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Cerebral Hyperthermia in Children after Cardiopulmonary Bypass

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Background: **Cerebral hyperthermia after hypothermic cardiopulmonary bypass has been poorly documented for adults and never in children. This study was designed to monitor brain temperature during and up to 6 h after cardiopulmonary bypass in infants and children.**

Methods: **Fifteen infants and children, between 3 months and 6 yr of age, were studied. A right retrograde jugular bulb catheter was used to measure the jugular venous bulb temperature (JVBT) during the procedure and the first 6 h in the critical care unit. The temperature of the blood from the bypass machine was measured at the aorta through the cannula using an indwelling temperature probe. All data were acquired every minute.**

Results: **The age of the patients ranged from 3 to 71 months (median, 15 months). The mean weight was 11.5 ± 8.4 kg. The mean JVBT recorded at the end of cardiopulmonary bypass was 36.9 ± 1.4°C but reached 39.6 ± 0.8°C after six h ($P < 0.01$). The kinetics of brain rewarming was determined by the slope of the mean JVBT and corresponded to $y \pm 0.006\times + 37.21$ ($r^2 = 0.97$). The JVBT differed from the tympanic temperature after 200 min ($P < 0.01$) and the lower esophageal ($P < 0.05$) and rectal ($P < 0.001$) temperatures after 300 min. After 6 h, the tympanic, rectal, and lower esophageal temperatures were 37.8 ± 0.9, 37.7 ± 0.6, and 38.4 ± 0.7°C, respectively, whereas the JVBT was 39.6 ± 0.8°C ($P < 0.001$). However, the correlation coefficients between the JVBT and the tympanic, rectal, and esophageal temperatures were 0.98, 0.85, and 0.97, respectively. No complications were recorded with placement of the jugular bulb catheter.**

Conclusions: **Mean JVBT was significantly increased over the mean core temperature at all times from rewarming by cardiopulmonary bypass onward. Although the lower esophageal, rectal, and tympanic temperatures correlated well with JVBT, all three failed to reflect JVBT during recovery. This observation might help to elucidate factors involved in the functional and structural neurologic injury known to occur in pediatric patients. (Key words: Jugular bulb catheterization; pediatric cardiac anesthesia; temperature monitoring.)**

WITH major advances in surgical, anesthetic, and cardiopulmonary bypass technology, the mortality rate for repair of congenital heart disease (CHD) has been reduced to 5% in many centers. The most serious risk to the long-term health and well-being of children with CHD is neurologic damage.[1] The mechanisms of injury are multifactorial, and up to 25% of children have residual neurological sequelae.[1–3]

The cerebral metabolic rate is significantly higher in healthy children than in adults,[4,5] and hypothermia re-

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mains the mainstay of therapy to reduce cellular metabolism and the oxygen requirement of the brain. The decrease in cerebral metabolic rate with decreased temperature is an exponential relation in children.[6,7] The relations between the various mechanisms of cerebral injury are not understood well.[8] Kurth *et al.*[9] suggested, using a piglet model of deep hypothermia, that thermal gradients of several degrees within brain tissue may exist and may contribute to brain damage. These differences in brain tissue temperature could worsen ischemic damage.[10] Wass *et al.*[11] demonstrated in a canine model of complete cerebral ischemia that small, clinically relevant changes in temperature of 1 or 2°C during rewarming resulted in significant alterations in postischemic neurologic function and cerebral histopathology. In a brief communication of 10 adults undergoing cardiopulmonary bypass (CPB), cerebral hyperthermia was documented after 15 min of rewarming using hyperthermic CPB.[12] Better monitoring of brain temperature to minimize cerebral hyperthermia might be associated with a reduction in cerebral morbidity.[13]

These observations raise the concern that brain temperature might be increased above core temperature in the immediate postoperative period in children undergoing CPB. This study was designed to prospectively monitor jugular bulb and core temperature during and up to 6 h after CPB and to determine the rewarming kinetics of brain temperature in infants and children undergoing CPB.

Methods

Patient Inclusion

After obtaining scientific and ethical approval of the Human Subjects Review Committee of the Hospital for Sick Children and written informed consent, 15 infants and children, American Society of Anesthesiologists physical status II or III, between 3 months and 6 yr of age, undergoing elective repair of CHD necessitating mild to moderate hypothermic CPB, were studied. All patients included in this observational, prospective study had been full-term. Preoperative exclusion criteria included children undergoing palliative procedures, patients with known neurologic disorders, or family history of malignant hyperthermia. Children requiring significant inotropic support for low cardiac output, defined by the administration of dopamine (more than 15 $\mu g \cdot kg^{-1} \cdot h^{-1}$) or the presence of poor myocardial contractility seen during transesophageal echocardiography (TEE), and those with major postoperative hemorrhage (> 50% of the circulating volume) would have been excluded.

Anesthetic Management

Premedication and induction of anesthesia was left to the discretion of the anesthetist, with the understanding that the child's trachea would remain intubated for 6 h postoperatively. At arrival in the operating room, routine monitoring devices were applied to the patient. Anesthesia was induced with use of either an inhalational agent or fentanyl (10–30 μg/kg) and thiopental (up to 5 mg/kg) and was maintained with either a volatile agent or midazolam and a supplemental narcotic as necessary. Muscular relaxation was achieved using pancuronium (0.2 mg/kg). A maximum of 1 minimum alveolar concentration (MAC) of volatile anesthetic (end-tidal) was administered. When necessary, patients received sodium nitroprusside (2–5 μg/kg) for peripheral vasodilation and 1% isoflurane during CPB according to level of mean arterial pressure. CPB was conducted in the routine fashion used at The Hospital for Sick Children and the University of Toronto, with flow rates of 100–150 ml/kg and alpha-stat *p*H management with a arterial partial pressure of carbon dioxide ($Paco_2$) at 40–45 for moderate hypothermic CPB. At weaning from CPB, inotropic agents were administered at the discretion of the anesthetist or the surgeon. Propofol was used postoperatively to provide sedation in those children suitable for early tracheal extubation. Invasive monitoring consisted of an indwelling arterial catheter for continuous blood pressure and arterial blood gas analysis, a central venous catheter, and a right retrograde jugular bulb catheter. The catheter positioned within the jugular bulb consisted of a 22-gauge (0.48 mm ID) catheter (Arrow, Reading, PA) and was inserted using a technique previously described.[14] The use of a right jugular bulb catheter allowed continuous measurement of cerebral venous blood temperature during the study period.

Study Protocol

The room temperature was set at 17°C, and the heating blanket was not used before the institution of CPB. The lowest temperature of the child during CPB was chosen according to the preference of the surgeon and monitored from the rectal temperature probe. The child was rewarmed using CPB until the rectal temperature was 35°C and the repair of the congenital heart lesion was completed. The temperature of the perfusate was not greater than 37°C at any time. The heating blanket

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was set to 42°C, and a convective warming system (Bair Hugger, Eden Prairie, MN) turned to medium temperature. The convective heat surface warmer was turned off when the rectal temperature reached 35°C. The room temperature was increased to 22°C. Modified ultrafiltration was performed on all children for a maximum of 20 min or until the circuit was empty. All patients were transferred to the critical care unit. Intermittent positive-pressure ventilation and muscle paralysis were maintained for a minimum period of 6 h. No external warming sources were used during the first 6 h postoperatively. All patients were monitored according to the critical care unit protocol with use of a rectal temperature probe and received paracetamol or the application of ice on their heads if the temperature reached 38.5°C. The nurse caring for the patient was not aware of the JVBT during the study period.

Temperature probes (Mallinckrodt, St. Louis, MO) were placed in the following sites: in the rectum, in the esophagus, on skin surfaces, in the tympanic membrane, and in the axilla for the duration of the procedure and for the first 6 h after admission to the critical care unit. Skin surface temperature sites included the toe, thigh, calf, finger, forearm, and forehead. All temperature probes were fast-response thermocouples. The temperature recording of the jugular venous bulb was obtained using a type T, copper-constantan thermocouple microprobe (Columbus Instruments, Columbus, OH) with a diameter of 0.41 mm, a time constant of 0.08 s, and a precision of 0.1°C (range, 0°C–50°C). The thermocouple was advanced within the jugular bulb catheter to avoid coiling of the tip during insertion or downward displacement by the venous flow within the jugular vein. The final position of the thermocouple was confirmed radiologically in all patients. The temperature of the blood returning to the patient was measured using a thermocouple inserted into the aortic cannula (Mallinckrodt). The time from induction of anesthesia to surgical preparation was noted. The minimum temperature achieved during CPB and the duration of time at that temperature was recorded. The duration of active rewarming, defined as the beginning of rewarming until the end of the CPB, was also monitored and recorded electronically. This period of time does not represent the time taken to rewarm to 35°C, but rather to complete the repair. However, it represents the total duration of heat energy transfer to the child. All temperature data were monitored continuously and recorded on a computer database for further analysis. The temperature data acquisition interface (Columbus Instruments) was calibrated every week. All data were acquired every minute for the duration of the study period, which was discontinued after 6 h in the critical care unit.

Statistical Analysis

All data with parametric values are expressed as the mean ± SD. The number of patients needed to identify a clinically relevant increase in brain temperature postoperatively was based on the expectation to observe a difference between JVBT and tympanic temperature greater than 1.0°C. This determination was calculated based on a statistical power of 0.8, an α of 0.05, and a β of 0.2. A total of 12 patients was suggested. Fifteen patients were studied to account for methodologic difficulties that could have led to exclusion from the study. Mean jugular bulb and tympanic and esophageal temperatures were analyzed using analysis of variance and the Dunnett test for multiple comparisons, with the temperature recorded at the end of the rewarming period in the operating room and subsequently every 100 min until completion of the study. Data analysis between different temperature sites at similar times was analyzed using analysis of variance and the Student-Newman-Keuls test for multiple comparisons. The JVBT rewarming kinetics for all patients were analyzed using linear regression analysis, and the coefficient of determination (r^2) was determined. A $P < 0.05$ was used to express statistical significance.

Results

Fifteen patients were enrolled and studied. Demographic data for all patients are summarized in table 1. The median age was 15 months (range, 3 to 71 months), and the mean weight was 11.5 ± 8.4 kg. The duration of rewarming and the minimum temperature during CPB are also reported in table 1. No complications associated with the study were noted.

Figure 1 shows the temperature profile recorded from patient 8 (see table 1). The JVBT increased continuously after rewarming and for the next 6 h to reach 39.2°C. The coefficient of correlation between the JVBT and the lower esophageal, rectal, and tympanic temperatures were 0.97, 0.85, and 0.98, respectively.

Figure 2 shows the temperature:time relation obtained for each individual patient and the mean JVBT. The mean temperature recorded at the end of CPB was 36.9 ± 1.3°C but reached 39.6 ± 0.8°C at the end of the study period ($P < 0.01$). The JVBTs recorded after 200 and 300

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Table 1. Demographic and Study Data

Patients (No.)	Age (months)	Weight (kg)	Sex (M/F)	Surgical Procedure	CPB Rewarming to Weaning (min)	Minimum Temperature (°C)
1	5.4	14	M	TOF	61	25
2	4.5	4.6	F	VSD	31	26.7
3	67	32	M	Arch repair	68	28
4	31.5	14	M	VSD	26	30
5	18.5	9.2	F	TOF	38	30
6	3	4.1	F	VSD	28	30
7	4.5	5.4	M	TOF	38	30
8	4.75	5.9	F	VSD, ASD	39	30
9	51	19	M	VSD, ASD	44	25
10	10	5.9	F	VSD	47	25
11	15	5.3	F	DORV	55	25
12	71	32.2	M	Conduit replacement	50	30
13	18	7.5	M	AVSD	76	30
14	15.5	8.1	M	Rastelli	126	25
15	4.5	4.9	M	AVSD	49	25

ASD = atrial septal defect; AVSD = atrioventricular septal defect; CPB = cardiopulmonary bypass; DORV = double outlet right ventricle; minimum temperature = minimum rectal temperature recorded during cardiopulmonary bypass; TOF = tetralogy of fallot; VSD = ventricular septal defect.

min were also statistically different from the temperature obtained at the end of the rewarming period (38.6 ± 0.9 and 39.3 ± 0.8°C, respectively; $P < 0.01$) The JVBT variability decreased progressively as the brain temperature became hyperthermic from 1.4°C at the end of the rewarming period to 0.8°C at the end of the study period. The kinetics of rewarming of the brain in the postoperative period was determined by the slope of the mean JVBT and corresponded to y = 0.006× + 37.21. The coefficient of determination of the temperature:time relation was highly significant ($r^2 = 0.97$). In one pa

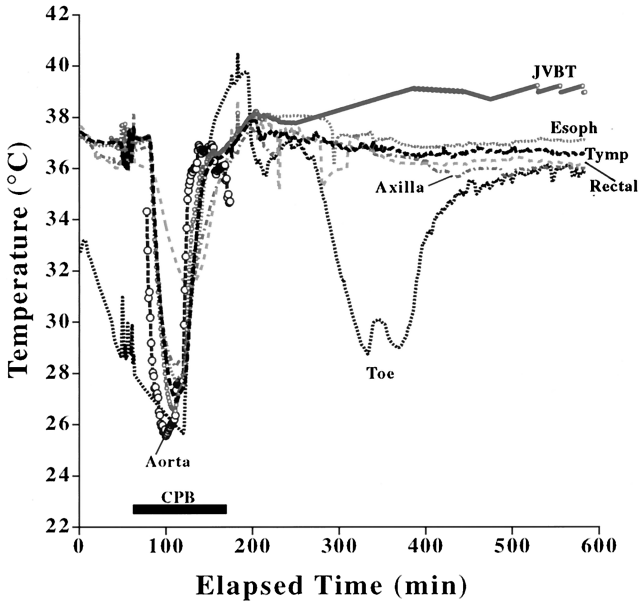

Fig. 1. Graphic presentation of progressive temperature changes during cardiopulmonary bypass and deep hypothermia for one patient. The temperatures from six monitoring sites are plotted every minute. JVBT = jugular venous bulb temperature; esoph = lower esophageal temperature; Tymp = tympanic membrane and the outer ear canal; CPB = period corresponding to cardiopulmonary bypass.

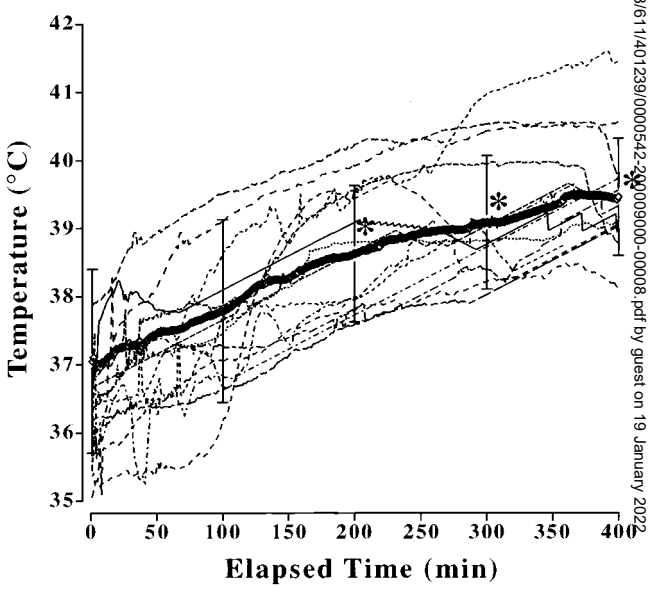

Fig. 2. Graphic depiction of the jugular venous bulb temperature:time relation, recorded during the last 400 min of the study, of 15 patients. It includes the last 40 min in the operating room and the next 6 h in the critical care unit. The thicker lines represent the mean value for all patients, with SD shown at an interval of 100 min. All data are recorded every minute for the duration of the study period. *Statistical difference between all points and temperature at the end of rewarming in the operating room ($P < 0.01$).

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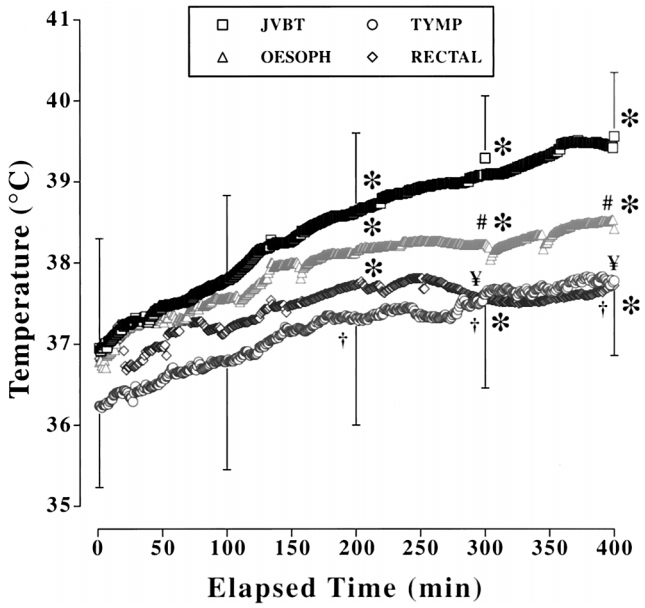

Fig. 3. Graphic depiction of mean jugular venous bulb temperature (JVBT) and lower oesophageal and tympanic temperature: time relation, recorded during the last 400 min of the study, for 15 patients. It includes the last 40 min in the operating room and the next 6 h in the critical care unit. *Statistical difference with the baseline values for each temperature site; #statistical difference between lower esophagus and JVBT; †statistical differences between tympanic temperature and JVBT; ¥ shows rectal temperature differs significantly from JVBT. There were no differences between lower esophageal, rectal, and tympanic temperatures. The SD for the esophageal and rectal temperatures have been omitted for clarity.

tient, JVBT was as high as 41.4°C at the end of the sixth hour, whereas the tympanic and rectal temperatures were 39.9 and 36.9°C, respectively.

Figure 3 shows a comparison between the JVBT and the lower esophageal, rectal, and tympanic temperatures. Although there were no statistical differences between each site at the end of CPB and rewarming, JVBT continued to increase progressively to become statistically different from tympanic temperature after 200 min ($P < 0.05$) and from lower esophageal ($P < 0.05$) and rectal ($P < 0.001$) temperatures after 300 min of the recovery period. The temperature of the lower esophageal probe was 38.4 ± 0.7°C at the end of the study period, which was significantly different from the JVBT at 39.6 ± 0.8°C ($P < 0.05$). After 6 h of recording, the tympanic and rectal temperatures reached a maximum of 37.8 ± 0.9 and 37.7 ± 0.6°C, respectively, which was also different from the JVBT ($P < 0.001$). There were no differences among the esophageal, rectal, and tympanic temperatures during the 6 h of recovery in the intensive care unit.

Discussion

In this study, significant jugular venous bulb hyperthermia occurred in all infants and children after hypothermic cardiopulmonary bypass. Mean JVBT was significantly higher than mean core temperature between 2 and 6 h. Although the correlation between the lower esophageal, rectal, and tympanic temperatures showed a close approximation with JVBT during the recovery period, the lower esophageal and rectal temperature sites did not accurately reflect the change in brain temperature after 2 or 3 h, whereas the tympanic temperature did not reflect the changes in JVBT.

The cerebral metabolic rate of the brain is one of the highest in the body and, as a result, heat is produced.[15,16] The normal brain temperature is an average of 0.5°C warmer than the core temperature.[17–19] However, the increase in JVBT observed in this study cannot be explained simply on this basis. It is possible that this increase in temperature also may be associated with surgery or the consequences of hypothermia alone. This observational study lacks the presence of a non-CPB control group. Alternatively, there is evidence that CPB could be responsible for the recorded increase in JVBT recorded. Cardiac surgery and CPB activate a systemic inflammatory response characterized clinically by systemic vasodilation, hyperthermia, postoperative bleeding, and reperfusion injury.[16,17] It has been shown in a study of 20 children undergoing CPB that removing inflammatory mediators using zero-balanced hemofiltration resulted in lower maximum body temperature in the first 24 h postoperatively.[20] Although they did not measure brain or jugular bulb temperature, these observations correlate with the current study. It may be that cerebral hyperthermia occurs as a result of increased endogenous pyrogens, such as cytokines.

The first hours after CPB in infants and children are critical. Previous investigators studied pediatric patients undergoing CPB and speculated that some patients could be at risk of cerebral ischemia postoperatively because of the presence of uncoupling of cerebral blood flow and cerebral metabolic rate for oxygen (CMr_{O_2}).[22] Burrows *et al.*[23] studied 21 neonates and infants undergoing CPB and deep hypothermia circulatory arrest and reported significant increases in anterior fontanel pressure at the end of rewarming. These authors correlated this increase in intracranial pressure with the delayed return of cerebral electrical activity and showed that the duration of the increase correlated with the time taken for the visual evoked potentials to reappear. O'Hare *et al.*[24]

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studied 10 infants undergoing deep hypothermia circulatory arrest and reported a significant decrease in cerebral blood flow velocity until 6 h postoperatively, despite optimal cerebral perfusion pressure. Although the current study did not investigate patients undergoing deep hypothermia circulatory arrest, neurologic injury is known to occur during CPB.[25] Cerebral hyperthermia might important in the presence of an existing brain injury. It has been shown that brain temperature increases after cerebral ischemia, despite normal ambient and core body temperature.[26]

Experiments have shown that the central nervous system is sensitive to heat.[27] Shum-Tim *et al.*,[28] using a piglet model, reported that cerebral hyperthermia (40°C) was associated with persistent deterioration of neurobehavioral outcome after ischemia, and Kuroiwa *et al.*[29] confirmed that such hyperthermic episodes are implicated in the exacerbation of neurologic injury. Studies of the pathologic changes in the human brain have shown that, within 6 h of whole-body hyperthermia (40°C), the cerebral cortex becomes congested and degenerative changes in the neurons are prominent.[27] The effects of cerebral hyperthermia on the cerebellum are more serious and independent of the duration of the heat exposure.[27] Previous studies of focal ischemia in animals showed a direct correlation between elevated intracerebral temperature and worsened outcome.[11,30] Temperature increases of 1 or 2°C resulted in a significant deterioration of neurologic function, which correlated with histopathologic disease lesions.[11]

Cerebral hyperthermia at 40°C has been shown to increase extracellular glutamate concentration in cats after ischemia.[31] Excitatory amino acid receptors are present at birth and their concentrations increase drastically during the first few weeks of life.[32–34] The level of these excitatory amino acids in a 3-month-old infant approximates the adult concentration. The occurrence of seizures in infants after cardiac surgery has been suggested to caused by excitotoxic mechanisms *via* neuronal injury and the release of excitatory amino acids.[3] In a recent article, which reported use of astrocyte cell cultures during and after rewarming with sustained moderate hyperthermia (38.5°C), a continuous and significant increase in extracellular glutamate was seen.[35] This astrocytic dysfunction and the resultant accumulation of extracellular glutamate may account for the observed neurologic dysfunction seen in infants after repair of CHD. Marked cerebral swelling, mainly cortical in origin, has been documented by use of magnetic resonance imaging immediately after hypothermic (28°C) and normothermic CPB.[36,37] In an editorial about brain protection during anesthesia, Drummond[38] raised concerns about the occasional use of hyperthermic perfusate during rewarming and suggested that iatrogenic hyperthermia contributes to the substantial incidence of neuropsychiatric dysfunction observed after CPB in adults. In the current study, cerebral hyperthermia occurred independently of the perfusate temperature.

Potential methodologic flaws in the current study include accuracy in positioning of the jugular bulb catheter and the reliability of this site to monitor global brain temperature. In the supine position, the right jugular bulb and vein usually are larger than the left bulb and vein and are known to drain the majority of the venous blood from both cerebral hemispheres, whereas the flow through the paravertebral plexus is minimal.[39,40] Although it may be assumed that JVBT does not represent the temperature of the brain, the value of its monitoring in the current study is based on the second law of thermodynamics. The temperature recorded in the venous blood cannot be greater than the brain temperature itself. This was confirmed by a previous study that used direct measurement of cerebral temperature in head injured patients.[41] It is also known that JVBT does not reflect brain temperature because it measures core temperature as a result of the admixture of extracranial venous blood from the facial and mastoid veins.[41] Finally, jugular venous bulb oxygen saturation during CPB has been reported to be of clinical value because it is a measure of cerebral blood flow.[42]

It has been suggested that "deep in the esophagus" could correlate with brain temperature.[15] It has also been suggested that lower esophageal temperature readings provide an approximate indication of the cerebral temperature in the absence of an open thorax or a rapid transfusion of cold blood.[18] In the current study, the lower esophageal temperature probe followed closely the temperature of the jugular bulb after rewarming but failed after 2 h to reflect it accurately at higher temperatures. Mechanical ventilation can significantly affect the temperature of the esophagus.[43]

The tympanic membrane temperature did not correlate with JVBT. Temperature probes used in this context do not always touch the tympanum because of the presence of cerumen or because of the small ear canal of children. This results in delayed response time and inaccuracy. Furthermore, it has been shown that convective air flow applied to the face of the patient decreases,[15] or radiant heating of the head increases,[44] tympanic temperature without affecting brain temperature. None of

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the patients in the current study were exposed to an external source of heating, either convective or radiating, during the initial 6 h in the critical care unit. They were treated for systemic hyperthermia when the rectal temperature probe recorded a temperature greater than 38.5°C, at which time the patient either received paracetamol or the application of ice packs on the head.

The importance of maintaining normothermia has been a fundamental premise in the neonatal and cardiac intensive care unit for many years.[28] This has led to the application of aggressive rewarming techniques for even modest degrees of hypothermia, such as occur frequently after CPB.[28] To our knowledge, this is the first study of infants and children that shows a significant increase in JVBT during the first 6 h of recovery after CHD repairs during CPB. Whether CPB, hypothermia, or surgery alone is responsible for this increase in temperature seen in this pediatric population is unclear. No matter what the cause of neurologic injury after repair of CHD, ample evidence in animal studies suggests that cerebral hyperthermia worsens neurologic outcome.

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References

1. du Plessis A: Neurologic complications of cardiac disease in the newborn. Clin Perinatol 1997; 24:807–26

2. Ferry PC: Neurologic sequelae of open-heart surgery in children. An "irritating question." Am J Dis Child 1990; 144:369–73

3. Newburger JW, Jonas RA, Wernovsky G, Wypij D, Hickey PR, Kuban KC, Farrell DM, Holmes GL, Helmers SL, Constantinou J, Carrazana E, Barlow J, Walsh A, Lucius K, Share J, Wessel D, Hanley F, Mayer JJ, Castaneda A, Ware J: A comparison of the perioperative neurologic effects of hypothermic circulatory arrest versus low-flow cardiopulmonary bypass in infant heart surgery. N Engl J Med 1993; 329:1057–64

4. Kennedy C, Sokoloff L: An adaptation of nitrous oxide method to the study of the circulation in children: Normal values for cerebral blood flow and cerebral metabolic rate in childhood. J Clin Invest 1957; 36:1130–7

5. Sokoloff L: Circulation and energy metabolism of the brain, Basic Neurochemistry: Molecular, Cellular and Medical Aspects. Edited by Siegel G, Agranoff B, Albers R, Molinoff P. New York, Raven Press, 1989, pp 565–91

6. Greeley WJ, Kern FH, Ungerleider RM, Boyd Jd, Quill T, Smith LR, Baldwin B, Reves JG: The effect of hypothermic cardiopulmonary bypass and total circulatory arrest on cerebral metabolism in neonates, infants, and children. J Thorac Cardiovasc Surg 1991; 101:783–94

7. Hillier SC, Burrows FA, Bissonnette B, Taylor RH: Cerebral hemodynamics in neonates and infants undergoing cardiopulmonary bypass and profound hypothermic circulatory arrest: Assessment by transcranial Doppler sonography. Anesth Analg 1991; 72:723–8

8. du Plessis A: Cerebral hemodynamics and metabolism during infant cardiac surgery. Mechanisms of injury and strategies for protection. J Child Neurol 1997; 12:285–300

9. Kurth CD, O'Rourke MM, O'Hara IB, Uher B: Brain cooling efficiency with pH-stat and alpha-stat cardiopulmonary bypass in newborn pigs. Circulation 1997; 96(suppl 9): II-358–63

10. Sano T, Drummond JC, Patel PM, Grafe MR, Watson JC, Cole DJ: A comparison of the cerebral protective effects of isoflurane and mild hypothermia in a model of incomplete forebrain ischemia in the rat [see comments]. ANESTHESIOLOGY 1992; 76:221–8

11. Wass CT, Lanier WL, Hofer RE, Scheithauer BW, Andrews AG: Temperature changes of > or = 1 degree C alter functional neurologic outcome and histopathology in a canine model of complete cerebral ischemia. ANESTHESIOLOGY 1995; 83:325–35

12. Cook D, Orszulak T, Daly R, Buda D: Cerebral hyperthermia during cardiopulmonary bypass in adults. J Thorac Cardiovasc Surg 1996; 111:268–9

13. Murkin JM: Hypothermic cardiopulmonary bypass—Time for a more temperate approach. Can J Anaesth 1995; 42:663–8

14. Goetting MG, Preston G: Jugular bulb catheterization: Experience with 123 patients. Crit Care Med 1990; 18:1220–3

15. Shiraki K, Sagawa S, Tajima F, Yokota A, Hashimoto M, Brengelmann GL: Independence of brain and tympanic temperatures in an unanesthetized human. J Appl Physiol 1988; 65:482–6

16. Wass CT, Cable DG, Schaff HV, Lanier WL: Anesthetic technique influences brain temperature during cardiopulmonary bypass in dogs. Ann Thorac Surg 1998; 65:454–60

17. Baker MA, Stocking RA, Meehan JP: Thermal relationship between tympanic membrane and hypothalamus in conscious cat and monkey. J Appl Physiol 1972; 32:739–42

18. Whitby JD, Dunkin LJ: Cerebral, oesophageal and nasopharyngeal temperatures. Br J Anaesth 1971; 43:673–6

19. Hayward JN, Baker MA: Role of cerebral arterial blood in the regulation of brain temperature in the monkey. Am J Physiol 1968; 215:389–403

20. Journois D, Israel BD, Pouard P, Rolland B, Silvester W, Vouhe P, Safran D: High-volume, zero-balanced hemofiltration to reduce delayed inflammatory response to cardiopulmonary bypass in children [see comments]. ANESTHESIOLOGY 1996; 85:965–76

21. Greeley WJ, Kern FH, Meliones JN, Ungerleider RM: Effect of deep hypothermia and circulatory arrest on cerebral blood flow and metabolism. Ann Thorac Surg 1993; 56:1464–6

22. Mault JR, Ohtake S, Klingensmith ME, Heinle JS, Greeley WJ, Ungerleider RM: Cerebral metabolism and circulatory arrest: Effects of duration and strategies for protection. Ann Thorac Surg 1993; 55:57–63

23. Burrows FA, Hillier SC, McLeod ME, Iron KS, Taylor MJ: Anterior fontanel pressure and visual evoked potentials in neonates and infants undergoing profound hypothermic circulatory arrest. ANESTHESIOLOGY 1990; 73:632–6

24. O'Hare B, Bissonnette B, Bohn D, Cox P, Williams W: Persistent low cerebral blood flow velocity following profound hypothermic circulatory arrest in infants. Can J Anaesth 1995; 42:964–71

25. Pua HL, Bissonnette B: Cerebral physiology in paediatric cardiopulmonary bypass. Can J Anaesth 1998; 45:960–78

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26. Colbourne F, Nurse SM, Corbett D: Spontaneous postischemic hyperthermia is not required for severe CA1 ischemic damage in gerbils. Brain Res 1993; 623:1–5

27. Sminia P, van der Zee J, Wondergem J, Haveman J: Effect of hyperthermia on the central nervous system: A review. Int J Hyperthermia 1994; 10:1–30

28. Shum-Tim D, Nagashima M, Shinoka T, Bucerius J, Nollert G, Lidov HG, du PA, Laussen PC, Jonas RA: Postischemic hyperthermia exacerbates neurologic injury after deep hyperthermia circulatory arrest. J Thorac Cardiovasc Surg 1998; 116:780–92

29. Kuroiwa T, Bonnekoh P, Hossmann KA: Prevention of postischemic hyperthermia prevents ischemic injury of CA1 neurons in gerbils. J Cereb Blood Flow Metab 1990; 10:550–6

30. Dietrich WD: The importance of brain temperature in cerebral injury. J Neurotrauma 1992; 9:S475–85

31. Tagushi J, Graf R, Wegener C, Rosner G, Saito R, Sato M, Hayakawa T, Heiss W: Hyperthermia augments glutamate accumulation and infarct size in cat focal ischemia. J Cereb Blood Flow Metab 1995; 15:S321–2

32. Insel TR, Miller LP, Gelhard RE: The ontogeny of excitatory amino acid receptors in rat forebrain: I. N-methyl-D-aspartate and quisqualate receptors. Neuroscience 1990; 35:31–43

33. Miller LP, Johnson AE, Gelhard RE, Insel TR: The ontogeny of excitatory amino acid receptors in the rat forebrain: II. Kainic acid receptors. Neuroscience 1990; 35:45–51

34. McDonald JW, Johnston MV: Physiological and pathophysiological roles of excitatory amino acids during central nervous system development. Brain Res Brain Res Rev 1990; 15:41–70

35. Bissonnette B, Pellerin L, Ravussin P, Borel-Daven V, Magistretti P: Deep hypothermia and rewarming alters glutamate levels and glycogen content in cultured astrocytes. ANESTHESIOLOGY 1999; 91:1763–9

36. Harris DN, Bailey SM, Smith PL, Taylor KM, Oatridge A, Bydder GM: Brain swelling in first hour after coronary artery bypass surgery. Lancet 1993; 342:586–7

37. Harris DN, Oatridge A, Dob D, Smith PL, Taylor KM, Bydder GM: Cerebral swelling after normothermic cardiopulmonary bypass. ANESTHESIOLOGY 1998; 88:340–5

38. Drummond JC: Brain protection during anesthesia. A reader's guide. ANESTHESIOLOGY 1993; 79:877–80

39. Andrews PJ, Dearden NM, Miller JD: Jugular bulb cannulation: Description of a cannulation technique and validation of a new continuous monitor. Br J Anaesth 1991; 67:553–8

40. Wilson EM, Halsey JJ, Vitek JJ: Validation of jugular venous flow as an index of total cerebral blood flow. Stroke 1972; 3:300–21

41. Rumana CS, Gopinath SP, Uzura M, Valadka AB, Robertson CS: Brain temperature exceeds systemic temperature in head-injured patients. Crit Care Med 1998; 26:562–7

42. Croughwell ND, Frasco P, Blumenthal JA, Leone BJ, White WD, Reves JG: Warming during cardiopulmonary bypass is associated with jugular bulb desaturation. Ann Thorac Surg 1992; 53:827–32

43. Bissonnette B, Sessler DI, LaFlamme P: Intraoperative temperature monitoring sites in infants and children and the effect of inspiredgas warming on esophageal temperature. Anesth Analg 1989; 69:192–7

44. Marcus P: Some effects of radiant heating of the head on bodie-temperature measurements at the ear. Aerosp Med 1973; 44:403–6

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