

Efficacy of Postoperative Rewarming after Cardiac Surgery

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Objective: To compare the efficacy of forced-air warmers and radiant heaters on rewarming after cardiac surgery in a prospective randomized study.

Methods: Fifty male patients who had undergone coronary artery bypass graft surgery were studied. The control group (Gr. C, n=10) was nursed under a standard hospital blanket. Two groups were treated with forced-air warmers: WarmTouch® 5700 (Gr. WT, n=10) and Bair Hugger® 500 (Gr. BH, n=10). Two other groups were treated by 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). Changes of oesophageal temperature, mean skin temperature, mean body temperature and relative heat balance were calculated from oesophageal temperature, 4 skin temperatures and oxygen consumption ($\dot{V}O_2$).

Results: All actively treated groups with exception of the TC group showed significantly faster oesophageal warming than the control group. 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. The mean $\dot{V}O_2$ and the maxima of the $\dot{V}O_2$ during the study period did not differ significantly between the groups.

Conclusion: In the current setting active warming, forced-air warming more than radiant warming, increased speed of rewarming two- to threefold in comparison to insulation with a blanket. (Ann Thorac Cardiovasc Surg 2004; 10: 171-7)

Key words: cardiac surgery, intensive care, hypothermia, rewarming, oxygen consumption

Introduction

In spite of intraoperative rewarming on cardiopulmonary bypass, patients after cardiac surgery very often present residual hypothermia at the end of the operation,¹⁾ even with extended rewarming on cardiopulmonary bypass.²⁾ One reason for the residual hypothermia is inadequate rewarming of the peripheral tissues during the rewarming phase.³⁾ But there are other reasons. After bypass intraoperative heat losses continue³⁾ with only a small body

surface left for external heat application and a restricted time for rewarming. Cold intravenous fluids may also significantly contribute to the temperature drop after bypass, depending on the volume infused.

The resulting postoperative hypothermia and the ensuing thermoregulatory reaction expose this group of patients to postoperative risks, e.g. postoperative shivering which induces unnecessary cardiac stress. Conventionally this is prevented by pharmacological suppression of the regulatory facultative thermogenesis (shivering) while taking advantage of the obligatory thermogenesis (resting energy expenditure) for rewarming. Simultaneously heat losses are reduced using insulation with blankets. However, this preventive approach to control thermoregulatory thermogenesis by sedation requires prolonged mechanical ventilation, delays extubation and impairs

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hemodynamics.

The additional use of effective external postoperative warming devices seems not only to suppress thermoregulatory shivering more reliably⁴⁾ but also can accelerate rewarming,⁵⁾ enabling earlier extubation. The following study compared the efficacy of two forced-air warmers and two overhead radiant heaters on rewarming and on oxygen uptake.

Methods

Patients

The study was approved by the institutional review board and written informed consent was obtained from each patient. Fifty male American Society of Anesthesiologists (ASA) physical status III patients who had undergone coronary artery bypass graft surgery were admitted to the study. Inclusion criteria were: preoperative left ventricle ejection fraction >40%, uncomplicated surgical course, postoperative oesophageal temperature <35.5°C, body weight within -10% and +30% of normal weight, no pre-existing endocrine disease, only low dose inotropic support on arrival in the ICU.

The patients were randomly assigned to one of five groups (n=10). The control group (Gr. C) was nursed under a standard hospital polyester filled blanket. The blanket had an insulation value of 1.7 clo (unpublished data). This amount of insulation reduces radiative and convective heat losses by about 70% compared to insulation by the surrounding air alone (patient completely exposed).

The second and the third group were treated with different forced-air warming systems, WarmTouch® 5700 (Gr. WT, n=10, Mallinckrodt Medical, Inc., St. Louis, MO, USA) and Bair Hugger® 500 (Gr. BH, n=10, Augustine Medical, Inc., Eden Prairie, MN, USA) using the respective whole body blankets. The forced-air warmers were set to maximal flow and temperature throughout the study.

The fourth and fifth group were treated by two different overhead radiant heaters. One was the Aragona Thermal Ceilings™ CTC X radiant heater (Gr. TC, n=10, Aragona Medical AB, Täby, Sweden), the second was a self assembled radiant heater of 4 Hydrosun 500 infrared lamps (Gr. HY, n=10, Hydrosun Medizintechnik GmbH, Mühlheim, Germany).

The Aragona Thermal Ceilings™ CTC X is a low temperature radiant heater (100°C) with a power of 1,000 W and an infrared C spectrum (IR-C; wavelength 7,000-8,000 nm) on a parabolically shaped radiation surface

(80*210 cm). The radiant heater was set to maximum heating mode at a distance of 75 cm from the patient's chest according to the specification of the manufacturer. The patients were not covered except for a towel over the pelvic region.

The four Hydrosun 500 infrared lamps (each 160 W) radiate at a temperature of 2,600°C. The halogen lamps are water filtered creating an infrared A spectrum (IR-A; wavelength 600-1,300 nm). The lamps were mounted on a frame attached to the ceiling. The IR-A heating sources were used in a distance of 60 cm from the patients chest.

Premedication

An oral benzodiazepine (flunitrazepam 2 mg) was given the night before surgery and one hour before anaesthesia.

Anaesthesia

Anaesthesia was induced with sufentanil 3.5-10 µgkg⁻¹ and supplemented by midazolam 0.1-0.2 mgkg⁻¹ if necessary. Pancuronium 0.1 mgkg⁻¹ was used for muscle relaxation and supplemented when necessary. Anaesthesia was maintained with a sufentanil and midazolam infusion, additional bolus injections were given when necessary.

Thermal management on cardiopulmonary bypass (CPB)

After initiation of CPB patients were cooled to a rectal temperature of 30-32°C and rewarmed to 36°C before weaning from CPB.

Postoperative care

At the end of the surgical procedure the patients remained intubated and were transferred to the ICU. Mechanical ventilation was performed in synchronised intermittent mandatory ventilation mode. The FIO₂ was reduced stepwise to a level of 0.4 to 0.6 to maintain a PaO₂ of 100 to 150 mmHg. Minute ventilation was adjusted aiming at a PaCO₂ level of 37 to 43 mmHg.

Low dose catecholamines were used as clinically indicated and nitroglycerin was infused at a rate of 0.4-0.6 µgkg⁻¹min⁻¹ in all patients.

Analgesia was provided by intravenous piritramide minimum 3 mg⁻¹. Sedation was provided by continuous propofol infusion 1-3 mgkg⁻¹h⁻¹ if necessary. The sedation aimed at a sedation level of 6 according to a scale proposed by Ramsay et al.⁶⁾

Infusions were given at room temperature except for packed red cells and fresh frozen plasma which were

warmed to 37°C. Heat and moisture exchangers were used to reduce heat losses from the airways (HumidVent 2P, Gibeck Respiration AB, Upplands Väsby, Sweden).

Shivering was treated with injections of intravenous meperidine (25 mg) which were repeated after five minutes until it stopped.

Measurements

Measurements were started immediately after admission of the patient to the ICU and continued until the oesophageal temperature reached 37.5°C.

The amount of infusions, sedation, meperidine and ambient temperature was documented. Temperature was monitored with 5 thermistors. For the measurement of oesophageal temperature, an oesophageal probe with oesophageal stethoscope (Mallinckrodt Medical, Inc.) was used. This was positioned at the point of loudest heart sounds. For calculation of the mean skin temperature 4 cutaneous temperatures were measured by YSI Series 409 thermistors (Yellow Springs Industries, OH, USA) covered with reflective adhesive foil (YSI Tempheart 4009, Yellow Springs Industries). These were positioned at the mid-calf, mid-thigh, lateral thorax and upper arm. The thermistors were connected to temperature recording units (Hellige Servomed 236039, Hellige, Freiburg, Germany). Each probe and matched recording unit were calibrated over the entire range (22–42°C) against a reference quartz thermometer (Hewlett Packard Model 2801 A, Hewlett Packard Company, Palo Alto, CA, USA, accuracy $\pm 0.01^\circ\text{C}$) in a thermostated water bath before the investigation.

Mean skin temperature (MST) was calculated according to Ramanathan:⁷⁾

$$\text{MST} = 0.3 * (\text{T}_{\text{chest}} + \text{T}_{\text{arm}}) + 0.2 * (\text{T}_{\text{thigh}} + \text{T}_{\text{calf}})$$

Mean body temperature (MBT) was derived according to Burton:⁸⁾

$$\text{MBT} = (0.66 * \text{T}_{\text{oes}}) + (0.34 * \text{T}_{\text{skin}})$$

Total body heat (TBH) was calculated from this using the equation:

$$\text{TBH} = \text{MBT} * \text{body weight} * \text{specific heat of the human body}$$

where the specific heat of the human body is 3.475 kJ°C⁻¹kg⁻¹.

The rate of change in total body heat was calculated as follows:

$$\Delta\text{TBH} = \text{TBH}_{(\text{end of rewarming})} - \text{TBH}_{(\text{first measurement})} / \text{time for rewarming.}$$

Oxygen uptake ($\dot{V}\text{O}_2$) and carbon dioxide elimination ($\dot{V}\text{CO}_2$) were measured with the Deltatrac™ Metabolic

Monitor (Datex Instrumentarium Corp., Helsinki, Finland) which was calibrated according to the manufacturers recommendation. The performance of this device measuring on ventilated patients has been found to be in the range of $\pm 7\%$ for $\dot{V}\text{O}_2$ and $\dot{V}\text{CO}_2$.⁹⁾ Measured energy expenditure was calculated according to the Weir formula.¹⁰⁾ To provide a highly stable FIO_2 , a reservoir blender (KM60-2, Witt, Witten, Germany) was interposed upstream of the respirator.

A relative heat balance was calculated as the ΔTBH divided by body heat production (energy expenditure) for the specified interval.

Statistics

Results are given as median values (min-max). The Mann-Whitney U-test for unpaired data was used for comparison of differences between the single groups and the control group. Analysis was performed using the Statistica® Ver. 4.5 B software package (StatSoft, Inc., Tulsa, OK, USA). A $p < 0.05$ was considered significant. The Bonferroni correction was applied to adjust the level of significance for repeated testing.

Figures

All data in the figures are arranged as box and whiskers plots. The boundary of the grey box closest to 0 indicates the 25th percentile, the line within the grey box marks the median, and the boundary of the grey box farthest from 0 indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles. The circles represent the outlying data points.

Results

All groups were comparable for anthropometric data and the amount of fluids given (Table 1). The mean room temperature was 22.8°C.

All actively treated groups showed faster oesophageal warming than the control group. The rate of oesophageal rewarming was significantly higher for all actively treated groups with exception of the TC group. The forced-air warmers increased the oesophageal temperature at double the rate [WT 0.8 (0.4–1.7)°Ch⁻¹, BH 0.9 (0.4–1.3)°Ch⁻¹ for Gr. C [0.4 (0.2–0.6)°Ch⁻¹] (Fig. 1). The rise in oesophageal temperature was intermediate for the radiant heaters: 0.6 (0.4–1.0)°Ch⁻¹ for the TC and 0.7 (0.5–0.9)°Ch⁻¹ for the HY.

Within group C the mean skin temperature (MST) rose with the same rate as the oesophageal temperature [0.4 (0.2–0.8)°Ch⁻¹. Compared to group C forced-air warming

Table 1. Patient characteristics

Group	Control	WarmTouch®	Bair Hugger®	Thermal Ceilings™	Hydrosun
Age (yr)	64.5 (57-70)	65.5 (50-74)	59 (50-73)	66 (50-75)	64 (57-70)
Height (cm)	173.5 (168-182)	173 (167-182)	175 (167-192)	175 (168-185)	175.5 (160-180)
Weight (kg)	81 (61-105)	81 (63-97)	73.5 (51-120)	75 (72-95)	81.5 (70-87)
Infusions (ml)	1,775 (1,000-4,000)	1,385 (800-2,040)	1,250 (500-2,200)	1,830 (720-3,600)	1,550 (700-3,780)
Propofol (mgkg ⁻¹ h ⁻¹)	1.2 (0-2.2)	0.9 (0-1.4)	0.6 (0-1.9)	1.1 (0-1.8)	1.0 (0.4-1.5)
Meperidine (mg)	25 (0-150)	0 (0-100)	0 (0-150)	0 (0-100)	37.5 (0-150)

There are no significant differences between the groups for any anthropometric variable, the amount of infusions, sedation and meperidine.

increased MST 4 to 5 times as fast [WT 1.6 (1.0-2.1)°Ch⁻¹ and BH 2.0 (1.2-2.4)°Ch⁻¹], and radiant heat therapy 2 to 3 times as fast [TC 1.2 (0.6-2.2)°Ch⁻¹ and HY 0.8 (0.3-1.4)°Ch⁻¹] (Fig. 2). These differences were significant, with exception of the HY group.

Within group C mean body temperature (MBT) rose 0.4 (0.2-0.7)°Ch⁻¹. Forced-air warming caused a rise in MBT of 1.1 (0.7-1.7)°Ch⁻¹ with the WarmTouch® system and 1.3 (0.7-1.5)°Ch⁻¹ with the Bair Hugger® system. The radiant heat therapy caused a rise in MBT of 0.8 (0.5-1.4)°Ch⁻¹ with the Aragona Thermal Ceilings™ and 0.7 (0.4-1.0)°Ch⁻¹ with the Hydrosun system. This was significantly faster for all groups compared to the control group.

Neither the mean $\dot{V}O_2$ (Fig. 3) nor the maxima of the $\dot{V}O_2$ (Fig. 4) during the study period differed significantly between the treatment groups and Gr. C.

Efficacy of external heat application can be quantified more reliably by considering the patients own heat production. The calculation of the relative heat balance (Fig. 5) showed that a fraction of 0.4 (0.3-0.8) of the patients own heat production could be utilised for rewarming in the control group compared to 1.0 (0.7-1.4) and 1.0 (0.7-1.4) with forced-air warming (WT and BH) and 0.8 (0.5-1.2) and 0.6 (0.5-0.9) with radiative treatment (TC and HY). This was significantly more than in the control group.

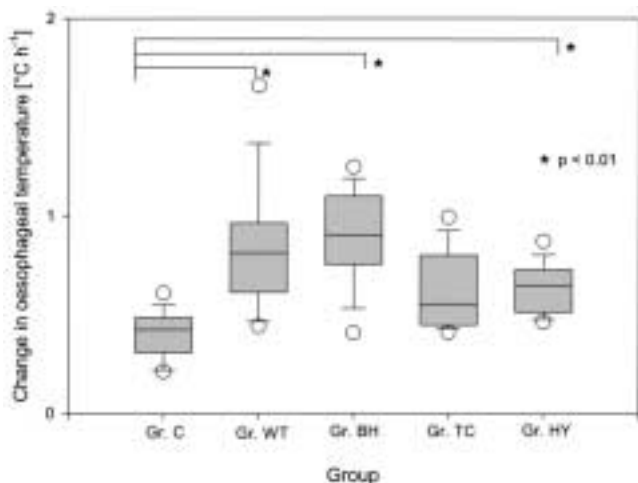


Fig. 1. Rate of oesophageal temperature changes during rewarming after coronary artery bypass graft surgery. Two different forced-air warmers (WarmTouch® [Gr. WT], Bair Hugger® [Gr. BH]) and two different overhead radiant heaters (Aragona TC [Gr. TC], Hydrosun [Gr. HY]) were compared with passive insulation by a blanket (Control [Gr. C]). A significant higher rate of central temperature change was found for all actively treated groups with exception of the Aragona TC group.

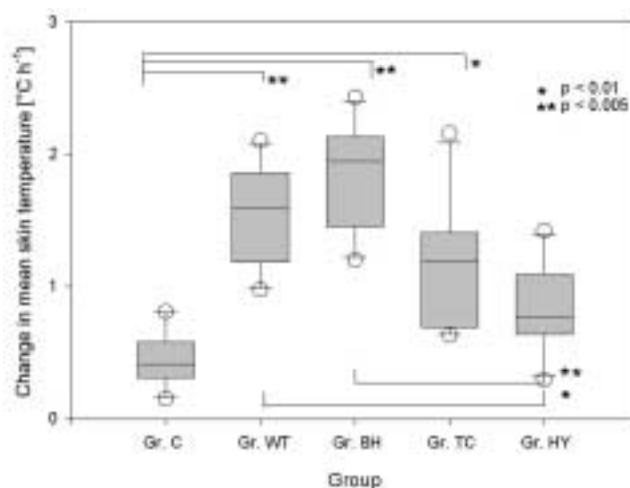


Fig. 2. Rate of mean skin temperature changes during rewarming after coronary artery bypass graft surgery. Two different forced-air warmers (WarmTouch® [Gr. WT], Bair Hugger® [Gr. BH]) and two different overhead radiant heaters (Aragona TC [Gr. TC], Hydrosun [Gr. HY]) were compared with passive insulation by a blanket (Control [Gr. C]). A significant higher rate of mean skin temperature change was found for all actively treated groups, with exception of the Hydrosun group. The highest mean skin temperature changes were induced by forced-air warming.

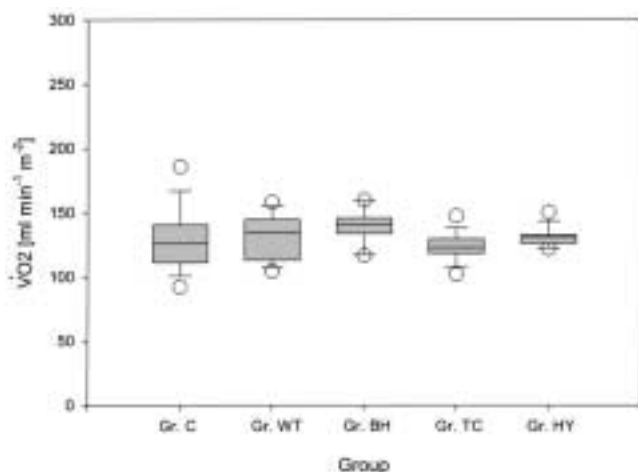


Fig. 3. Mean oxygen uptake ($\dot{V}O_2$) during rewarming after coronary artery bypass graft surgery. The mean $\dot{V}O_2$ stands for the continuous load to the cardiorespiratory system. Two different forced-air warmers (WarmTouch® [Gr. WT], Bair Hugger® [Gr. BH]) and two different overhead radiant heaters (Aragona TC [Gr. TC], Hydrosun [Gr. HY]) were compared with passive insulation by a blanket (Control [Gr. C]). No significant differences could be detected between groups.

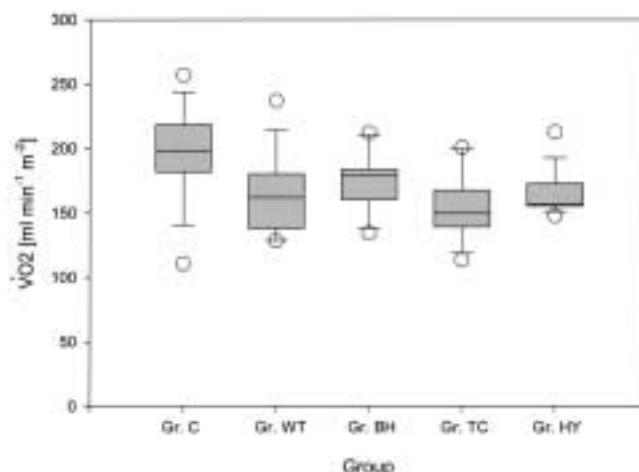


Fig. 4. Maximal oxygen uptake ($\dot{V}O_2$) during rewarming after coronary artery bypass graft surgery. The maximal $\dot{V}O_2$ stands for the peak load to the cardiorespiratory system. Two different forced-air warmers (WarmTouch® [Gr. WT], Bair Hugger® [Gr. BH]) and two different overhead radiant heaters (Aragona TC [Gr. TC], Hydrosun [Gr. HY]) were compared with passive insulation by a blanket (Control [Gr. C]). No significant differences could be detected between groups.

Discussion

Residual hypothermia may especially impose risks to patients after cardiac surgery, e.g. higher blood loss via the chest tubes.¹¹ Effective postoperative heat application could help to reduce those risks by reducing the time of rewarming.

The ideal postoperative rewarming method should be safe and enable fast, reliable and predictable rewarming, without causing burns. Therefore as much of the skin surface as possible should be warmed.

Forced-air and radiative warming systems are known to be very effective in terms of rewarming.^{5,12-14}

Two different forced-air warmers were included, because they differ in flow rate, air temperature, length of tube and blanket design. On this basis differences in efficacy could be expected. The two radiative devices were included, because IR-A radiation (Hydrosun) penetrates the tissue to a relevant degree,¹⁵ whereas IR-C radiation (Aragona Thermal Ceilings™) does not.

Change of core temperature is the clinical parameter to determine efficacy of rewarming. Forced-air warming doubled the rate of core temperature rise compared to control group. There was no significant difference between the two systems (Fig. 1). The radiant heaters increased speed of core rewarming by 50% (TC) or 75% (HY) respectively. However, oesophageal rewarming of

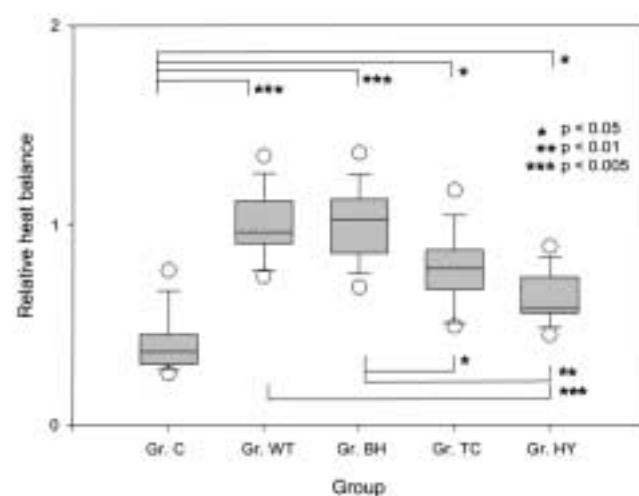


Fig. 5. Relative heat balance during rewarming after coronary artery bypass graft surgery. This balance is 0 during steady state conditions where heat production equals heat losses. Two different forced-air warmers (WarmTouch® [Gr. WT], Bair Hugger® [Gr. BH]) and two different overhead radiant heaters (Aragona TC [Gr. TC], Hydrosun [Gr. HY]) were compared with passive insulation by a blanket. A significant higher relative heat balance was found for all actively treated groups.

the TC group was not significantly faster compared to the control group.

The higher efficacy of the forced-air warming systems was also associated with an up to fivefold faster rise in

mean skin temperature compared to the control group (Fig. 2).

In comparison, the radiative heaters showed a slower increase in mean skin temperature. The Hydrosun radiant heater created less rise in mean skin temperature than the Aragona Thermal Ceilings™. At the same time it produced a slightly higher increase in core temperature. Considering the inferior power of the Hydrosun (640 W) and the less homogeneous heat distribution compared to the Aragona Thermal Ceilings™ (1,000 W), this is an unexpected finding. A possible explanation for this is the fact that the Hydrosun was applied closer to the patient and uses IR-A radiation that penetrates the tissue more than IR-C. The deeper penetration reduces the heat load to the skin and increases the heat transfer to subcutaneous structures.¹⁵⁾ Additionally lower skin temperature lead to less heat losses from the skin to the environment.¹⁶⁾

Both parameters, oesophageal temperature representing the central compartment and mean skin temperature representing the peripheral compartment, were used to calculate mean body temperature and consequently the calculated gain of total body heat. However, this formula with fixed weighting factors has not been validated for external heat application. Thus an incorrect estimation of mean body temperature may occur in this setting due to the different heat load to the skin.¹⁷⁾

A relative heat balance was used to describe the contribution of the patients own heat production for rewarming. Within a steady state condition, where all heat produced is lost to the environment this relative heat balance equals 0. It is positive <1 when a respective fraction of the heat production can be retained to increase the total body heat and it exceeds 1 if the change in total body heat exceeds the heat production, which indicates a net uptake of external heat.

Insulation was able to retain about 40% of the heat production for rewarming (Gr. C). The radiant heaters reduced heat losses to a degree that 60% to 80% of the heat production could be retained for rewarming, with no significant difference between the two systems. The patients warmed by forced-air showed the highest relative heat balance. The change in total body heat equalled the heat production, which means that all heat losses were compensated by the forced-air warming system. There was no significant difference between the two forced-air warming systems. This is in contrast to a study of Giesbrecht et al.¹⁸⁾ on volunteers.

The present comparison of forced-air warming systems and radiative warmers could lead to the conclusion that

forced-air warming is principally more effective than radiative warming. This conclusion has been drawn⁵⁾ and is true when the devices are used as recommended by the manufacturers. However, the efficacy of radiative warmers depends not only on the power of the heater and the used IR spectrum, but on the distance and the angle between the radiant source and the patients skin. English et al.¹⁹⁾ used a more powerful Aragona Thermal Ceilings™ with 1,500 W in patients after cardiac surgery in a distance of 60 cm and 30 cm. They found a rise in mean body temperature of 1.8°C/h and 2.2°C/h respectively. This is a higher rate than we could find for the forced-air warmers tested (Bair Hugger 1.3°C/h).

The lower rise in mean skin temperature for radiative warming compared to forced-air warming points towards an insufficient distance of the radiant sources. In this respect a study on efficacy of radiant warming and forced-air warming appears to be necessary. This study should use equal mean skin temperatures created by varying the distance of the radiant source.

In conclusion, active warming can increase speed of rewarming after cardiac operations. Radiant warmers were less effective than the forced air-warmers when applied in the distance recommended by the manufacturer.

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