

Warming by resistive heating maintains perioperative normothermia as well as forced air heating[†]

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Background. Even mild perioperative hypothermia is associated with several severe adverse effects. Resistive heating has possible advantages compared with other active warming systems because it can heat several fields independently. To assess this new warming system, we measured core temperature in patients during surgery who were warmed with circulating water mattresses, forced air covers or resistive heating covers.

Methods. Twenty-four patients undergoing laparoscopic cholecystectomy were randomly assigned to (i) circulating water mattress (38°C), (ii) forced air warming (set to 'medium') or (iii) carbon-fibre resistive warming (38°C). Warming was applied throughout anaesthesia and surgery. The groups were compared using one-way ANOVA and Student–Newman–Keuls tests.

Results. Confounding factors were similar among the groups. Core temperatures in each group decreased for 20 min, but subsequently increased in the forced air and resistive heating groups. There was no significant difference between the forced air and resistive heating groups at any time. In contrast, core temperature in the circulating water group continued to decrease. Consequently, core temperature in the circulating water group was significantly lower than in the other groups 30 min after anaesthetic induction and at later times.

Conclusions. Resistive heating maintains core body temperature as well as forced air heating and both are better than circulating water. Resistive heating offers the advantage of adjustable heating pods.

Br J Anaesth 2003; **90**: 689–91

Keywords: temperature, body; temperature, monitoring; temperature, regulation

Accepted for publication: January 13, 2003

Mild perioperative hypothermia is associated with several adverse effects, including wound infections, bleeding (cold-induced platelet dysfunction) and cardiac ischaemic changes.¹ Unless hypothermia is specifically indicated, standard practice is to maintain normothermia during surgery.

A novel non-disposable resistive warming system has recently become available. It is based on carbon-fibre technology and uses low-voltage direct current. The system generates heat by passing 15 V of direct current through semiconductive carbon-fibre fabric. Because the system is powered by low-voltage direct current, it is intrinsically safe. For example, it will not interfere with other operating room electronics. Similarly, no danger would result from penetrating the fabric with a sharp instrument, and the

system would continue to operate normally because the current would simply flow through adjacent fabric.

The resistive heating cover is controlled by a computer that maintains the carbon-fibre fabric at a set temperature between 37°C and 42°C. This system, unlike circulating water mattresses or forced air warmers, can heat several fields independently, allowing a large fraction of the body surface to be warmed during almost any operation. This is important because routine heat loss and heat transfer by clinical warmers is roughly a linear function of heated surface area.¹ Warmers are available in a large number of

[†]None of the authors has personal financial interests related to this study.

configurations, which can be used in many combinations to provide a large heating surface during surgery.

To assess this new warming system, we compared core body temperature using circulating water mattresses, forced air warmers or resistive heating during laparoscopic cholecystectomy. We tested the hypothesis that resistive heating and forced air warming maintain core temperature equally well.

Methods and results

After ethics committee approval and with written informed consent, we studied 24 patients undergoing elective laparoscopic cholecystectomy in an open leg position. All were ASA I or II and aged 20–80 yr. Patients with preoperative fever, evidence of current infection, thyroid disease or disturbance of autonomic function were excluded.

Thirty minutes before surgery, patients were given pentazocine 15 mg, hydroxyzine 25 mg and atropine 0.5 mg i.m. General anaesthesia was induced with thiamylal 5 mg kg⁻¹ and fentanyl 0.2 mg and maintained with sevoflurane 2% with nitrous oxide 60% in oxygen. Patients were paralysed with vecuronium and mechanically ventilated to maintain end-tidal carbon dioxide partial pressure near 4.6 kPa. All fluids were warmed to 37°C and ambient temperature was kept near 22°C.

Participating patients were assigned randomly to warming with (i) a full-length circulating water mattress set to 38°C (Blanketroll; CSZ, Cincinnati, OH, USA) (circulating water group), (ii) an upper-body forced air cover with the controller set to 'medium' (WarmTouch; Tyco-Mallinckrodt Anaesthesiology Products, St Louis, MO, USA) (forced air group), or (iii) a carbon-fibre resistive heating blanket set to a medium temperature (38°C) (SmartCare OP System; Thermamed, Bad Oeynhausen, Germany) (resistive heating group). The resistive heating system covered both arms, the chest and both legs. All warmers were started just after induction of general anaesthesia and maintained throughout surgery. Randomization was based on computer-generated codes

that were kept in sequentially numbered opaque envelopes until just after induction of anaesthesia.

Physical characteristics of the participants were recorded. We also recorded the duration of surgery, all standard anaesthetic variables, and fluid balance. All temperatures were measured with Mon-a-therm thermocouples (Tyco-Mallinckrodt Anaesthesiology Products). Measurements started after induction of anaesthesia and continued throughout surgery at intervals of 5–15 min.

Ambient temperature was measured with a thermocouple positioned at the level of the patients but well away from any heat-producing equipment. Mean skin temperature was calculated from temperatures (*T*) recorded at four cutaneous sites, using the formula $0.3(T_{\text{chest}}+T_{\text{arm}})+0.2(T_{\text{thigh}}+T_{\text{calf}})$.

Core temperature was measured at the tympanic membrane using aural probes. The probes were inserted by the patients until they felt the thermocouple touch the tympanic membrane; appropriate placement was confirmed when they detected a gentle rubbing of the attached wire. The aural canal was then occluded with cotton wool and the probe taped in place.

Changes in core temperature are presented as a function of intraoperative time, with induction of anaesthesia considered elapsed time 0. All other intraoperative measurements were averaged over time in each patient, and then averaged for the patients given each treatment. Differences among the groups were compared with one-way ANOVA (analysis of variance) and Student–Newman–Keuls tests. Results are presented as mean (SD) unless otherwise indicated; *P*<0.05 was considered statistically significant.

Eight patients were assigned to each group. The characteristics of the patients in the groups were similar, as were surgical factors, ambient temperature, fluid balance and haemodynamic responses (Table 1). No complications related to any of the warming methods were observed.

Mean skin temperatures were significantly less in the circulating water group than in the other two groups at all times after 5 min had elapsed; however, temperatures in the forced air and resistive heating groups never differed significantly.

Initial core temperatures were near 36.6–36.9°C and did not differ significantly among the three groups. Core

Table 1 Patient details and core temperatures. Values are mean (SD). None of the values differed significantly among the three treatment groups except final intraoperative core temperature, which was significantly lower in the circulating water group (**P*<0.05)

	Circulating water	Forced air	Resistive heating
Age (yr)	57 (36–77)	48 (32–71)	59 (41–73)
Sex (male/female)	4/4	6/2	5/3
Weight (kg)	59 (8)	73 (20)	63 (17)
Body mass index (kg m ⁻²)	22 (2)	24 (5)	23 (4)
Heart rate (beats min ⁻¹)	66 (8)	70 (15)	78 (9)
Mean arterial pressure (mm Hg)	95 (18)	99 (17)	94 (15)
Fluid administered (ml kg ⁻¹ h ⁻¹)	19 (5)	16 (4)	17 (4)
Urine output (ml kg ⁻¹ h ⁻¹)	3 (2)	2 (2)	3 (1)
Total operation time (min)	101 (20)	98 (13)	106 (24)
Initial core temperature (°C)	36.8 (0.3)	36.9 (0.3)	36.6 (0.5)
Final intraoperative core temperature (°C)	36.2 (0.4)*	36.8 (0.4)	36.7 (0.5)

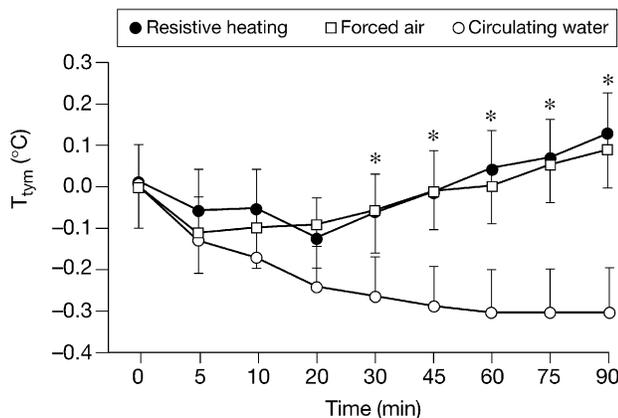


Fig 1 Change in core temperature with time in patients assigned to circulating water, forced air and resistive heating. Temperatures in the circulating water group differed significantly from those in the other groups after 30 elapsed minutes. Temperatures in the forced air and resistive heating groups never differed significantly. Results are mean and SD. * $P < 0.05$.

temperatures were significantly less in the circulating water group than in the other two groups at all times after 30 elapsed minutes; however, temperatures in the forced air and resistive heating groups never differed significantly (Fig. 1).

Comment

Heat redistribution is usually the most important cause of hypothermia during general anaesthesia.² This rapid transfer of heat from core to periphery makes nearly all surgery patients hypothermic, including those undergoing relatively short, small procedures. Redistribution hypothermia is difficult to treat because it results from an internal flow of heat rather than net exchange of heat with the environment. Redistribution can be prevented, however, by preinduction warming^{3,4} or by inducing pharmacological vasodilatation before induction of anaesthesia.⁵

Heat loss from the skin is a nearly linear function of body surface area. The efficacy of passive insulation^{6,7} and active warming systems⁸ is proportional to the available skin surface area. Resistive heating offers an advantage over other systems because it can be adjusted to cover large amounts of surface in almost any surgical position. Flexibility in positioning several different heating segments

is valuable in operations that leave a limited surface area available for warming.

Resistive heating is more effective in maintaining normothermia than reflective covers ('space blankets')⁹ and metallic foil insulation.¹⁰ It is better than circulating water mattresses and comparable to forced air warmers. However, unlike most forced air systems, resistive heaters do not use disposable elements, so this system has a much lower running cost.

In summary, in patients undergoing laparoscopic cholecystectomy, core body temperatures were maintained similarly by resistive heating and forced air warming. Resistive heating maintains core body temperature as well as forced air systems and offers the advantage of flexible positioning.

Acknowledgements

The authors are grateful to Dr Makoto Ozaki (Professor and Chair, Department of Anaesthesiology, Tokyo Women's Medical University, Tokyo, Japan) for his valuable comments on this study and manuscript.

References

- 1 Sessler DI. Perioperative hypothermia. *N Engl J Med* 1997; **336**: 1730–7
- 2 Matsukawa T, Sessler DI, Sessler AM, et al. Heat flow and distribution during induction of general anaesthesia. *Anesthesiology* 1995; **82**: 662–73
- 3 Hynson JM, Sessler DI, Moayeri A, McGuire J, Schroeder M. The effects of pre-induction warming on temperature and blood pressure during propofol/nitrous oxide anaesthesia. *Anesthesiology* 1993; **79**: 219–28
- 4 Just B, Trévien V, Delva E, Lienhart A. Prevention of intraoperative hypothermia by preoperative skin-surface warming. *Anesthesiology* 1993; **79**: 214–18
- 5 Vassilief N, Rosencher N, Sessler DI, Conseiller C, Lienhart A. Nifedipine and intraoperative core body temperature in humans. *Anesthesiology* 1994; **80**: 123–8
- 6 Sessler DI, McGuire J, Sessler AM. Perioperative thermal insulation. *Anesthesiology* 1991; **74**: 875–9
- 7 Sessler DI, Schroeder M. Heat loss in humans covered with cotton hospital blankets. *Anesth Analg* 1993; **77**: 73–7
- 8 Sessler DI, Moayeri A. Skin-surface warming: heat flux and central temperature. *Anesthesiology* 1990; **73**: 218–24
- 9 Greif R, Rajek A, Laciny S, Bastanmehr H, Sessler D. Resistive heating is a more effective treatment for accidental hypothermia than metallic-foil insulation. *Ann Emerg Med* 2000; **35**: 337–45
- 10 Kober A, Scheck T, Fulesdi B, et al. Effectiveness of resistive heating compared with passive warming in treating hypothermia associated with minor trauma: a randomized trial. *Mayo Clin Proc* 2001; **76**: 369–75