Forced-Air Warming Decreases Vasodilator Requirement After Coronary Artery Bypass Surgery

Hossam K. El-Rahmany, MD*, Steven M. Frank, MD*, Giselle M. Schneider, BS†, Nader A. El-Gamal, MD‡, Carole A. Vannier, MD*, Ramadan Ammar, MD‡, and Ahmed S. Okasha, MD‡

*Department of Anesthesiology and Critical Care Medicine, The Johns Hopkins Medical Institutions, Baltimore, Maryland; †University of Louisville, School of Medicine, Louisville, Kentucky; and ‡Department of Anesthesiology and Intensive Care, Alexandria University, Alexandria, Egypt

Postoperative hypothermia is common and associated with adverse hemodynamic consequences, including adrenergically mediated systemic vasoconstriction and hypertension. Hypothermia is also a known predictor of dysrhythmias and myocardial ischemia in high-risk patients. We describe a prospective, randomized trial designed to test the hypothesis that forced-air warming (FAW) provides improved hemodynamic variables after coronary artery bypass graft. After institutional review board approval and written informed consent, 149 patients undergoing coronary artery bypass graft were randomized to receive postoperative warming with either FAW (n = 81) or a circulating water mattress (n = 68). Core temperature was measured at the tympanic membrane. A weighted mean skin temperature was calculated. Heart rate, mean arterial blood pressure, central venous pressure, cardiac output, and systemic vascular resistance were monitored for 22 h postoperatively. Mean arterial blood pressure was maintained by protocol between 70 and 80 mm Hg by titration of nitroglycerin and sodium nitroprusside. The two groups had similar demographic characteristics. Tympanic and mean skin temperatures were similar between groups on intensive care unit admission. During postoperative rewarming, tympanic temperature was similar between groups, but mean skin temperature was significantly greater in the FAW group (P < 0.05). Heart rate, mean arterial pressure, central venous pressure, cardiac output, and systemic vascular resistance were similar for the two groups. The percent of patients requiring nitroprusside to achieve the hemodynamic goals was less (P < 0.05) in the FAW group. In conclusion, aggressive cutaneous warming with FAW results in a higher mean skin temperature and a decreased requirement for vasodilator therapy in hypothermic patients after cardiac surgery. This most likely reflects attenuation of the adrenergic response or opening of cutaneous vascular beds as a result of surface warming. Implications: Forced-air warming after cardiac surgery decreases the requirement for vasodilator drugs and may be beneficial in maintaining hemodynamic variables within predefined limits.

Coronary artery bypass grafting (CABG) is commonly performed by using hypothermic cardiopulmonary bypass (HCPB) to provide myocardial and cerebral protection by decreasing metabolic demands and attenuating the detrimental effects of ischemia. Before the termination of HCPB during cardiac surgery, patients are rewarmed by warming the perfusate. Despite this rewarming, residual hypothermia is a common finding after HCPB (1,2) because heat redistributes from the blood and the warm vascular core to the cold peripheral tissues.

Undesired residual hypothermia is therefore common and many patients arrive in the intensive care unit (ICU) with a core temperature <35.0°C. Hypothermia predisposes to shivering with the associated increase in oxygen consumption and carbon dioxide production. Patients with coronary artery disease may lack normal cardiac reserves and, thus, may not tolerate these increased metabolic demands. Hypothermia is also associated with an adrenergic response, which is manifested by increased norepinephrine, systemic vasoconstriction, hypertension, dysrhythmias, and myocardial ischemia (3–5). Despite the frequency and magnitude of hypothermia after

©2000 by the International Anesthesia Research Society
cardiac surgery, there is little or no evidence showing the importance of thermal management after CABG. Although circulating water mattresses (CWM) and forced-air warming (FAW) have been compared, these studies have focused on the intraoperative, not postoperative treatment (6,7).

We examined the hemodynamic profile after CABG surgery in patients who were mildly hypothermic during the rewarming period. We describe a prospective, randomized trial designed to test the hypothesis that FAW improves hemodynamic variables after CABG when compared with treatment with CWM. The basis for this hypothesis is that FAW is more effective in intraoperative studies (6,7), and aggressive warming is known to attenuate adrenergically mediated vasoconstriction (3).

**Methods**

**Patient Enrollment and Randomization**

With approval from the Committee on Clinical Investigation and after written, informed consent, 149 patients at The Johns Hopkins Hospital (Baltimore, MD) undergoing CABG were enrolled in the study. No patient having reoperation for CABG was enrolled. Patients were randomized by using computer-generated random numbers into two groups. The first group (FAW, n = 81) received postoperative warming with whole body FAW by using the forced-air heat source set to high flow and high temperature (42°–46°C) and a disposable patient cover blanket (Warm Touch; Mallinckrodt Medical Inc., St. Louis, MO), which was inserted until the patients felt the thermocouple touch the tympanic membrane. Skin temperature was measured at several sites including the anterior chest, upper arm, midthigh, and midcalf. Skin temperature was monitored by using a special skin-surface thermocouple with a foam insulated backing (Mon-a-therm®) to prevent direct warming of the probe.

Temperatures at all sites were recorded on admission to the ICU and at the following times: 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 5, 6, 7, 8, 10, 14, 18, and 22 h after admission. Approximately 10% of the patients had missing data immediately on admission to the ICU, and the temperature data from 5 min after admission were substituted for these missing data points. Temperatures were monitored and recorded by a multichannel body temperature monitoring and data acquisition system (Iso-thermex; Columbus Instruments, Columbus, OH) with a direct interface to a laptop computer. Mean skin temperature was calculated using the following formula (8):

\[
\text{Mean skin temperature} = 0.3(\text{upper arm} + \text{chest}) + 0.2(\text{thigh} + \text{calf}) 
\]

Shivering was assessed on a 0–4 point scale (9).

**Hemodynamic Monitoring**

Intraoperative and postoperative monitoring included electrocardiogram, pulse oximetry, a radial arterial catheter for continuous display of blood pressure, and a pulmonary artery catheter. Anesthesia was induced with thiopentone sodium (50–200 mg) and fentanyl (20–40 μg/kg), and maintained with 100% oxygen. Isoflurane was used, if necessary, to maintain the systolic blood pressure within 20% of the preoperative baseline. Neuromuscular blockade was achieved with pancuronium (0.15 mg/kg). Standard hypothermic cardiopulmonary bypass (approximately 28°C) was instituted with a roller pump providing nonpulsatile flow with a membrane oxygenator. Myocardial protection was achieved with cold hyperkalemic cardioplegic arrest and topical cooling of the heart by pouring cold saline (4°C) intermittently into the pericardial sac. A standard technique and composition of the cardioplegic solution were used. IV fluids and blood were warmed to approximately 37°C before the administration to the patients by using a fluid-warming device. Muscle relaxants were reversed with neostigmine and glycopyrrolate on arrival to the ICU. Both nitroglycerin and sodium nitroprusside were continuously titrated in the postoperative period to maintain the mean arterial blood pressure between 70 and 80 mm Hg.
by dividing the cardiac output by the body surface area and presented in \(L \cdot \text{min}^{-1} \cdot \text{m}^{-2}\).

The \(\chi^2\) and unpaired Student’s \(t\)-tests were used to compare the two groups for dichotomous and continuous outcomes, respectively. A nonparametric test (Wilcoxon’s ranked sum test) was used for variables not normally distributed. Analysis of variance for repeated measures was used to compare differences between and within the two groups for variables measured over time. A Bonferroni correction was used to adjust for multiple comparisons. All analyses were performed with either SuperANOVA (Abacus, Berkeley, CA) or JMP (SAS Institute INC, Cary, NC) computer programs. All data were given as mean \(\pm \text{se}\) of the means, and \(P < 0.05\) was used to determine significance.

**Results**

Fifteen patients did not receive the treatment to which they were assigned, in most cases because of unavailability of warming devices. Five patients randomized to the FAW group received no warming. Seven patients randomized to CWM group received FAW, and three received no warming. The analyses were performed according to both treatment assigned and treatment received, and there were no differences in statistical significance in these two analyses. We therefore report the results according to treatment assigned.

**Demographic**

A demographic comparison of the two groups, FAW and CWM, is shown in Table 1. The groups did not differ with respect to preoperative demographic variables (sex, height, weight, body mass index, percent body fat) except age, which was slightly greater in the FAW group \((P = 0.02)\). Total crystalloid, colloids, and packed red blood cells given in the operating room (OR) were similar between groups. Cardiopulmonary bypass (CPB) duration and the postbypass time in the OR were also similar between groups (Table 2). The postoperative variables compared between the two groups are displayed in Table 3. The percent of patients requiring nitroprusside at any time during the postoperative evaluation period was greater in the FAW group compared with the CWM group \((P = 0.008\) and \(P = 0.0001\), respectively) (Figure 1). During the postoperative period, there were no significant differences in tympanic temperature between groups \((P = 0.8)\).

**Hemodynamic Changes**

Postoperative heart rate and systemic vascular resistance were similar in the FAW and the CWM groups, \((P = 0.4\) and \(P = 0.8\), respectively). MAP and cardiac index were also similar between groups in the postoperative period \((P = 0.8\) and \(P = 0.3\)) (Figure 2).

**Vasodilator Requirement**

The percent of patients requiring nitroprusside during the postoperative period to maintain MAP between 70 and 80 mm Hg was significantly less in the FAW group compared with the CWM group \((P = 0.0006)\) (Figure 3). The percent of patients requiring nitroglycerin was not different between groups (Figure 3).

**Discussion**

Patients in both groups had similar tympanic and mean skin temperatures on ICU admission after
cardiac surgery. In the postoperative period (especially in the first few hours), FAW was associated with a higher mean skin temperature and a requirement of less nitroprusside to achieve predetermined hemodynamic goals.

Heat exchange through the bypass circuit on CPB achieves dramatic cooling of the circulation and rapid temperature changes in the central core, but the peripheral compartment (muscle and fat) cools more slowly (2,10). Subsequently, and before separation from CPB, rapid core warming is provided. However, the peripheral compartment remains relatively cold, and residual hypothermia persists into the postoperative period (2,11). In addition, during cardiac surgery, as in any surgical procedure, patients tend to lose heat to the environment because the chest is opened for a prolonged period (11). General anesthetics, opioids, and barbiturates all affect thermoregulation by blocking afferent input, changing the set point, or preventing efferent responses, either centrally or peripherally.

Different rewarming methods had been used after CPB, including control of ambient temperature, passive inspiratory gas heating and humidification,
insulation with cotton blankets, and active warming with FAW or CWM. Villamaria et al. (12) showed, in a randomized clinical trial, that FAW did not increase the rate of core warming above that of standard techniques in postoperative cardiac surgery patients and did not result in improvement in the clinical variables measured. The only other studies of FAW after bypass surgery are those of Pathi et al. (13) and Mort et al. (14). They detected no difference in core temperature between patients warmed postoperatively with a forced-air device and those warmed with cotton blankets. Mort et al. (14) found warmer skin surface temperatures (upper and lower extremity and shoulder temperatures) and less shivering in the forced-air group than in the warm cotton blanket group.

FAW was more effective in maintaining core temperature than CWM in patients undergoing renal transplantation as observed by Hynson et al. (6). Similar findings were observed by Kurz et al. (7), who compared warming by FAW or CWM in adults undergoing major maxillofacial surgery (including radical neck resection and flap reconstruction), adults undergoing hip arthroplasty (having less than 20% of their body surface area available for warming), infants undergoing minor maxillofacial surgery, and young children undergoing pelvic or femoral osteotomy. In all four settings, FAW was considerably more effective than CWM in maintaining intraoperative normothermia (7). Similar findings were also observed by Muller et al. (15), who compared FAW with CWM in patients undergoing orthotopic liver transplant. These investigators concluded that patients warmed with only circulating water and passive insulation become hypothermic during surgery. In contrast, when FAW was added to this routine thermal management, patients were normothermic at the end of surgery. FAW thus prevents intraoperative hypothermia during liver transplant. The difference between the above-referenced studies and the current study is that we assessed warming postoperatively, not intraoperatively. One possible explanation for the difference in core rewarming rates in these two settings may be the presence of vasoconstriction that blocks heat transfer.
from the skin to the core thermal compartment (16). This phenomenon is more likely to occur postoperatively.

In the current study, mean skin temperature was significantly higher in FAW group in the postoperative period. This finding is similar to the observations of Mort et al. (14), who showed that FAW was responsible for increased skin surface temperature when compared with standard cotton blankets. In a recent study by Ti et al. (17) comparing forced air with overhead radiant heating, FAW improved skin rewarming and promoted a more rapid but nonsignificant increase in total body heat content. It is important to recognize that core temperature is not the only determinant of the physiologic responses to hypothermia and that skin-surface temperature plays a critical role in modulating this response (18). This concept is demonstrated in our results.

Nitroprusside requirements were lower in the FAW group. This might be because of decreased vascular tone as a result of a higher skin temperature and/or less adrenergic response and a more vasodilated cutaneous vascular bed. Frank et al. (3) demonstrated in a prospective, randomized study, that, compared with normothermic patients, patients developing mild hypothermia during surgery have a greater postoperative norepinephrine response and a greater degree of peripheral vasoconstriction. Sun et al. (19) showed that moderate hypothermia during CPB induces a gradual increase in plasma neuropeptide Y and norepinephrine as a measure of the sympathetic response to stress, in contrast to mild hypothermia during CPB, which causes a modest rise in plasma neuropeptide Y with no significant effect on plasma norepinephrine or epinephrine. Whatever the mechanism for the decreased nitroprusside requirement, patients may benefit from surface warming, because pharmacological vasodilation is not without side effects (e.g., reflex tachycardia and inadvertent hypotension).

The following limitations should be recognized in our study. First, the mean age was significantly greater in the FAW group. The difference was, however, small and probably not clinically significant. Second, there were a few patients who did not adhere to the random assignment of treatment for various reasons discussed above. These patients were analyzed according to treatment randomized and by treatment received with similar results.

In conclusion, aggressive cutaneous warming with FAW is associated with higher mean body and mean skin temperature compared with CWM treatment. There was also a decreased requirement for vasodilator therapy in hypothermic patients after cardiac surgery when FAW was used. These findings most likely reflect attenuation of the adrenergic response or opening of cutaneous vascular beds as a result of surface warming.

The authors gratefully acknowledge the contributions from Susan Kelly, Krista Olson, Christian Bulcao, and Jay Weller. They also appreciate cooperation from the residents, faculty, and nursing staff in the cardiac operating rooms and intensive care units.

References