Intracardiac temperature monitoring in infants after cardiac surgery

Sarah Tabbutt, MD, PhD,^{a,b} Richard F. Ittenbach, PhD,^c Susan C. Nicolson, MD,^b Nancy Burnham, RN,^d Shannon Hittle, RN,^d Thomas L. Spray, MD,^d and J. William Gaynor, MD^d

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Background: Hyperthermia after cerebral ischemia is associated with worse neurologic outcome. Our goals were 3-fold: (1) to describe the postoperative temperature course in infants after cardiac surgery, (2) to compare intracardiac temperature monitoring with traditional monitoring in infants, and (3) to determine variables that influence the patients' temperatures.

Methods: Longitudinal temperature data were collected for 100 infants undergoing cardiac surgery. Intra-atrial, nasopharyngeal, esophageal, rectal, and axillary temperatures were recorded in all patients.

Results: The mean age at the time of operation was 128 ± 166 days, and the mean weight was 5.1 ± 2.4 kg. Circulatory arrest was used for 54 patients. In the operating room, the maximum intra-atrial temperature ($37.5^\circ\text{C} \pm 0.6^\circ\text{C}$) was significantly greater than both the simultaneous esophageal temperature ($36.9^\circ\text{C} \pm 1.9^\circ\text{C}$, $P = .03$) and nasopharyngeal temperature ($36.3^\circ\text{C} \pm 2.5^\circ\text{C}$, $P < .001$). In the cardiac intensive care unit, intra-atrial temperature was significantly greater than both axillary and rectal temperatures. During the first 24 postoperative hours, intra-atrial temperature was greater than 38°C in 48 (48%) patients, rectal temperature was greater than 38°C in 36 (36%) patients, and axillary temperature was greater than 38°C in 7 (7%) patients.

Conclusions: In patients less than 2 years of age undergoing cardiac surgery requiring cardiopulmonary bypass, intra-atrial temperature peaked 4 to 6 hours after leaving the operating room. Traditional methods of temperature monitoring significantly underestimate core temperature after cardiac surgery in infants. Use of intracardiac temperature monitoring might result in avoidance of cerebral hyperthermia.

Surgical results for infants undergoing repair and palliation of congenital heart disease have improved dramatically over the past several decades. Current mortality rates for complex neonatal cardiac surgery are reported at less than 5% at some institutions.¹ Management now emphasizes minimizing associated morbidity. Optimizing long-term neurologic outcome is presently the focus of both clinical and research interests.

Cerebral hypothermia continues to be the mainstay of neurologic protection during the circulatory arrest period frequently used for repair or palliation of many

From the Department of Pediatrics, Division of Cardiology,^a Department of Anesthesia and Critical Care Medicine,^b Biostatistics and Data Management Core,^c and the Department of Surgery, Division of Cardiothoracic Surgery,^d The Children's Hospital of Philadelphia and the University of Pennsylvania School of Medicine, Philadelphia, Pa.

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Address for reprints: Sarah Tabbutt, MD, PhD, Cardiac Intensive Care Unit, The Cardiac Center, The Children's Hospital of Philadelphia, 34th St and Civic Center Blvd, Philadelphia PA 19104 (E-mail: tabbutt@email.chop.edu).

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Abbreviations and Acronyms

CICU	= cardiac intensive care unit
CPB	= cardiopulmonary bypass
DHCA	= deep hypothermic circulatory arrest
T _{ATR}	= intra-atrial temperature
T _{ES}	= esophageal temperature
T _{NP}	= nasopharyngeal temperature
T _R	= rectal temperature

congenital heart lesions.² Although the ideal temperature and optimal rates of cooling and warming remain controversial, the concept that the dramatic attenuation of cerebral cellular metabolism and enzymatic function during hypothermia provides a significant degree of neuroprotection is universally accepted. Mild-to-moderate hypothermia after warm ischemia has been shown to be beneficial in both animal models³⁻⁵ and human trials.^{6,7} The benefit of hypothermia after cardiac surgery with hypothermic ischemic arrest has not yet been prospectively studied and remains controversial.^{8,9} However, all management strategies attempt to avoid hyperthermia.

This observational study is the first to report the use of an intra-atrial thermister in a large number of infants. The purpose of the present study was 3-fold: (1) to describe the postoperative temperature course in infants after cardiac surgery, (2) to compare intracardiac temperature monitoring with traditional and more widely used temperature monitoring, and (3) to identify variables that influence central temperature in the postoperative period in infants.

Materials and Methods

This was a prospective, consent-waived, clinical data collection trial approved by The Children's Hospital of Philadelphia Institutional Review Board. One hundred sequential patients less than 2 years of age undergoing cardiac surgery with cardiopulmonary bypass (CPB) with indwelling intracardiac thermister catheters (Edward Lifesciences, Irvine, Calif) were included. Demographic, anatomic, and procedural data were collected. Intraoperative data included temperature (intra-atrial [T_{ATR}], nasopharyngeal [T_{NP}], esophageal [T_{ES}], and rectal [T_R] temperatures), bypass, and aortic crossclamp and deep hypothermic circulatory arrest (DHCA) times in addition to rates and depth of cooling and rewarming. Postoperative temperatures (T_R, T_{ATR}, and axillary temperature [T_{AX}]) were recorded hourly for 4 hours (continuous rectal monitoring: Thermistor:YS1700, Level 1, Rockland, Mass; intermittent rectal or axillary monitoring: IVAC Temp-plus II, Alaris Medical Systems, San Diego, Calif), every 2 hours for 8 hours and then every 4 hours until discharge from the cardiac intensive care unit (CICU). T_{ATR} recordings were discontinued when the thermister catheter was removed. The timing of the removal of intracardiac catheters was at the discretion of the care-giving team. This was reflected in a decrease in the number of T_{ATR} data points: postoperative hour 16 (n = 100), postoperative hour 24 (n = 75),

postoperative hour 40 (n = 50), postoperative hour 80 (n = 30), and postoperative hour 120 (n = 14). Additional variables that were believed to potentially influence the patients' temperatures were recorded: environmental temperature control, inotropic agents and vasodilators, transfusion of blood products, arterial blood gas data, and administration of base correction, acetaminophen, or ibuprofen.

Standard practice at our institution includes intraoperative placement of intracardiac catheters for pressure monitoring and vascular access. These catheters are preferentially placed in the right-sided atrium. Typically, 2 to 3 of these catheters are placed through the atrial cannulation site during decannulation. The 3F thermister catheters provide T_{ATR} monitoring. Placement of the intracardiac thermister was at the discretion of the surgeon. Intra-atrial catheters are removed simultaneously at the bedside when they are no longer deemed necessary. Most commonly, intracardiac catheters are removed after endotracheal extubation and after the patient has demonstrated the ability to maintain adequate enteral nutrition. These catheters are removed as early as the first postoperative morning in the older infants with less complex operations. No patient required surgical intervention related to the intracardiac catheter.

Operations were performed by 3 cardiac surgeons with a dedicated team of cardiac anesthesiologists. Alpha-stat blood gas management was used. Pump flow rates were not standardized for this study. DHCA was used at the surgeon's discretion. Before DHCA, patients underwent core cooling with topical hypothermia of the head to a T_{NP} of 18°C. Modified ultrafiltration was performed in 98 patients.

Routine CICU management was maintained for these patients. Normothermia was the routine temperature strategy. However, patients with accelerated junctional rhythm are often cooled slightly. Environmental temperature control with overhead warmers (Ohio-Infant Warmer System; Ohmeda, Columbia, Md), bear-huggers (Bair Hugger Model 500/OR; Augustine Medical Inc, Eden Prairie, Minn), and cooling blankets (Mul-T-Blanket; Gaymar Industries, Orchard Park, NY) were used in 49% of patients. Acetaminophen and ibuprofen were administered to 80% of patients for either hyperthermia or pain control. All patients received dopamine ($3 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, n = 95, or $5 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, n = 5). Eighty-eight percent of patients received milrinone ($0.25\text{-}1 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), 35% of patients received nitroprusside ($0.5\text{-}5 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), 7% of patients received epinephrine or norepinephrine ($0.01\text{-}0.1 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$), and 26% of patients received bicarbonate to correct a metabolic acidosis.

Data analysis proceeded in 4 distinct phases. Phases I and II were exclusively descriptive, and phases III and IV comprised the inferential part of the study. Phase I consisted of generating simple descriptive statistics for all relevant variables. In phase II mean temperature values (T_{ATR}, T_R, and T_{AX}) were computed and plotted from CICU admission until postoperative hour 120. Difference values between T_{ATR} and simultaneous T_R (T_{ATR} - T_R) and T_{AX} (T_{ATR} - T_{AX}) values were computed and plotted over the same time interval. In phase III T_{ATR} - T_R and T_{ATR} - T_{AX} values were tested for statistical significance, specifically to find the points of greatest difference. In addition, single covariate logistical regression models were used to investigate the relationship between selected variables and T_{ATR}

– T_R and $T_{ATR} - T_{AX}$. Phase IV consisted of testing a number of different single covariate logistic regression models to investigate the relationship between selected factors and the presence or absence of hyperthermia ($T_{ATR} > 38^\circ\text{C}$) and the presence or absence of hypothermia ($T_{ATR} < 36^\circ\text{C}$) both in the operating room and during the first 24 postoperative hours. In addition, a number of linear mixed-effects longitudinal models were used to investigate the relationship between selected CICU variables and T_{ATR} during the first 36 postoperative hours, the period for which we had sample sizes (T_{ATR} , $n = 55$ – 100) large enough to construct meaningful statistical models. Because of the exploratory nature of the study and the paucity of literature on which to base our comparison, all tests were conducted at an unadjusted α level of .05. All data were analyzed with STATA 8.0 (STATA Corp, College Station, Tex).

Results

At the time of the operation, the mean age was 128 ± 166 days, and the mean weight was 5.1 ± 2.4 kg. The most common diagnoses were hypoplastic left heart syndrome (25%), ventricular septal defect (12%), and tetralogy of Fallot (14%). The most common procedures were stage 1 reconstruction (22%); ventricular septal defect closure, including atrioventricular canal (14%); cavopulmonary anastomosis, including bilateral cavopulmonary anastomosis and the Kawashima procedure (19%); and tetralogy of Fallot repair, including pulmonary atresia with aortopulmonary collaterals (15%). Patients can also be separated into anatomic categories previously shown to be associated with outcome¹⁰: 2 ventricles with a normal arch (45%), 2 ventricles with arch obstruction (7%), single ventricle with normal arch (13%), and single ventricle with arch obstruction (35%).

Intraoperative Course

All patients underwent CPB, with a mean bypass time of 85.4 ± 35.7 minutes. DHCA was used in 54 patients, with a mean time of 36.3 ± 14.7 minutes. The mean cooling time was 16.3 ± 9.8 minutes, the minimum T_{NP} was $20.9^\circ\text{C} \pm 4.2^\circ\text{C}$, the minimum T_{ES} was $19.6^\circ\text{C} \pm 4.4^\circ\text{C}$, and the mean warming time was 22.6 ± 6.5 minutes. Modified ultrafiltration was used in 98 patients, with a mean filtration time of 9.5 ± 1.4 minutes. In the operating room, the maximum T_{ATR} ($37.5^\circ\text{C} \pm 0.6^\circ\text{C}$) was significantly higher than both the simultaneous T_{ES} ($36.9^\circ\text{C} \pm 1.9^\circ\text{C}$, $P = .03$) and T_{NP} ($36.3^\circ\text{C} \pm 2.5^\circ\text{C}$, $P < .01$). During warming, hyperthermia ($T_{ATR} > 38^\circ\text{C}$) occurred in 16 patients and was associated with the use of DHCA ($P = .03$) but not with the length of CPB or the anatomic category. A higher minimum temperature was associated with intraoperative hyperthermia (T_{ATR} , $P = .01$; T_{ES} , $P < .01$; and T_{NP} , $P < .01$), as was a shorter warming time ($P = .02$). Weight was not associated with intraoperative hyperthermia.

Postoperative Temperature Course

The postoperative temperature course is shown in Figure 1. The maximum mean ($+ 1$ standard error) (T_{ATR} , $37.6^\circ\text{C} \pm 0.1^\circ\text{C}$), occurred at 4 and 6 hours; the maximum mean (T_R , $37.4^\circ\text{C} \pm 0.2^\circ\text{C}$), occurred at 6 and again at 120 hours; and the mean T_{AX} peaked at $36.6^\circ\text{C} \pm 0.1^\circ\text{C}$ at 4 and 6 hours and again at $36.7^\circ\text{C} \pm 0.1^\circ\text{C}$ at 120 hours after leaving the operating room. Statistically significant relationships were observed between central temperature and several CICU variables. Not surprisingly, the use of acetaminophen ($P < .01$) and the use of nitroprusside ($P = .01$) were both associated with a lower T_{ATR} . Interestingly, a lower T_{ATR} was associated with higher transcutaneous oxygen saturation ($P < .01$).

Central hyperthermia ($T_{ATR} > 38^\circ\text{C}$) occurred in 48 patients during the first 24 hours in the CICU. This was seen most commonly during the third and fourth (26%) postoperative hours. T_R was greater than 38°C in 36 patients and T_{AX} was greater than 38°C in only 7 patients during the first 24 postoperative hours. Neither the use of DHCA nor the length of CPB was associated with hyperthermia. Hyperthermia was associated with older age ($P = .01$) and heavier weight ($P < .01$). Central hypothermia ($T_{ATR} < 36^\circ\text{C}$) was seen in 24 patients during the first 24 hours in the CICU. This was most frequently observed on admission ($n = 22$). Central hypothermia was associated with increased blood product administration (per kilogram, $P < .01$). In general, blood products were not warmed before transfusion, and the data do not enable determination as to whether administration of the blood products resulted in lower temperature or whether lower temperature was associated with increased bleeding.

Intracardiac Versus Traditional Monitoring

Statistically significant differences were noted between the intracardiac and rectal temperature ($T_{ATR} - T_R$) over the first 80 postoperative hours ($P < .01$, Figure 2). The maximum mean ($+ 1$ standard error) difference was $0.5^\circ\text{C} \pm 0.02^\circ\text{C}$, which occurred at the first postoperative hour. T_{AX} was also significantly lower than the intracardiac temperatures ($T_{ATR} - T_{AX}$) over the first 120 postoperative hours ($P < .01$, Figure 2). This maximum mean $T_{ATR} - T_{AX}$ value was $1.1^\circ\text{C} \pm 0.02^\circ\text{C}$, and this occurred at the 20th postoperative hour. There was a significant inverse correlation between the use of nitroprusside and $T_{ATR} - T_R$ value ($P = .01$). Similarly, there was a significant correlation between a greater base deficit and a larger temperature difference $T_{ATR} - T_{AX}$ value, ($P < .01$).

Discussion

Survival for repair and palliations of newborn congenital heart disease has improved dramatically over the past few decades. Current surgical mortality for complex lesions,

A

B

Figure 1. Temperature measurements are shown in degrees Celsius over the first 120 hours (A) and 36 postoperative hours (B). The data are presented as means with standard errors. *CICU*, Cardiac intensive care unit.

Figure 2. The difference between intracardiac and rectal temperatures ($T_{ATR} - T_R$) in degrees Celsius and intracardiac and axillary temperatures ($T_{ATR} - T_{AX}$) in degrees Celsius is shown over the first 48 postoperative hours. The data are presented as mean values with standard error bars. The difference between intracardiac and rectal temperatures was significant over all data points ($P < .01$), with particular significance over the first 28 hours ($P < .0001$). The difference between intracardiac and axillary temperatures was significant over all data points ($P < .0001$). *CICU*, Cardiac intensive care unit.

such as hypoplastic left heart syndrome, is reported at less than 5%.^{1,11} Both clinical management and research now focus on minimizing associated morbidities and optimizing neurologic outcomes.

Cerebral hypothermia has been shown to be an important component of neurologic protection during the circulatory arrest period sometimes necessary for repair or palliation of complex newborn congenital heart lesions.² Studies demonstrate the importance of temperature during reperfusion and recovery after warm cerebral ischemia. In animal models 24 to 48 hours of moderate postischemia hypothermia (32°C–34.8°C) significantly improved results comparing behavior and neuronal histopathology with those of animals managed with normothermia.^{3–5} In adult clinical trials induced hypothermia (32°C–34°C) after cardiac arrest has been shown to improve neurologic outcome and decrease mortality.^{6,7} Recent neonatal trials have evaluated the safety and effect on neurologic outcome of mild hypothermia (34.5°C) in term infants after perinatal asphyxia.^{12,13} Neurologic follow-up indicated a trend toward improved out-

come with cooling.¹² Patients tolerated the cooling well, with only relative bradycardia noted in the comparison trials; however, in small case-controlled trials the incidences of hypotension, metabolic acidosis, infection, and hypoglycemia were not increased. In a noncontrolled neonatal trial ($n = 16$, $T_R = 33.2^\circ\text{C} \pm 0.6^\circ\text{C}$) an increased metabolic acidosis and higher blood lactate level were noted with hypothermia.¹⁴ Less encouraging, in a large series of adults after coronary artery bypass surgery performed with normothermic CPB, those with lower temperatures ($<36^\circ\text{C}$, bladder) showed increased mortality, longer time to endotracheal extubation, increased transfusion requirement, and greater hospital length of stay.¹⁵

The benefits of temperature management after hypothermic circulatory arrest are less defined. A recent porcine animal model suggested detrimental effects of moderate hypothermia (32°C, rectal) compared with normothermia (37°C, rectal).⁸ The higher 7-day mortality in the hypothermia group (30% vs 70%, $P = .08$) limited neurologic evaluation. During the first 4 postoperative hours, oxygen

extraction was significantly less during hypothermia; however, the groups were not controlled for arterial pH or hemoglobin. Although limited by low numbers, the study raises some concerns about postoperative hypothermia. A recent retrospective review of the Boston Circulatory Arrest Trial looked at the effect of a normothermia to mild hypothermia postoperative temperature strategy on long-term neurologic outcome. In this cohort of children ($n = 329$) who underwent infant congenital heart surgery (95% with DHCA) during the first 36 postoperative hours, they reported only 6% of all recorded temperatures greater than 38°C (rectal) and 39% of recorded temperatures between 35.5°C and 36°C. The authors found no significant association between postoperative temperature and neurodevelopmental evaluation at 1 year ($n = 244$) and 4 years ($n = 156$) using a normothermic postoperative temperature strategy.⁹

Although the clinical effect of a hypothermic temperature strategy on neurologic outcome after DHCA remains uncertain, evidence indicates that hyperthermia should be avoided. Animal models demonstrate that even mild hyperthermia ($>38^{\circ}\text{C}$) after either warm ischemia¹⁶ or DHCA¹⁷ can be associated with worsened neurologic outcome. We found that although the incidence of postoperative hyperthermia ($>38^{\circ}\text{C}$) was relatively low by conventional measurements (T_R , 35% of patients; T_{AX} , 7% of patients), by tracking core temperature with an intracardiac thermister catheter, we found nearly half the patients had postoperative hyperthermia. Clearly conventional temperature monitoring will underestimate the degree and frequency of central hyperthermia in infants after cardiac surgery. Older age and heavier weight were risk factors associated with postoperative hyperthermia.

Temperature trends immediately (<6 hours) after cardiac surgery in children have been previously reported.^{2,18} Both studies found that temperature increased over the first 4 to 6 hours after bypass. Our extended temperature evaluation demonstrated that postoperative temperature peaks at 4 to 6 hours after CICU admission. The secondary increase seen in T_R and T_{AX} at postoperative hour 120 most likely reflects the thermostat for the normothermic temperature management shifting from central to rectal and axillary as the intracardiac catheters were removed ($n = 14$ at hour 120).

Animal models have shown that intracranial temperature is significantly greater than sites at which temperature is routinely monitored clinically.¹⁹ T_R correlates well with intra-cranial temperature ($r = 0.91$, $P < .0001$) but underestimates the directly measured brain temperature by 0.2°C to 0.7°C. Clinical studies have shown statistically higher jugular venous bulb temperature compared with T_R , T_{ES} , and tympanic temperature.^{2,20} Similarly, we found that intracardiac temperature was significantly higher than both T_R and T_{AX} over the first 80 and 120 postoperative hours,

respectively. $T_{ATR} - T_R$ value was most pronounced during the first few hours after leaving the operating room. This difference between central and T_R inversely correlated with the use of nitroprusside. These findings might reflect low cardiac output and increased vascular resistance. The time frame of low cardiac output is consistent with that seen in previous reports.²¹

Because this study was observational, its limitations include the decrease in power over time as intracardiac catheters were removed when clinically indicated. In addition, patients were not randomized to different temperature strategies, and outcome measures are not evaluated.

Our data demonstrate the importance of measuring central temperature. T_R significantly underestimates central temperature in the first 80 hours after cardiac surgery with CPB in infants less than 2 years of age. This is of clinical importance as a strategy to avoid hyperthermia. Further prospective trials are needed to address the effect of postoperative temperature management on morbidity and neurologic outcomes.

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