JECT. 2010;42:301–304
The Journal of ExtraCorporeal Technology

Patient Directed Bypass: Cooling for Aortic Surgery – A Preliminary Concept

Kenneth Palmer, FRCA; Tim Ridgway, FRCA; Omar Al-Rawi, FRCA; Ian Johnson, DipPerf; Michael Poullis, BSc(Hons), MBBS

The Cardiothoracic Centre Liverpool, Liverpool, United Kingdom

Presented at 48th International Conference of the American Society of ExtraCorporeal Technology, Reno, Nevada, April 28th–May 1st, 2010.

Abstract: No consensus exists as to the temperature to cool to on bypass for surgery involving the aortic arch. Excluding normothermic surgery, which is rarely performed for arch work, circulatory arrest, anterograde, and retrograde cerebral perfusion either in isolation or in combination remain the techniques of "cerebral protection." To date, no account of individual patient body or cerebral function variation is involved. Utilizing an electronic perfusion database we retrospectively analyzed 10 patients undergoing aortic arch work with regard to mixed venous saturations during cooling. Perfusion related variables were registered and uploaded to www.perfsort.net. We regarded a saturation of 100% as being indicative of no oxygen extraction, implying no metabolic activity—the theoretical goal prior to a circulatory arrest period. There is enormous variation in the temperature at which metabolic activity of the body stops. We had a range from 17–25 degrees. Patients were cooled for an average of 6 (SD 3.4) degrees below which oxygen extraction had ceased to occur. Potentially we are adding 111 minutes (SD 62) of unnecessary bypass time. This may imply that excessive cooling is occurring in some individuals undergoing arch surgery. Patient directed cooling for aortic arch surgery may help to reduce the morbidity/physical insult associated with severe hypothermia. This work is very preliminary but may help us to depart from the one size fits all paradigm that exists in current clinical practice. Correlation with bispectral index, electroencephalogram monitoring and neurological outcomes is needed. **Keywords:** cardiopulmonary bypass, aortic, temperature. *JECT. 2010;42:301–304.*

Little consensus exists as to the temperature to cool to on bypass for surgery involving the aortic arch. Every surgeon cools to a different temperature for a given operation, especially so for potential circulatory arrest cases (1). Excluding normothermic surgery, which is rarely performed for arch work, hypothermia, anterograde, and retrograde cerebral perfusion either in isolation or in combination remain the techniques of "cerebral protection" (2).

Prolonged bypass is a known marker for adverse outcomes in cardiac surgery (3). Aortic surgery can be associated with long bypass times secondary to the long periods of cooling and rewarming in addition to the technical nature of the operation. Excessive cooling and thus rewarming increases total CPB time, increasing the inflammatory reaction, platelet and coagulation disorders, and increasing organ ischemia. However inadequate cooling renders organs, particularly the brain, susceptible to irreversible ischemic insult (4).

To date, frequently no account of individual patient variation is involved in the decision as to what temperature to cool to. We speculate that patient directed bypass with regard to cooling for aortic surgery may be beneficial.

METHODS

Utilizing an electronic perfusion database we retrospectively analyzed 10 patients undergoing aortic arch work with regard to mixed venous saturations during cooling. Perfusion related variables were registered and uploaded to www.perfsort.net.

We regarded a saturation of greater than 98% as being indicative of no oxygen extraction, implying no metabolic activity—the theoretical goal prior to a circulatory arrest period. Ninety-eight percent was chosen due to the

Received for publication April 25, 2010; accepted November 16, 2010.
Address correspondence to: Michael Poullis, Consultant Cardiothoracic Surgeon, Liverpool Heart and Chest Hospital, Thomas Drive, Liverpool, L14 3PE. E-mail: mike.poullis@lhch.nhs.uk
The senior author has stated that authors have reported no material, financial, or other relationship with any healthcare-related business or other entity whose products or services are discussed in this paper.

observation that pulse oximeters oscillate between 98% and 100% during active cooling, implying that ischemia and increased oxygen extraction is not the cause of the oscillation. Patient temperature was measured using the nasopharynx and the rectum. The rectal temperature was utilized for this study.

RESULTS

Perfsort Compliance Statement

Study number: P00048. PerfSORT compliance version 1:

Tier 1 Compliance: 100% (Blood pressure, Temperature, Haematocrit, Glucose, Lactate),
Tier 2 Compliance – Equipment and bypass: 80%.

For further details of perfusion data please go to http://www.perfsort.net.

Clinical Study in Patients Undergoing Aortic Surgery

A typical cooling rewarming profile data is shown in Figure 1. None of the patients in our series were inadequately cooled. Comparison of individual patients demonstrated that the rate of cooling/rewarming was highly variable. There seemed to be a general relationship of higher mixed venous saturations being associated with lower temperatures, but great variation existed between the cases.

At 180 minutes a steep drop in mixed venous oxygen saturations occurred. This is secondary to commencement of CPB after a period of circulatory arrest, indicating that an oxygen debt has been incurred during the arrest period.

Temperature that Patients were Cooled to verses Oxygen Extraction

There is enormous variation in the temperature at which metabolic activity of the body stops. We had a range from 17–25 degrees. Patients were cooled for an average of 6 (SD 3.4) degrees below which oxygen extraction had ceased to occur (Figure 2), which was significantly different, $p = .0004$. This may imply that "excessive" cooling is occurring in some individuals undergoing arch surgery.

"Excessive" Cool Time

The time from when oxygen extraction ceased (T1) to the time when cooling to the minimum temperature (T2) occurred was recorded (Figure 3). This demonstrated that potential excessive cooling, (T2-T1) occurred for an average of 71 minutes (SD 56).

"Excessive" Rewarm Time

The time from when rearming (T3) to the time when oxygen extraction ceased on cooling (T4) was recorded (Figure 3). This demonstrated that potential excessive cooling, (T4-T3) occurred for an average of 40 minutes (SD 32).

Total "Excessive" CPB Time

Combining "excessive" cooling and warming times demonstrated that potentially we are adding on average 111 minutes (SD 62) of unnecessary bypass time.

CONCLUSION

Patient directed cooling for aortic arch surgery may help to reduce the morbidity/physical insult associated with severe hypothermia and prolonged bypass. This work

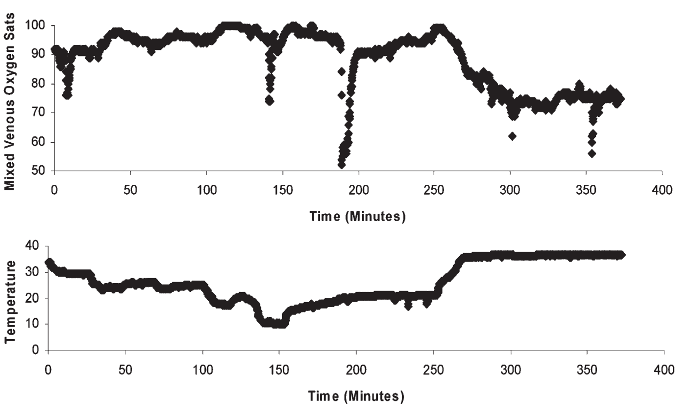

Figure 1. Typical cooling and rewarming profile of a patient undergoing aortic surgery. (A) Temperature profile, (B) Mixed venous oxygen extraction profile.

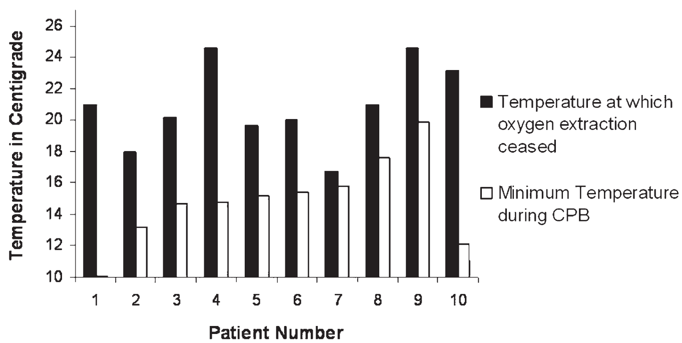

Figure 2. Comparison between temperature at which oxygen extraction ceased and temperature patient was cooled to.

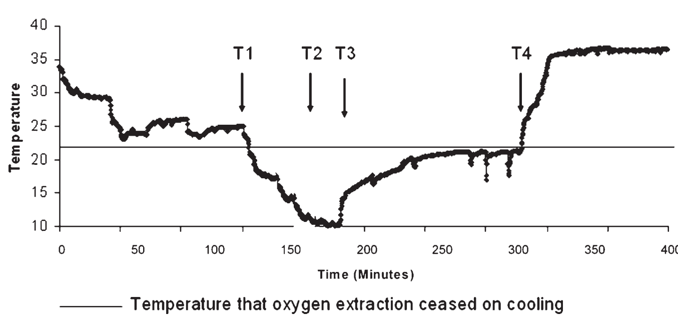

Figure 3. Typical cooling and rewarming profile. The "excessive" cooling (T1 to T2) and rewarming (T3 to T4) was calculated.

is very preliminary but may help us to depart from the one size fits all paradigm that exists in current clinical practice.

A margin of safety is necessary with regard to the target temperature to cool to. This has resulted in the surgical dogma of cooling to between 12 and 16°C, as everyone will have stopped extracting oxygen prior to reaching this temperature. Patient rewarming does occur during surgery due to ambient sources, so how much lower you cool to below the temperature that oxygen extraction ceases remains to be evaluated.

We did not have data on the differentials between jugular bulb, inferior vena caval, and superior vena caval oxygen saturations to evaluate if the cerebral, upper, and lower body may have different "turn off" temperatures. Mixed venous oxygen saturation should not be confused with central venous oxygen saturation, as the latter is prone to mixing errors due to variations in the oxygen saturation of blood in the inferior and superior vena cava (5). During bypass, the mixed venous saturation is measured at the pump so this error is unlikely to be present in our data.

Using mixed venous saturations as a surrogate marker of "tissue quiescence" depends upon the tissues all being perfused, as a lack of perfusion of a tissue bed will not be revealed with this marker. If a tissue bed is not perfused, further cooling will not help, as tissue has to be perfused to cool.

We utilized rectal temperature for this study. Wide variation in monitoring sites (rectal, pharyngeal, esophageal, tympanic, bladder, and venous return) and their cross correlation exists (6). Rectal temperature is widely utilized in aortic surgery as a marker of central temperature, despite its known limitations.

We estimate that bypass in our small series was on average nearly an hour longer than the theoretical minimum. Clearly every case is different and aortic surgery is not as simple as cool, operate, and rewarm, as surgical activity frequently takes place during all three phases. A reduction in time on bypass may help reduce the deleterious effects of cooling and rewarming on organ, platelet, and coagulation factors that are known to occur (7,8). In addition reduced rewarming time secondary to higher turn off temperatures may reduce the urge to increase arterial inflow temperature to decrease the rewarm time.

Opinion is divided between employing circulatory arrest when the electroencephalogram goes flat or cooling to a predetermined temperature (1,9). The increased utilization of selective anterograde cerebral perfusion has increased the number of confounding issues affecting outcomes.

Temperature management is mainly directed at reducing neurological damage. The rate of rewarming and the maximum temperature of rewarming are additional important variables (10). Interestingly little attention is paid to the rate of cooling, which due to Henry's law and Van't Hoff equation, may result in tissue microbubbles, exactly the same reasoning why excessive rates of rewarming should not be used (11). These temperature issues relate to neurological outcomes, and are not patient directed, but based on basic science of cooling and rewarming, hence their exclusion in this concept paper.

Cooling to a temperature at which no oxygen extraction occurs is "safe" for the body and the brain. Cooling to electroencephalogram (EEG) quiescence may stop cerebral damage occurring, but even this is debated. A lack of cerebral activity may occur despite organs of the body still metabolizing when switch off occurs. In addition, EEG quiescence, as a marker of lack of metabolism, can be confounded by anesthetic drugs (12). Cooling to EEG/jugular venous saturations reaching 100%, in combination with mixed venous saturations reaching 100%, may seem prudent. We speculate that patient directed bypass with regard to cooling for aortic surgery maybe beneficial.

Limitations

No correlation with bispectral index, EEG, or neurological outcomes were recorded. In addition, we did not have any lactate or base excess measurements available. Our sample size is small, but clearly demonstrates a significant inter individual variation.

Future Work

Correlation with known techniques of cerebral monitoring and quantitative neurological outcomes is necessary to confirm if the concept of patient directed bypass is clinically correct in a larger cohort of patients. Due to the frequency of aortic surgery, this may need to be multicenter in nature.

ACKNOWLEDGMENT

We gratefully acknowledge the surgical efforts of Aung Oo, Manoj Kudavalli, and Mark Field.

REFERENCES

1. Coselli JS, Crawford ES, Beall AC Jr, Mizrahi EM, Hess KR, Patel VM. Determination of brain temperatures for safe circulatory arrest during cardiovascular operation. Ann Thorac Surg. 1988; 45:638–42.
2. Emrecan B, Tulukoglu E. A current view of cerebral protection in aortic arch repair. J Cardiothorac Vasc Anesth. 2009;23:417–20.
3. Kumle B, Boldt J, Suttner SW, Piper SN, Lehmann A, Blome M. Influence of prolonged cardiopulmonary bypass times on splanchnic perfusion and markers of splanchnic organ function. Ann Thorac Surg. 2003;75:1558–64.
4. Kirshbom PM, Skaryak LA, DiBernardo LR, et al. Effects of aortopulmonary collaterals on cerebral cooling and cerebral metabolic recovery after circulatory arrest. Circulation. 1995;92:490–4.
5. Lorentzen AG, Lindskov C, Sloth E, Jakobsen CJ. Central venous oxygen saturation cannot replace mixed venous saturation in patients undergoing cardiac surgery. J Cardiothorac Vasc Anesth. 2008;22:853–7.

6. Nussmeier NA, Cheng W, Marino M, et al. Temperature during cardiopulmonary bypass: The discrepancies between monitored sites. Anesth Analg. 2006;103:1373–9.
7. Mossad EB, Machado S, Apostolakis J. Bleeding following deep hypothermia and circulatory arrest in children. Semin Cardiothorac Vasc Anesth. 2007;11:34–46.
8. Speziale G, Ferroni P, Ruvolo G, et al. Effect of normothermic versus hypothermic cardiopulmonary bypass on cytokine production and platelet function. J Cardiovasc Surg (Torino). 2000;41:819–27.
9. McCullough JN, Zhang N, Reich DL, et al. Cerebral metabolic suppression during hypothermic circulatory arrest in humans. Ann Thorac Surg. 1999;67:1895–9.
10. Coselli JS, LeMaire SA. Temperature management after hypothermic circulatory arrest. J Thorac Cardiovasc Surg. 2002;123:621–3.
11. Poullis M. Exploring the boundaries of perfusion. Left field: Square tubes and current changes! J Extra Corpor Technol. 2009;41:21–4.
12. San-Juan D, Chiappa KH, Cole AJ. Propofol and the electroencephalogram. Clin Neurophysiol. 2010 (in press).