ORIGINAL ARTICLE

Comparison of forced-air warming and resistive heating

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ABSTRACT

Background. Perioperative hypothermia is common during anesthesia and surgery and is accompanied by several complications. Forced-air warming is recognized as an effective procedure to prevent hypothermia. The aim of this study was to compare a resistive heating device with a forced-air warming device.
Methods. Prospective randomized trial. Setting: heat transfer laboratory of a University hospital. Participants: six healthy volunteers. Interventions: warming with a forced-air warming device (BairHugger™ 505 and Upper Body Blanket 522; Arizant Healthcare Inc., Eden Prairie, MN, USA) or a resistive heating device (Geratherm Adult system™; Geratherm Medical AG, Geschwenda, Germany). Measures: heat transfer was measured with 11 calibrated heat flux transducers on the upper body. Additionally, blanket and skin temperatures were measured. The t-test for matched pairs was used for statistical evaluation.
Results. Skin temperature under the covered surface was not statistically different between the two groups (37.3±0.2°C in the forced-air warming group and 37.8±0.2°C in the resistive heating group). In contrast, 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) were significantly higher in the resistive heating group.
Conclusion. Heat transfer in the resistive heating system was significantly greater than that of the forced-air warming system.
Key words: Anesthesia - Heating - Hypothermia, prevention and control.

Perioperative hypothermia causes intraoperative coagulation disturbances,[1-3] increased blood loss and transfusion requirements,[4, 5] increased postoperative oxygen consumption via induction of shivering,[6, 7] increased cardiac morbidity,[8, 9] higher incidences of wound-infection,[10, 11] and therefore prolonged hospital stays.[10]

It has been demonstrated that even during extensive abdominal operations, the skin represents the major source of heat loss.[12] Thus, reducing heat loss from the skin is the most promising approach for avoiding hypothermia.

Several materials for insulation and active warming systems have been established. Forced-air warming as an active warming method has shown better results than insulation or other active warming systems.[13, 14] Comparisons of forced-air warming systems with resistive heating devices have seldom been investigated.[15, 16]

The aim of this study was to compare the efficacy of a forced-air warming device to that of a resistive heating system using heat flux transducers to measure the heat transfer from the warming system to the body surface.
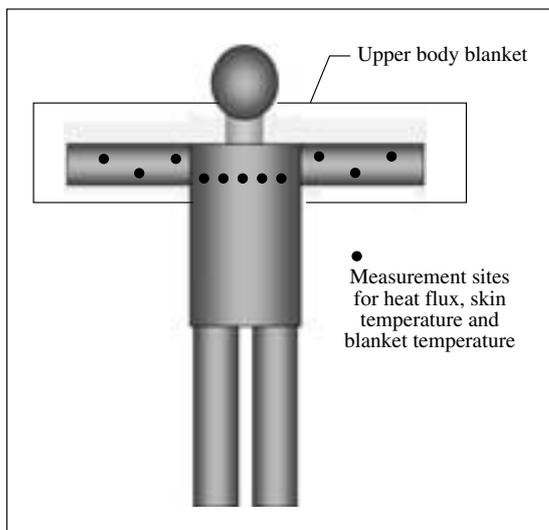
Figure 1.—Distribution of heat flux transducers and measurement sites.

Materials and methods

With the approval of the local Ethics committee and written informed consent, we studied six healthy male volunteers (ASA physical status I). The volunteers' mean age was 28±2 years, mean height was 182±6 cm, and mean weight was 89±9 kg. None of the volunteers was obese, taking medication, or had a history of recent infection, fever or thyroid disease. Intolerance to plaster was an exclusion criterion.

The following systems were studied:

— BairHugger™ Model 505 blower and upper body blanket model 522 (Arizant Healthcare Inc., Eden Prairie, MN, USA). This forced-air warming system consists of a power unit utilizing an electrical heater and fan to generate an air flow that is delivered downstream to an upper body blanket;

— Geratherm Adult system™ (Geratherm Medical AG, Geschwenda, Germany) and the corresponding reusable upper body blanket. This system was developed in the late 90s by Thermamed GmbH (Bad Oeynhausen, Germany) and is a non-disposable resistive warming system that is based on carbon-fiber technology using 15-V direct current. The resistive heating cover is controlled by a computer that maintains the carbon-fiber fabric at a set temperature.

Measurements

Room temperature, air velocity and relative humidity were measured with a thermoanemometer (Velocicalc Plus, TSI™, Model 8388-M-D, TSI Incorporated, St. Paul, MN, USA).

Heat flux was measured using eleven heat flux transducers (Heat Flow Sensor Model FR-025-TH44033-F16, Concept Engineering, Old Saybrook, CT, USA). The heat flux transducers were calibrated using a Dynatech R-Matic Heat Flow Meter (Dynatech, Cambridge, MA, USA). This calibration method is expected to have an accuracy of ±3% and conforms to the ASTM C-518 standard test method for steady state thermal transmission. The lower side of the heat flux transducers was covered with thermal conductive paste and attached to the skin with a small plaster ring.

Skin temperature was measured using thermistors integrated in the heat flux transducers (YSI Inc. "Thermolinear" 44018, measurement range -30 to +105°C). The thermistors were calibrated in a water bath at temperatures of 22°C and 40°C. The reference thermometer was a Hewlett Packard Model 2801 (Palo Alto, CA, USA) with an accuracy of ±0.01°C.

The forced-air warming system blanket temperature was measured using 11 thermocouples (Myocardial Probe, 18 mm Needle Length, Mallinckrodt Medical, St. Louis, MO, USA) mounted 1 cm above each heat flux transducer. The blanket temperature of the resistive heating device was measured with 11 self-adhesive thermocouples (Mon-A-Therm Skin, Mallinckrodt Medical, St. Louis, MO, USA).

Protocol

Two examination days were planned for each volunteer. One warming system was used each day, with assignments randomly determined. The volunteers were minimally clothed and positioned on an examination bed. The arms were adjusted to a 90° angle and positioned on arm rests. The heat flux transducers and thermocouples were distributed to three measuring-points per arm and five measuring-points on the upper body (Figure 1).

The upper body blanket was fixed at the nipples. Additionally, the volunteer was covered with two cotton sheets identical to those used in clinical

practice. The hose of the BairHugger™ power unit was connected to the left side of the blanket. The power unit of the BairHugger™ was set at 43°C and the Geratherm Adult system™ was set at 42°C. After approximately 60 min, steady-state conditions were achieved; a measurement period of 20 min followed.

From the measurements obtained, we calculated the average heat flow per unit area, the mean skin temperature and the mean blanket temperature. Heat transfer was calculated by multiplying average heat flow per unit area by the estimated covered area, 0.35 m².

Statistical analysis

Power analysis (β=0.8) was used to calculate the required number of volunteers. With an estimated heat flux of 10 W, a standard deviation (SD) of 3 W and a significant difference of 5 W, six volunteers were required. Statistical significance was determined by t-test for coupled samples after normal distribution of the data was checked using the Shapiro-Wilks-test. The level of significance was set at P=0.05. All data are presented as mean ± SD.

Results

Ambient temperature was 21.9±0.4°C, air velocity was <0.1 m/s and relative humidity was 26±5%.

The skin temperature under the covered surface was not statistically different between the two groups (37.3±0.2°C in the forced-air warming group and 37.8±0.2°C in the resistive heating group, P=0.06). In contrast, 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) were significantly higher in the resistive heating group (Figure 2).

Discussion

Forced-air warming is an effective method for preoperative warming,[17] intraoperative heat conservation[10, 13, 14, 18] and postoperative rewarming.[19]

A comparison of upper body blanket warming systems is relevant because these systems are often used in the intraoperative period during abdominal surgery, characterized by high hypothermia risk. To the best of our knowledge, this is the first study that
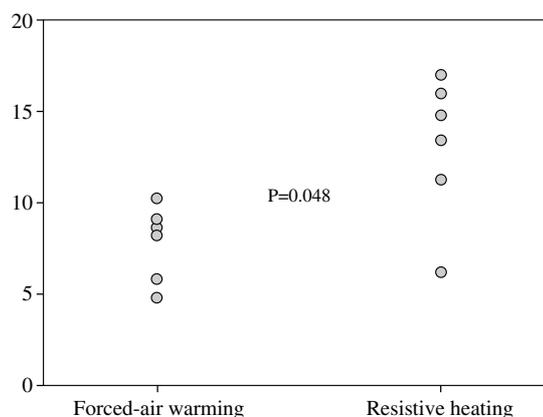

Figure 2.—Heat transfer of the forced-air warming group and the resistive heating group.

directly compares the performance of a forced-air warming system with an upper body blanket and resistive heating device. The efficacy of the warming systems was quantified by measuring the heat transfer with 11 calibrated heat flux transducers.

The heat transfer of the resistive heating device was significantly higher (13.2±3.4 W) than the heat transfer of the forced-air warming device (7.8±1.9 W). The heat transfer of the forced-air warming device correlates very well with previous measurements. A volunteer study yielded a mean heat transfer value of 8.1±1.1 W [20]; a manikin study showed heat transfer of 4.9 to 13 W depending on the surface temperature.[21]

The difference between systems was rather small; heat transfer of the resistive heating device was in the same range as that achieved by the forced-air warming system.[20, 21] This was confirmed by two clinical investigations[15, 16] showing the resistive heating device exhibited no advantage in comparison to a forced-air warming device. However, the settings of these clinical investigations differed from that of our study. Matsuzaki compared an upper body blanket and a leg-covering blanket of the resistive heating device to a forced-air warming system with an upper body blanket. Additionally, the temperature setting for both devices was lower than in our investigation. Negishi *et al.* compared the lower-body blanket of a forced-air warming device to the resistive heating device's upper-body and leg-covering blankets.[15]

However, both studies also showed that a forced-

air warming system or resistive heating system alone will not solve the problem of perioperative hypothermia. Avoiding the initial decrease of core temperature after induction of anesthesia requires a strategy that includes prewarming of the patient. Otherwise, relevant redistribution of heat will occur and the patient may become hypothermic during surgery.

The blanket temperatures of the resistive heating group were significantly higher than the blanket temperatures of the forced-air warming group. However, the skin temperatures did not differ significantly. The risk of thermal skin burns is therefore very low with both systems, because the threshold of human skin heat tolerance is estimated to be about 43°C.[22] The tolerance threshold is time-dependent, but even long-term exposure of skin to temperatures of <44°C is believed to be safe;[23] the highest measured skin temperatures in this study did not reach that value.

Unlike most forced-air warming systems, the resistive heating system does not require a disposable element. Once acquired, there is no substantial additional cost of using the system. Thus, the resistive heating system is likely to be less expensive than forced-air warming for routine use.

Conclusions

Heat transfer of the resistive heating system was significantly higher than that of the forced-air warming system we examined. However, the clinical relevance of this difference is of minor importance; the heat transfer of the resistive heating system is in the same range as the heat transfer of various forced-air warming systems.

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