replacement surgery and attempted to visualize the airflow in the operating room using neutral-buoyancy helium bubbles.

The researchers stated that in the specific setup utilized for testing, the clearest interference with unidirectional airflow occurred when the mannequin was warmed with the forced-air device. The generated convection currents in this simulation showed that the smoke machine generated particles increased in concentration for forced-air warming more than the control and the radiant warming.

The authors note in their conclusion that the study does not show that forced-air warming increases the risk of infection – only that in certain types of theatre set-up it can significantly disrupt unidirectional airflow.

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A retrospective audit to examine the effectiveness of preoperative warming on hypothermia in spine deformity surgery patients.

A retrospective study was conducted by BC Children's Hospital to compare two 7 month periods: November 2011 to June 2012 and two years prior to this period. The latter was the period before intraoperative patient warming (Bair Hugger™ forced air warming) was introduced.

The patient population in this study was spine deformity surgery patients. Data collected for this analysis included: case duration, first and last temperature measured, percentage of subjects who experienced hypothermia, number of hypothermic episodes per patient, and delay of surgery start and time of first temperature measured. The results showed that Bair Hugger preoperative warming reduced the percentage of case duration spent hypothermic by a median of 111.1 minutes (P < 0.001, 95% CI 77.1-139.9 min). For the forced-air warmed patients, the first measured temperature increased by a median of 0.5°C (P < 0.001, 95% CI 0.3-0.7°C), while the last temperature measured remained unchanged (P = 0.57, 95% CI -0.2-0.1°C).

The authors concluded that preoperative warming significantly reduces percentage of time hypothermic and may potentially reduce the risk of perioperative complications for children undergoing spine deformity surgery.

Patient warming excess heat: the effects on orthopedic operating room ventilation performance.

In this study, authors investigated two patient warming systems for potential impact on ventilation performance in an orthopedic operating room. The two warming technologies utilized were forced-air warming (the Bair Hugger™ system) and conductive fabric (the HotDog™ system).

A draped mannequin was used to simulate a patient undergoing a total knee replacement procedure. Researchers introduced neutrally buoyant bubbles behind the anesthesia drape, then tracked whether the heat produced by the warming systems carried the bubbles into the surgical field. A randomized design was utilized to assess the impact of the device and drape height on the bubbles reaching the surgical site.

The article indicates that exhaust from the forced-air warming system created hot air convection currents that transported bubbles up and over the anesthesia drape and then down into the surgical site, resulting in a significant increase in bubble counts (132.5) compared to convective fabric (0.48) or control conditions (0.01). Differences in bubble counts relating to drape height were insignificant.

The authors conclude that the waste heat resulting from the forced-air device disrupted the ventilation air flow over the surgical site, but note that the disruption was dependent on O.R. setup (draping, lights, personnel) and did not include other elements which may impact ventilation, such as instrument trays and a working surgical team. Future research to determine whether this has any impact on clinical outcome is recommended.

Forced-air warming devices and the risk of surgical site infections.

Kellam MD, et al., *Forced-air warming devices and the risk of surgical site infections.* AORN J, Oct 2013:98(4): p.354-66

Authors examined 192 evidence sources to investigate the whether forced-air warming devices increase the risk of SSI in general, vascular or orthopedic surgery patients.

The project was initiated due to concerns raised in some recent literature that the use of the Bair Hugger™ system may increase SSI risk by acting as a vector or causing unwanted airflow disturbances. Of the 192 evidence sources, 15 met the inclusion criteria. Only three studies followed patients to determine whether there was an increased incidence of SSI. Each study reviewed by the authors contained methodological concerns, and no there was no conclusive evidence to suggest that the use of forced-air warming presented a risk.

Knowing the efficacy of forced-air warming in preventing hypothermia, the researchers recommend that clinicians should continue their use of forced-air warming according to manufacturer instructions until well-conducted, large-scale clinical trials can be done.

Contact a 3M Representative

Temperature management during the perioperative period and frequency of inadvertent hypothermia in a general hospital.

This prospective observational study enrolled 167 consecutive patients scheduled to have surgery with general anesthesia of ≥30 minutes.

The study evaluated the incidence of hypothermia (defined as forehead skin temperature of ≤35.9°C). The prevalence of monitoring of intraoperative temperature was 10%, warm intravenous fluids were used in 78% of patients, and the Bair Hugger™ forced-air warming system was used in 63% of patients. Hypothermia was observed in 56.29% of patients and was associated with the female gender, age of ≥65 years old and BMI of ≥ 30 kg/m^2.

The authors concluded that warming measures without temperature monitoring did not necessarily lead to a desired conclusion that there was a reduction in hypothermia. However with the identification of high frequency of inadvertent hypothermia, especially in patients > 65 years of age and female, it would be advantageous to advocate for action guidelines to proactively prevent and manage hypothermia in this high risk patient population.

A retrospective study of the accuracy of surgical care improvement project metrics for documenting normothermia.

A retrospective study of a systematic sample of 150 patients who underwent abdominal surgery revealed that 53 (35.3%) patients had all intraoperative temperatures in the hypothermic range (<36.0°C). Fifty-two (98.1%) of the 53 patients met one or both surgical care improvement project criteria for normothermia.

This study demonstrated that a substantial proportion of patients who underwent surgical procedures involving an abdominal incision were hypothermic throughout the time period in which their temperatures were monitored intraoperatively. Improved metrics are needed to assure intraoperative normothermia.

A proposed methodology to control body temperature in patients at risk of hypothermia by means of active rewarming systems.

Costanzo, S., et al., *A Proposed Methodology to Control Body Temperature in Patients at Risk of Hypothermia by means of Active Rewarming Systems*. BioMed Research International. 2014: p. 10.

The authors set up an experimental investigation of hypothermia by using several types of warming blankets and combining them with broader research on environmental conditions, pollution, heat stress, and hypothermia risk in operating rooms.

Their aim was to identify how the heat was flowing from the blanket and the blanket's effect on the average temperature of the patient's body. The authors proposed methodology could allow surgeons to fix in advance the thermal power to supply through a warming blanket for reaching, in a prescribed time, the desired body temperature starting from a given state of hypothermia.

Contact a 3M Representative

Peri-operative warming devices: Performance and clinical application.

This article focuses on the review of peri-operative warming devices and provides a critical view of the evidence assessing their performance.

Forced-air warming is a common and extensively tested warming modality and the results of testing has shown this method outperforms passive insulation and water mattresses. It has also been shown that forced air warming is at least as effective as resistive heating.

Authors also discussed the challenge of fluid warming and how device performance varies according to flow rate. The aim of this review article was to provide guidance for an informed and accurate choice of devices to be used in the hospital environment.

Comparison of the efficacy of a forced-air warming system and circulating-water mattress on core temperature and post-anesthesia shivering in elderly patients undergoing total knee arthroplasty under spinal anesthesia.

Kim, H.Y., et al., *Comparison of the efficacy of a forced-air warming system and circulating-water mattress on core temperature and post-anesthesia shivering in elderly patients undergoing total knee arthroplasty under spinal anesthesia.* Korean Journal of Anesthesiology, May 2014. Vol. 66, No. 5, p. 352-357.

This was a randomized study examining the changes in body temperature and the occurrence of shivering in elderly patients under spinal anesthesia during total knee arthroplasty. A total of 46 patients were warmed either with the Bair Hugger™ forced-air warming system (N = 23) or circulating-water mattress (N = 23) and core temperature was recorded. Incidence and intensity of post-anesthesia shivering and verbal score for thermal comfort were also assessed.

Results showed that core temperature did not differ in these two groups, thus the circulating-water mattress was as effective as the forced-air warming system for maintaining body temperature.

The incidence of post-anesthesia shivering was significantly lower in the Bair Hugger forced-air system group than in the circulating-water mattress group.

Enhanced recovery for elective caesarean section: Neonatal issues an important cause of delayed discharge.

Pothireddy, R., et al., *Enhanced recovery for elective caesarean section: Neonatal issues an important cause of delayed discharge*. Annual Meeting of the Obstetrics Anaesthetist's Association, 2014.

This paper describes an introduction of an enhanced recovery program for caesarian section, which included perioperative information for patients and staff, a high calories preoperative drink, active warming in surgery room (Bair Hugger™ system underbody blanket), skin-to-skin contact between the mother and neonate and delayed cord clamping. Data were collected from 60 patients who underwent caesarean section over a 6-week period.

The results of this program showed enhanced recovery with room for improvement. Twenty percent of the patients were discharged after only a single night in the hospital and 50% after two nights. All patients received intraoperative active warming, informational leaflets and energy drinks, while 73% had skin-to-skin contact with the neonate. Delayed cord clamping was practiced in 40% of cases, so the latter two represent the areas where the program could improve.

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Warming with an underbody warming system reduces intraoperative hypothermia in patients undergoing laparoscopic gastrointestinal surgery: a randomized controlled study.

Intraoperative hypothermia can delay the metabolism and prevent tissue damage. In addition, long-term and severe intraoperative hypothermia may also lead to perioperative complications, such as increasing of peripheral resistance, coagulation dysfunction, intraoperative hemorrhage and postoperative shivering.

A total of 110 patients undergoing laparoscopic surgery for gastrointestinal cancer between January and December 2011 were randomized into the laparoscopic control (Control) group and laparoscopic intervention (Intervention, Bair Hugger™ underbody warming) group. Nasopharyngeal temperature, prothrombin time, activated partial thromboplastin time, and thrombin time were measured and recorded (before and during surgery), as well as intraoperative and postoperative complications, and shivering after anesthesia. Visual analog scale score was used for pain evaluation after surgery.

The results showed a large difference in the percent of patients experiencing intraoperative hypothermia in the two groups (5.5% in intervention and 52.7% in control group). After 30 minutes from the onset of surgery, nasopharyngeal temperature in the controls was already significantly decreased, while in the intervention group temperature was maintained at 36°C throughout the surgery.

These results demonstrated that the underbody warming system could prevent intraoperative hypothermia in this patient population. Other parameters which compared favorably in intervention vs control group included: no significant change of coagulation function as the surgery progressed, better hemoglobin level as well as less intraoperative hemorrhage, less postoperative shivering and lower visual analog scale score. Multivariate logistic regression analysis identified two independent predictors of perioperative hypothermia: anesthesia time and volume of CO_2.

The authors concluded that the use of Bair Hugger underbody warming was a feasible and effective measure to prevent intraoperative hypothermia in this patient population.

Forced Air Warming Devices in Orthopaedics: A Focused Review of the Literature.

This is a literature review focused on the use of patient warming devices in hospitals. The Bair Hugger™ system (3M Healthcare, St. Paul, MN) and similar forced air devices prevent hypothermia and maintain or increase core temperature in patients during the perioperative period. Clear benefits include the reduction of surgical wound infections, maintenance of normal coagulation, and faster discharge from the post-anesthesia care unit (PACU). Hypothermia can cause adrenergic activation, myocardial ischemia, thermal discomfort, decreased drug metabolism, coagulopathy, and increased risk of infection.

Several reports in the literature raised concerns regarding a possible increased risk of deep surgical site infections associated with the use of the forced air warming systems. This concern was based on theoretical mechanisms, laboratory simulations, retrospective case series, and studies showing the growth of potentially pathogenic microorganisms in the hoses and filters of forced air warming devices.

Multiple other studies and a Continuing Education statement by the Association of periOperative Registered Nurses (AORN) suggest that the proper use of forced air warming devices mitigates or eliminates risk while maximizing the benefits of patient warming.

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Interventions for treating inadvertent postoperative hypothermia.

Warttig, S., et al., *Interventions for treating inadvertent postoperative hypothermia*. The Cochrane Database of Systematic Reviews, 2014.

The objective of this meta-analysis of publications was to estimate the effectiveness of treating inadvertent perioperative hypothermia through postoperative interventions to decrease heat loss and apply passive and active warming systems in adult patients who have undergone surgery.

The authors searched a number of databases housing RCTs (CENTRAL, MEDLINE, EMBASE, ISI, Web of Science, CINAHL, EBSCO), as well as www.controlled-trials.com and www.clincialtrials.gov to identify eligible studies. Only randomized studies comparing active post-operative warming methods or patient warming against control were eligible. Eleven RCTs including a total of 699 patients were selected to be included in their analysis and 10 studies contributed to the results.

Normothermia was achieved more quickly when active warming was used; 30 minutes faster compared to warmed blankets and 1.5 hours faster compared to non-warmed blankets. The evidence was of moderate quality and showed mean difference (MD) of -32.13 minutes, 95% confidence interval (CI) -42.55 to -21.71 for warmed blankets and MD -88.86 minutes, 95% CI -123.49 to -54.23 for non-warmed blankets.

When comparing two active warming methods, forced air versus circulating hot water devices, it took one hour less to achieve normothermia by using forced air devices (MD=-54.21 minutes 95% CI= -94.95, -13.47).

The authors concluded that the reduction in time needed to achieve normothermia in patients experiencing post-operative hypothermia by using forced air devices was clinically significant. The limitation noted was the lack of high quality evidence on outcomes other than achieving normothermia, as well as the high quality evidence on other warming methods.

Infection control hazards associated with the use of forced-air warming in operating theatres.

Wood AM, et al., *Infection control hazards associated with the use of forced-air warming in operating theatres*. J Hosp Infect, Nov 2014; 88(3): p. 132-40.

Ultra-clean ventilation (UCV) is thought to reduce the number of infectious particulates at the surgical wound site; however, even small movements by personnel in the OR can disrupt laminar airflow and increase the number of colony-forming units (CFUs) at the surgical wound site. Ultra-clean ventilation systems are quite popular in the UK, but they are not widely used in the rest of the developed world.

Heat losses experienced by surgical patients in UCV operating rooms can be quite high and may result in rapidly developing hypothermia. The major technologies used for warming patients involve convection, by forced-air warming (FAW) systems, or conduction, by either resistive heat warmers or circulating water mattresses.

Despite the fact that there are many sources of obvious disruption of UCV in the OR, several authors have raised concerns about the effect of FAW on UCV, either through the introduction of thermal eddies or direct contamination of the air. These studies may be categorized as either flow visualization or particle counting activities. Under certain conditions, several investigators report movement of particles into sterile areas when FAW systems are used, and others report increased particulate counts or CFUs using experimental assays. Other in vitro studies have demonstrated no effect on airflow or particulate concentrations.

At present, there is no robust evidence to suggest that FAW increases the risk of surgical site infection, and the authors urge caution in condemning FAW. While acknowledging the real cross-contamination risks of resistive heating systems, the authors suggest consideration of their use in arthroplastic surgery until a definitive trial can be conducted to assess contamination risks.

The influence of mild hypothermia on reversal of rocuronium-induced deep neuromuscular block with sugammadex.

Lee, H.J., et al., *The influence of mild hypothermia on reversal of rocuronium-induced deep neuromuscular block with sugammadex*. BMC anesthesiology, 2015. 15(1): p. 7.

The study analyzed patient recovery time and response to sugammadex after a prolonged rocuronium-induced deep neuromuscular block (NMB) during mild hypothermia.

Sixty patients were randomly (1:1) allocated to the mild hypothermia and normothermia groups, defined as having core temperatures between 34.5-35.0°C and 36.5-37.0°C, respectively. Bair Hugger™ therapy was used to manipulate core temperature into the normothermic range for the control group.

NMB was induced and maintained by two doses of rocuronium during surgery (0.6 mg/kg, followed by 7-10 μg/kg/min), while the sugammadex dose to break the NMB was 4.0 mg/kg. The neuromuscular function was considered to be restored when train-of-four (TOF) ratio was >0.9 and time to achieve TOF of 0.9 was measured to determine the recovery time.

The recovery time was significantly slower (on average by 46 seconds) in the mildly hypothermic group. Mean total recovery times and (SD) were 171.1 (62.1) and 124.9 (59.2) seconds for hypothermic and normothermic patients, respectively. Although statistically significant ($P<0.05$), the difference was not considered clinically significant.

The efficacy of pre-warming on reducing intraprocedural hypothermia in endovascular coiling of cerebral aneurysms.

This RCT of 72 patients compared the core temperatures and the rates of hypothermia in two groups of intubated patients; pre-warmed patients and controls. Prewarming before surgery was achieved by using the Bair Hugger™ forced-air system set at 38°C for 30 minutes. The evaluation was performed at six 20 minute intervals (T0 through T120).

The results showed that core temperature was significantly higher in prewarmed group from T20 to T120 (P<0.01). While the intraoperative core temperature declined in both groups compared to T0, the hypothermia was less prevalent in the prewarmed group (P = 0.002 at T20, P < 0.001 at T40 to T120).

Despite the similar rate of intraoperative core temperature decline in both groups, pre-warming considerably reduced the risk of intraprocedural hypothermia.

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Intraoperative core temperature patterns, transfusion requirement, and hospital duration in patients warmed with forced air.

Sun, Z., et al., *Intraoperative Core Temperature Patterns, Transfusion Requirement, and Hospital Duration in Patients Warmed with Forced Air*. Anesthesiology. 2015. 122(2): p. 276-285.

This retrospective study evaluated core temperatures of nearly 59,000 actively warmed surgical patients (surgeries > 60 minutes) to determine the impact of inadvertent intraoperative hypothermia on transfusion requirements and length of stay. Most patients in this study were warmed utilizing Bair Hugger™ therapy.

Nearly all patients achieved an end of anesthesia temperature of ≥36.0°C, yet intraoperative hypothermia was common, and often prolonged, as a result of redistribution temperature drop. Hypothermia was independently associated with both transfusions and duration of hospitalization, although the prolongation of hospitalization was small.

Even in actively warmed patients, hypothermia is routine during the first hour of anesthesia.

Prewarming in a Pediatric Hospital: Process Improvement Through Interprofessional Collaboration.

This interdisciplinary quality improvement project assessed the compliance to prewarming recommendations by pediatric hospital staff and patients when a new product (Bair Paws™ warming gowns) was used in place of an existing product (Bair Hugger™ blankets).

The new forced air warming product was a preferred method of prewarming and resulted in doubling of the rate of compliance. The project demonstrated the importance of collaboration among various disciplines and the positive impact interprofessional collaboration can have on compliance with practice changes.

Enhanced recovery: The role of patient warming.

Edis, H., *Enhanced recovery: The role of patient warming*. British Journal of Healthcare Management, 2015. 21(8).

The Enhanced Recovery After Surgery (ERAS) program is intent on protecting patients from inadvertent hypothermia to improve the surgical experience and promote physical wellbeing.

As many as 70% of surgical patients can experience inadvertent perioperative hypothermia and the multiple associated complications. The ERAS program focusses on maintaining normothermia throughout the perioperative process.

This article discusses risk factors and strategies to keep patients warm throughout the surgical journey.

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Value of Extended Warming in Patients Undergoing Elective Surgery.

This study assessed the clinical and wellbeing benefits of extending normothermia by using a portable warming gown.

This RCT of 94 patients compared the rates of hypothermia (<36°C), patient well-being, and the costs of warming for two different groups. The standard warming group utilized standard warming from anesthesia induction through the end of surgery. The extended warming group utilized the 3M™ Bair Paws™ system for prewarming, intraoperative warming, and PACU recovery until patient discharge.

The rate of hypothermia was reduced by 48% and intraoperative core temperature drop was minimized with the extended warming group. In addition, patients in the extended warming group had decreased anxiety levels and apprehension with increased patient comfort. Extended warming with the Bair Paws system resulted in a cost savings of $84 per patient versus standard warming processes in this study.

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The effect of a forced-air warming blanket on patients' end-tidal and transcutaneous carbon dioxide partial pressures during eye surgery under local anaesthesia: a single-blind, randomised controlled trial.

This randomized study investigated the use of Bair Hugger™ blankets (n=20) versus a control heated blanket (n=20) on carbon dioxide accumulation under the drapes in patients undergoing eye surgery.

All patients were given oxygen and had their transcutaneous and end-tidal carbon dioxide partial pressures measured before and after draping, and every 5 minutes afterwards for thirty minutes. Also measured at these time points were heart rate, arterial pressure, respiratory rate, temperature, and oxygen saturation.

In the forced-air warming group (the Bair Hugger system) the mean transcutaneous carbon dioxide pressure stayed constant after draping (5.7 kPa) but in the heated overblanket group, these measurements rose to a maximum of (6.4 kPa) for a significant difference (p = 0.0001) at the 15 minute timepoint and thereafter.

The authors conclude that forced-air warming reduces carbon dioxide accumulation under drapes for eye surgery under anesthesia.

Comparison of resistive heating and forced-air warming to prevent inadvertent perioperative hypothermia.

The investigators evaluated the abilities of a resistive heating and forced-air warming device to prevent perioperative hypothermia in a randomized control trial of 160 patients. Patients were randomly assigned to receive either intraoperative warming with a Bair Hugger forced-air warming (FAW) system or an Inditherm® underbody conductive mattress.

Both units were operated at their highest operating temperatures. At the end of surgery, the mean core temperature in patients assigned to the FAW system was significantly higher than that in the patients assigned to the conductive mattress system. Hypothermia rates at the end of surgery were 36% in the FAW group and 54% in the resistive heating group. The investigators concluded that forced-air warming is more effective than conductive when used to prevent postoperative hypothermia.

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