

# Accuracy of Temperature Measurement in the Cardiopulmonary Bypass Circuit

Richard F. Newland, BSc, CCP(Aust);\* Andrew J. Sanderson, BSc, CCP(Aust);†  
Robert A. Baker, PhD, CCP(Aust)\*

\*Department of Cardiac and Thoracic Surgery, Flinders Medical Centre and Flinders University, Bedford Park; and †Ashford Hospital, Ashford, South Australia

**Abstract:** Oxygenator arterial outlet blood temperature is routinely measured in the cardiopulmonary bypass (CPB) circuit as a surrogate for the temperature of the arterial blood delivered to sensitive organs such as the brain. The aim of this study was to evaluate the accuracy of the temperature thermistors used in the Terumo Capiiox® SX25 oxygenator and to compare the temperature measured at the outlet of the oxygenator using the Capiiox® CX\*TL Luer Thermistor with temperatures measured at distal sites. Five experimental stages were performed in vitro to achieve this aim. Under our experimental conditions, the luer thermistors accurately measured the temperature as referenced by a precision thermometer. In the CPB circuit, the difference between arterial outlet and reference thermometer temperature varied with outlet temperature over-reading at low temperatures

and under reading at high temperatures. There was negligible heat loss ( $-0.4 \pm 0.1^\circ\text{C}$ ) measured at 4.5 m from the arterial outlet. The Terumo Capiiox® CX\*TL Luer Thermistor is an accurate and reliable instrument for measuring temperature when incorporated into the Capiiox Oxygenator. The accuracy in the measurement of temperature using these thermistors is affected by the thermistor immersion depth. Under reading of the arterial blood temperature by approximately  $0.5^\circ\text{C}$  should be considered at normothermic temperatures, to avoid exceeding the maximum arterial blood temperature as described by institutional protocols. The accuracy of blood temperature measurements should be considered for all oxygenator arterial outlet temperature probes. **Keywords:** arterial outlet temperature, measurement accuracy, cardiopulmonary bypass. *JECT. 2005;37:32–37*

Oxygenator arterial outlet blood temperature is commonly measured in the cardiopulmonary bypass (CPB) circuit and may be used as a surrogate for the temperature of the arterial blood delivered to sensitive organs such as the brain. A number of articles have described the deleterious effects of excessively warming the arterial blood (1–5); therefore, the accuracy of this measurement is important to maintain a safe rewarming strategy. The accuracy of thermistors in devices has not been extensively examined in the clinical setting, although manufacturers provide data on the accuracy and sources of error of thermistors (6). Sources of error that are relevant in the CPB circuit include the immersion stem effect (when a portion of the probe is at a different temperature to the sample), dissipation error (caused by excess power output to the thermistor), radiant error (radiant energy directed onto the thermistor), and pipe error (a significant temperature difference between the circuit and the fluid). Limitation of

these errors needs to be considered to maximize the accuracy of temperature measurement in the CPB circuit. The following experimental models were constructed to assess the following:

1. Evaluation of the accuracy of the temperature probes used in the CPB circuit when measuring a precise heat source,
2. Evaluation of the accuracy of the temperature probes when attached to the CPB circuit containing fluid traveling at various flow rates,
3. Evaluation of the accuracy of the temperature probes when attached to the CPB circuit containing fluid traveling at various temperatures,
4. A comparison of temperature measurements obtained at the oxygenator outlet and at various distances from the oxygenator outlet, and finally,
5. Determination of the influence of luer thermistor mounting on the performance of the thermistor.

## MATERIALS AND METHODS

Currently we use the Capiiox® SX25 (Terumo Corporation, Tokyo, Japan) oxygenator for all our CPB proce-

Address correspondence to: Dr Robert A. Baker, Department of Cardiac and Thoracic Surgery, Flinders Medical Centre Bedford Park, South Australia, Australia 5042. E-mail: Rob.Baker@Flinders.edu.au  
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.

dures. This device has an integrated disposable temperature probe connected to the arterial outlet and the venous inlet. Terumo also sells the Capiox® CX\*TL Luer Thermistor as a separate disposable device that attaches to the luer lock of a tubing connector facilitating temperature measurement at any place in the circuit. Both the temperature probe and thermistor are manufactured by YSI Temperature (Dayton, OH). The first stage of the experiment was designed to determine the accuracy of these disposable probes.

### Stage I

The thermal transfer standard is a device manufactured by the biomedical department at Flinders Medical Center. The device is designed to heat a number of test wells to a set temperature. Once this temperature is obtained, the set temperature remains constant once thermal equilibrium is achieved ( $<0.1^{\circ}\text{C}$  temperature fluctuations). The temperature of 0.9% saline heated by the thermal transfer standard was measured using a precision reference thermometer (Instrulab, Dayton, OH). Calibration of the thermometer was reported as 99% occurrence of  $\pm 0.05^{\circ}\text{C}$  (CSIRO, Adelaide, Australia).

The reference thermometer was compared consecutively against nine Capiox® CX\*TL luer thermistor probes (three probes from three different batch numbers). The reference thermometer was adequately immersed into one of the test wells while the thermistors were immersed 6 mm in another test well. The thermistor probes were connected to a Stockert S3 temperature monitor (part number 20-20-00, Stockert, Munich, Germany), and allowed 3 minutes each to achieve thermal equilibrium. Temperatures compared were ambient, 25, 30, 35, and  $38^{\circ}\text{C}$ . The thermal transfer standard was allowed 30 minutes to achieve thermal equilibrium at each temperature with the experimental apparatus positioned in the cardiac operating theatre away from drafts or sources of radiant heat. To verify the calibration of the Stockert temperature monitor, resistances and their corresponding temperature values were obtained from Stockert. An RD5 decade resistance box (Tech Instruments, Japan) was used to apply the various resistances to the lead that attaches to the thermistor.

### Stage II

The second stage determined the accuracy of the inte-

grated probes at various flow rates by comparing the temperatures measured by the integrated probes to those measured by the reference thermometer. The temperature of the fluid (2 liters of 0.9% saline solution) was measured using the reference thermometer inserted into the tubing through a tightly fitted hole, positioned adjacent to the integrated probe and fully immersed to avoid immersion stem effects. Because the reference probe was well inserted and placed at an angle to the direction of the fluid path, there should be no influence on the measurement as a result of boundary layer effects. The temperature was maintained at approximately  $37.5^{\circ}\text{C}$  using a Hemotherm® (Cincinnati Sub-Zero, Cincinnati, OH) heater cooler unit and recirculated using a Stockert S3 roller pump with flow rates set at 0, 1, 2, 3, 4, 5, 6 and 7 L/min. The CPB circuit outlet line consisted of 4 m  $3/8 \times 3/32$  PVC tubing (reconnected to the oxygenator venous reservoir), and a Quart  $40\text{-}\mu\text{m}$  arterial filter (Jostra®, Hirrlingen, Germany; Figure 1).

### Stage III

Stage III compared the accuracy of the integrated temperature probes at various temperatures. Comparisons were made between the temperatures measured by the probes and the temperature of the fluid path inside the tubing adjacent to the probes using the same method as in stage II. Saline was recirculated through the circuit at a flow rate of 3.5 L/min at temperatures of 10, 15, 20, 25, 30, 35, 38, and  $40^{\circ}\text{C}$ . Three different circuits were used in this stage.

### Stage IV

Stage IV determined the difference in temperature measurement between the oxygenator outlet and probes at various distances along the arterial line. Circulated fluid at 3.5 L/min and  $37.5^{\circ}\text{C}$  was measured at the oxygenator arterial outlet and with the luer thermistor fitted into a  $3/8'' \times 3/8''$  luer connector (Dideco, Mirandola, Italy) at distances of 50 cm, 1 m, 1.5 m, 2.0 m, 2.5 m, 3.0 m, 3.5 m, and 4.0 m from the arterial outlet to determine the change in temperature with distance from the oxygenator outlet. The temperature also was measured at the venous inlet at a distance of 4.5 m.

### Stage V

Stage V assessed the temperature measurement by con-

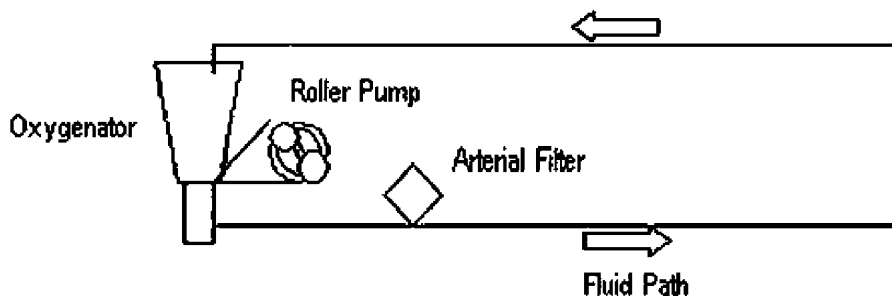


Figure 1. Circuit diagram.

connector type, and the immersion depths of the thermistor in the fluid path of these connectors using the method in stage IV. The arterial outlet, venous inlet (inbuilt thermistors) and venous luer connector on the Capiox® SX25 (adjacent to the venous inlet thermistor) were compared with the luer thermistors mounted in the Dideco and Medtronic (Minneapolis, MN) 3/8" × 3/8" connectors. The immersion depth was measured using a digital dial caliper (Mitutoyo, Kawasaki, Kanagawa, Japan) and a telescopic gauge (Mitutoyo).

## RESULTS

### Stage I: Probe Accuracy

The results obtained by the Terumo probes when compared to the reference temperature probe are illustrated in Figure 2. Results are presented as an average of nine thermistors as we did not observe a difference in results between batches. At ambient temperature ( $21.5 \pm 0.1^\circ\text{C}$ ) the Terumo probes were over reading by  $0.3 \pm 0^\circ\text{C}$ , and as temperature increased to  $39.8 \pm 0^\circ\text{C}$  the probes were under reading by  $0.2 \pm 0.1^\circ\text{C}$ . The probes were most accurate ( $<0.1^\circ\text{C}$  difference) when measurements were obtained between  $29.8$  and  $37.8^\circ\text{C}$ , which correlates well to the temperatures encountered during routine CPB.

### Stage II: Effect of Flow

The average reference temperature to determine the effect of flow was  $37.5 \pm 0.1^\circ\text{C}$ , with an average difference of  $-0.5 \pm 0^\circ\text{C}$  between reference temperature and arterial outlet temperature (Figure 3). These results indicate that although the thermistor was underreading at an average of  $-0.5^\circ\text{C}$ , flow rate did not alter the consistency of the temperature measurement, since all results were within  $0.1^\circ\text{C}$ .

### Stage III: Effect of Temperature

The average difference between arterial outlet and reference thermometer temperature of fluid recirculating at

$3.5$  l/min in three different circuits was between  $0.5 \pm 0.2^\circ\text{C}$  (at  $10.6 \pm 0.1^\circ\text{C}$ ) and  $-0.6 \pm 0^\circ\text{C}$  (at  $39.5 \pm 0^\circ\text{C}$ ; Figure 4).

### Stage IV: Effect of Distance

With fluid recirculated at  $3.5$  L/min at an average of  $37.4 \pm 0.1^\circ\text{C}$ , there was an average difference of  $-1.5 \pm 0.3^\circ\text{C}$  in the temperature measured at all sites  $0.5$ – $4.0$ m distal to the arterial outlet when measured with the luer thermistor fitted into a Dideco  $3/8" \times 3/8"$  luer connector (Figure 5). There was a difference of  $-0.4 \pm 0.1^\circ\text{C}$  measured both at the arterial outlet and at the venous inlet ( $4.5$  m from the outlet).

### Stage V: Effect of Connector Type

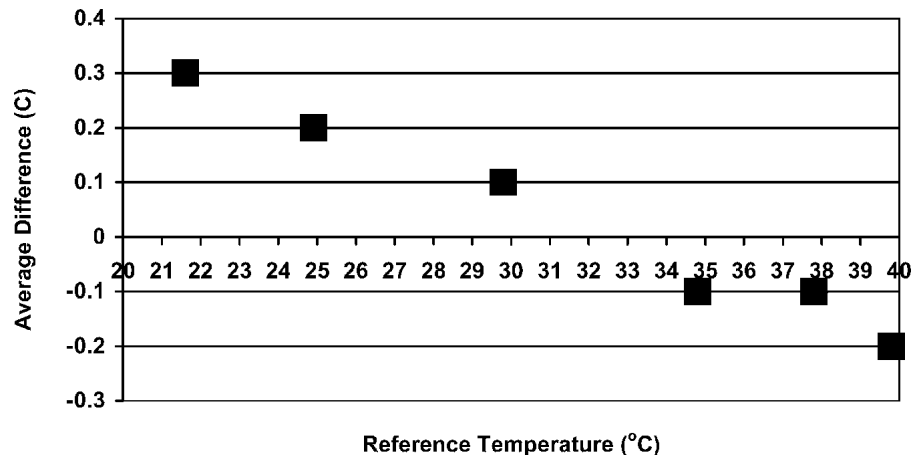
The integrated venous inlet connector had the greatest accuracy, with a difference of  $0.5^\circ\text{C}$  at  $10.1^\circ\text{C}$  and  $-0.6^\circ\text{C}$  at  $39.2^\circ\text{C}$  (Figure 6). The Medtronic and venous luer connectors had a comparable degree of accuracy, and the least accuracy was obtained with the Dideco connector with a difference of  $1.4^\circ\text{C}$  at  $10.1^\circ\text{C}$  and  $-2^\circ\text{C}$  at  $39.2^\circ\text{C}$ .

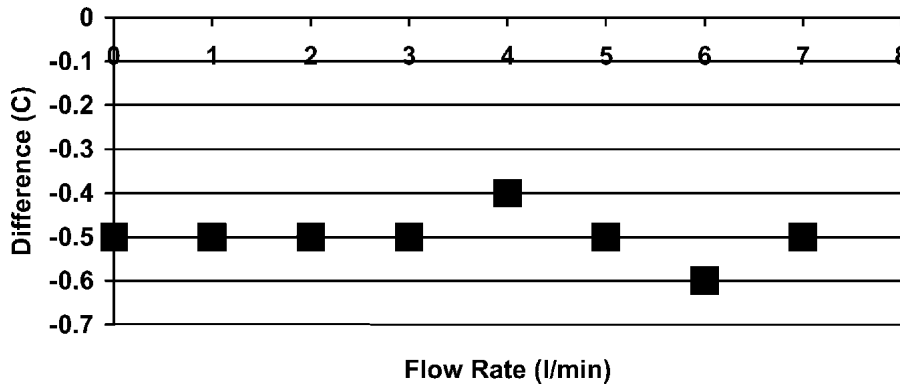
The results obtained in stage V appear to correspond with the immersion depth of the thermistor when mounted into the CPB circuit (Figure 7). The most accurate results were obtained when the thermistor was used with the thermal transfer standard (stage I), with an immersion depth of  $6$  mm. The most accurate results from the circuit thermistors were obtained by the inbuilt thermistor, with an immersion depth of  $1.9$  mm (venous) and  $1.5$  mm (arterial). The Dideco connector created a  $2.2$  mm dead space between the flow path and the thermistor.

## DISCUSSION

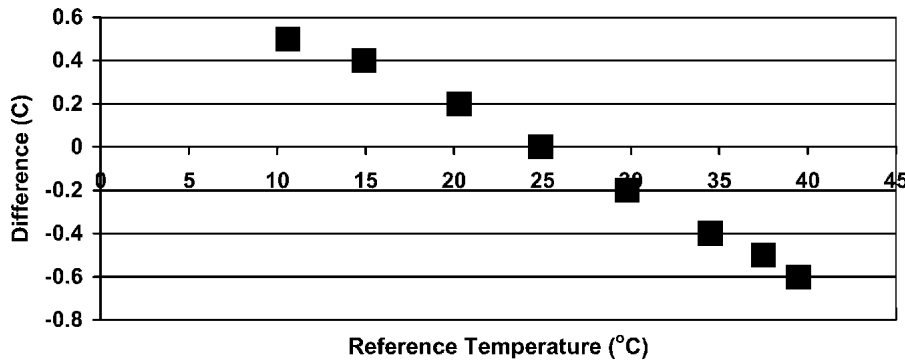
Our results highlight that the accuracy quoted by the manufacturer of  $\pm 0.2^\circ\text{C}$  (6) was similar to our results when tested with adequate immersion in stage I. Our method of testing accuracy in stage I is similar to the manufacturer, although the test solution used by the manufacturer is

**Figure 2.** Average difference between reference and thermistor measurements at various temperatures (using the thermal transfer standard). A positive difference indicates that the thermistors were underreading, and a negative difference indicates overreading (i.e., reference temperature  $21.6^\circ\text{C}$ , thermistor temperature  $21.3^\circ\text{C}$ ).

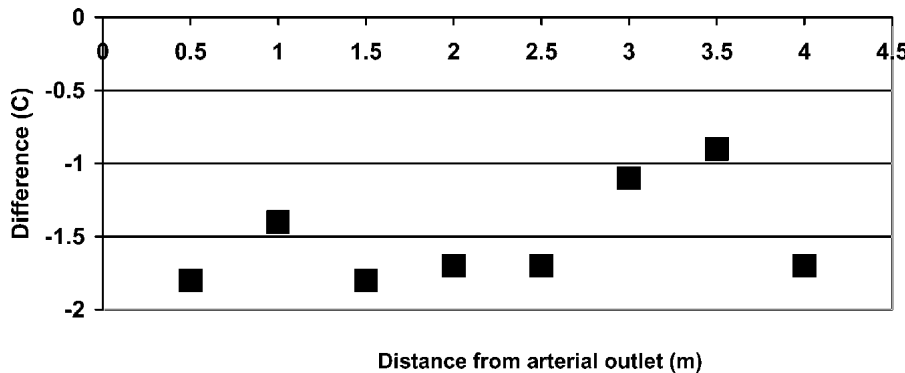




**Figure 3.** Difference between reference and arterial outlet temperatures at various flow rates in the cardiopulmonary bypass circuit. Although the thermistor was underreading at an average of  $-0.5^{\circ}\text{C}$ , flow rate did not alter the consistency of the measurements.



**Figure 4.** Comparison of temperature probe and fluid measurements at various temperatures. A greater difference was observed between the outlet and reference temperatures compared to the results obtained in stage I; however, the error was similar to that observed in stage II.



**Figure 5.** Difference in measurement between the oxygenator outlet and various distances along the arterial line. There was a difference of  $-0.4 \pm 0.1^{\circ}\text{C}$ , measured both at the arterial outlet and at the venous inlet (4.5 m from the outlet).

Fluorinert (3M, St. Paul, MN). The Fluorinert product information states that it is thermally stable with a wide liquid range and, therefore, ideal as a heat transfer fluid. In stage I we measured constant temperatures and compared measurements obtained from two devices measuring the same solution once thermal equilibrium was obtained; therefore, we were not concerned with thermal capacity of the test solution at this stage, and so 0.9% saline should be a suitable test solution. A greater difference in accuracy was observed when the thermistor was examined in the CPB circuit. Although most of the sources of error involved with thermistors are set by the manufacturer, the perfusionist should be aware of the limitations of these devices. In addition, the perfusionist should attempt to minimize these sources when connect-

ing luer thermistors to the CPB circuit. Of primary concern is ensuring an adequate immersion depth by connector type.

In relation to CPB practice, the pivotal factors involved in temperature management during CPB include the rate of rewarming, and the temperature of the blood being delivered to the patient. Numerous studies have examined the effects of rewarming on cerebral oxygen supply (1,2,4), demonstrating a decrease in jugular venous oxygen saturation during this period. The degree of desaturation has been shown to be related to the rate of rewarming (4), and associated with impaired cognitive test performance (3,4). The relationship between rewarming rate during CPB and neuropsychological deficit has not been clearly established; however, findings by Borger et al. (5), Newman et

Figure 6. Comparison of measured temperatures with different connector types.

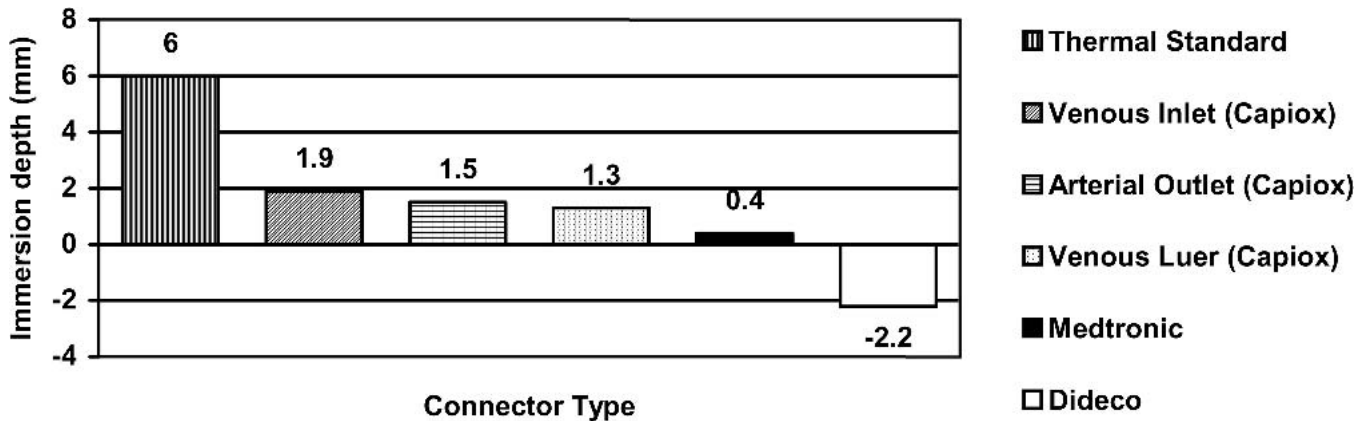
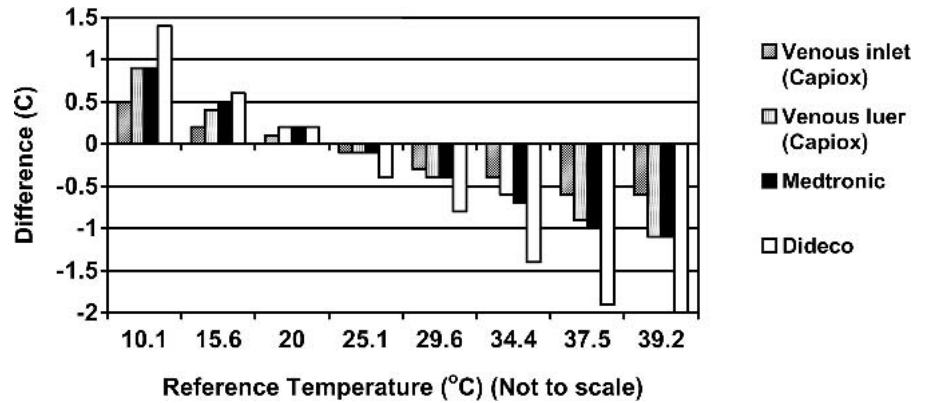


Figure 7. Comparison of immersion depths with 3/8" x 3/8" luer connectors from different manufacturers.

al. (7), and Grigore (8) suggest that a relationship exists between slow rewarming and less neurocognitive dysfunction. The deleterious physiological effects of excessive temperature are well recognized. No controversy exists in relation to harmful effects of hyperthermia on the blood-brain barrier, the brain reduction in its tolerance to ischemia, or the impairment of metabolic recovery after transient global cerebral ischemia. The impact of hyperthermia (39°C) on the brain has been reviewed by Ginsberg et al. (9) and should be acknowledged as pivotal to any discussion on the consequences of temperature management during CPB. Perhaps oxygenator arterial outlet temperature monitoring has just as important a role in CPB management as patient temperature monitoring, as commonly monitored patient temperature sites do not accurately reflect brain temperature (10). Therefore, the need for this measurement to be accurate is extremely important.

In stage I of our experiment, we showed that the thermistors themselves had an acceptable accuracy (<0.1°C difference) between 29.8 and 37.8°C, which correlates well to the temperatures encountered during routine CPB. Overreading by 0.3°C at 21.5°C and underreading by 0.2°C at 39.8°C was considered acceptable and supports the manufacturers quoted accuracy. Although the

consistency of measurements at various flow rates at the arterial outlet (stage II) was within 0.1°C, the difference in accuracy of the measurements when compared to stage I (approx -0.5°C) can be explained by the difference in immersion depth of the thermistors (6 mm in the thermal transfer standard, and 1.9 mm at the arterial outlet).

When the temperature of the saline was varied in the circuit (stage III), the accuracy of the arterial outlet thermistor showed a similar pattern when compared with measurements obtained using the thermal transfer standard in stage 1, however there was greater inaccuracy at the coldest and warmest temperatures (-0.7 at 39.4°C circuit cf -0.2 at 39.8°C thermal transfer standard). These results show a similar difference in accuracy when comparing stage II with stage I and may also be attributed to the difference in immersion depth.

We observed no temperature drop between the arterial outlet and the venous inlet when separated by a distance of 4.5 m. Because the specific heat of saline is similar to that of blood, we would suggest no significant heat loss to occur in the blood that exits the oxygenator prior to entering the aorta at normal clinical flow rates. We observed a greater difference in accuracy when the thermistors were attached at various distances (via luer connectors) along the outlet line with an average difference of -1.5 ± 0.3°C.

There was also less consistency in these measurements, indicating a possible difference in physical interaction with the CPB circuit when the thermistor was mounted in the Dideco luer connector.

To confirm our hypothesis, we compared the measurements obtained from the venous inlet thermistor with the thermistor connected to the luer connection on the venous inlet, the Dideco connector, and a Medtronic connector. Although the rate of accuracy showed a similar pattern, a difference was observed. Upon measurement of the immersion depths of the thermistors, we found that the accuracy was correlated with the immersion depth created by the physical connection of the luer into the circuit. Because the most accurate results were obtained using the thermal transfer standard with an immersion depth of 6 mm, we would suggest that a greater immersion depth of the arterial outlet thermistor may provide greater accuracy.

We observed a difference (under reading) in the arterial temperature measurement of  $-0.5 \pm 0$  °C at  $37.5 \pm 0.1$  °C. Potger (11) demonstrated a discrepancy in arterial probe temperature measurement accuracy. Because clinical practice has more of an impact on rate of rewarming than the accuracy of the measurement, the accuracy of arterial blood measurement is of greatest relevance in avoiding cerebral hyperthermia in the late stages of rewarming once the arterial blood temperature starts to exceed 37°C. We would recommend the difference of 0.5°C should be considered as arterial blood temperatures approach 37°C and greater to avoid exceeding the maximum arterial blood temperature as described by institutional protocols. The accuracy of arterial temperature allows the adoption of a safe rewarming perfusion protocol and will contribute to a satisfactory patient outcome in relation to temperature after CPB.

## CONCLUSIONS

The Terumo Capiox® CX\*TL Luer Thermistor is an accurate and reliable instrument for measuring tempera-

ture when incorporated into the Terumo Capiox® SX25 oxygenator. When using this thermistor, however, the immersion depth affects the accuracy of the temperature measurement. A negligible temperature drop is found between the Terumo Capiox® SX25 oxygenator arterial outlet and the venous inlet when connected 4.5 m distal to the outlet; therefore, the use of arterial blood temperature as a surrogate measure of delivery temperature is warranted. Under reading of the arterial blood temperature by approximately 0.5°C should be considered at normothermic temperatures when using the Terumo Capiox® SX25 oxygenator. The accuracy of all temperature measurements from the oxygenator arterial outlet should be determined to avoid exceeding the maximum arterial blood temperature as described by institutional protocols.

## REFERENCES

1. Nakajima T, et al. Clinical evaluation of cerebral oxygen balance during cardiopulmonary bypass: on-line continuous monitoring of jugular venous oxyhemoglobin saturation. *Anesth Analg.* 1992;74:630-5.
2. Croughwell ND, et al. Warming during cardiopulmonary bypass is associated with jugular bulb desaturation. *Ann Thorac Surg.* 1992;53:827-32.
3. Croughwell ND, et al. Jugular bulb saturation and cognitive dysfunction after cardiopulmonary bypass. *Ann Thorac Surg.* 1994;58:1702-8.
4. Sapire KJ, et al. Cerebral oxygenation during warming after cardiopulmonary bypass. *Crit Care Med.* 1997;25:1655-62.
5. Borger MA. Temperature management during cardiopulmonary bypass: effect of rewarming rate on cognitive dysfunction. *Proceedings of Perfusion Innovations in Cardiac Surgery.* Key West, Miami, 2000.
6. Temperature YSI. Dayton, OH. <http://www.ysi.com/temperature.htm>. YSI Temperature Industrial Products Catalog, 1999:71-72.
7. Newman MF, et al. Differential age effects of mean arterial pressure and rewarming on cognitive dysfunction after cardiac surgery. *Anaesth Analg.* 1995;81:236-42.
8. Grigore AM, et al. The association of rewarming rate and neurocognitive dysfunction after cardiac surgery. *Ann Thorac Surg.* 2000;70:1796.
9. Ginsberg MD, et al. Temperature modulation of ischaemic brain injury—a synthesis of recent advances. In Kogure K, Hossman K-A, Siesjo BK. *Prog Brain Res.* 1993;96:13-22.
10. Cook DJ, et al. Cerebral hyperthermia during cardiopulmonary bypass in adults. *J Thorac Cardiovasc Surg.* 1996;111:268-9.
11. Potger KC. Validation of “Affinity NT” membrane oxygenator arterial temperatures. *JECT.* 2004;36:000-000.