

# Performance of the transoesophageal echocardiography probe as an oesophageal temperature monitor in patients undergoing cardiac surgery with cardiopulmonary bypass: A prospective observational study

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## Research Article

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# Abstract

## Purpose

Core temperature monitoring is critical during cardiopulmonary bypass (CPB). In this prospective observational study, we investigated the performance of the transoesophageal echocardiography (TOE) probe as a core temperature (oesophageal) monitor during CPB.

## Methods

Thirty adult patients, 18–70 years, of either gender, and undergoing cardiac surgery on CPB were enrolled. All patients received a reusable nasopharyngeal (NP) probe for monitoring core temperatures. In addition, the oesophageal temperatures were monitored by the TOE probe. The arterial outlet temperatures at the membrane oxygenator were also monitored and taken as reference standard. Monitoring was performed every five minutes until 20 minutes, and then at 30 minutes during both cooling and rewarming periods.

## Results

During cooling, the temperatures recorded by both the TOE and NP probes lagged behind the arterial outlet temperatures. However, the intra-class correlation (ICC) of the TOE temperatures with the arterial outlet temperatures were better (ICC range 0.58–0.74) than the NP temperatures (ICC range 0.46–0.62), and with a lower degree of bias. During rewarming, while the NP temperatures lagged behind the arterial outlet temperatures, the performance of the TOE probe was significantly better. At 30 minutes of rewarming, the TOE and the arterial outlet temperature readings were similar, while the NP temperatures still lagged behind by 0.5<sup>o</sup> C. The ICC of the TOE temperatures with the arterial outlet temperatures were better compared with the NP probe with significant less bias.

## Conclusion

Performance of the TOE probe as an oesophageal temperature monitor is superior to the NP probe during CPB.

## Study registration:

CTRI no 2020/10/028228; ctri.nic.in

## Introduction

Cardiac surgery is associated with a significant risk for the development of central nervous system complications, which may range from subtle cognitive decline [1, 2], to stroke [3–5]. Thus, neuroprotection is one of the major challenges in patients undergoing cardiac surgery. Hypothermic cardiopulmonary bypass (CPB) is a measure to provide neuroprotection but inadvertent hyperthermia during rewarming may lead to cerebral injury [6]. Even mild hyperthermia (2–3<sup>0</sup> C above normal) results in more free radical production, excitatory neuroamine release, intracellular acidosis and increased blood-brain barrier permeability [7].

A variety of sites, including nasopharyngeal, oesophageal, rectal, and bladder have been used in an attempt to monitor the core temperature during cooling and rewarming but have limitations in approximating the brain temperature, commonly lagging behind brain temperature during both cooling and rewarming [7]. Tracking these sites may thus lead to undercooling or overheating the brain during the phases of cooling and rewarming respectively, leading to suboptimal neuroprotection [8].

Transoesophageal echocardiography (TOE) is indispensable in the conduct of cardiac surgery and has been shown to impact intraoperative management [9]. The TOE probe has a thermistor in its tip to track temperature changes in the surrounding tissues and is capable of detecting temperature changes within 17.5-42.5<sup>0</sup>C with auto shut down function at these limits, which is a safety measure to prevent ultrasound-induced thermal tissue injury [10]. As such, the thermistor is highly sensitive to the surrounding temperature and is able to track and reflect these changes quickly and accurately.

After the institution of CPB, the TOE probe is kept in standby mode and thus, the temperature recorded by the probe and displayed on the monitor may be reflective of arterial perfusate temperatures. The advantages over traditional oesophageal temperature probes would be that the TOE probe can be positioned at the exact site of interest, either mid-or upper oesophageal to reflect the temperature of the descending thoracic aorta or aortic arch respectively. Furthermore, given the fact that it is designed to prevent ultrasound-induced thermal injury rather than passively record temperature changes, it may track and reflect temperature changes quickly and thus provide an accurate estimation of brain temperature.

No previous studies have evaluated the performance of the TOE probe as a core temperature monitor during CPB. Prior studies have shown that the temperature at the arterial outlet of the membrane oxygenator is more representative of jugular bulb temperatures which have the best correlation with brain temperatures [7]. Thus, the aim of this study was to compare the performance of the TOE probe as an oesophageal temperature probe vs. nasopharyngeal temperature probe, considering the arterial outlet temperature at the membrane oxygenator as the standard comparator during cooling and rewarming in adult patients undergoing cardiac surgery under hypothermic CPB.

## Methods

### Study design, inclusion and exclusion criteria

The study was a prospective observational study carried out in adult patients, 18–70 years of age, of either gender, and undergoing cardiac surgeries under hypothermic CPB after Institutional Ethics Committee approval (IEC) (T/IM-NF/Anesth/20/10) and registration in the Clinical Trials Registry of India (CTRI) (CTRI no 2020/10/028228). Exclusion criterion was any known contraindication to the use of a TOE probe.

## Anaesthesia protocol

Anaesthesia was standardized in all patients and consisted of administration of intravenous injections of fentanyl 1–2 µg/kg for analgesia, propofol titrated to loss of verbal response and rocuronium 0.9 mg/kg to facilitate tracheal intubation. Maintenance of anaesthesia was carried out with isoflurane 0.7–0.8 end-tidal alveolar concentration in a 50% mixture of air: oxygen, and fentanyl and rocuronium administered as required. Lungs were ventilated to an end-tidal CO<sub>2</sub> of ~ 35 mm Hg. Ventilation was paused and the lungs allowed to collapse during CPB.

## Temperature measurements and conduct of CPB

After induction of anaesthesia and placement of invasive arterial and central venous catheters, a well-lubricated adult TOE probe (6VT, GE E95, GE, Horten, Norway) was inserted into the oesophagus for structural and functional evaluation of the heart before and after CPB. Core temperatures were monitored in all cases with a soft reusable nasopharyngeal temperature probe inserted into the nasopharynx; nasopharyngeal probes were available with the anaesthesia workstation (Dräger, Drägerwerk AG & Co. KGaA, Germany). The probes were inserted to a depth measured from the nasal ala to the tragus, so as to lie in the posterior nasopharynx. The probes were auto calibrated before each use.

After systemic anticoagulation with unfractionated heparin (300 IU/kg), and achieving activated coagulation time (ACT) of > 450 seconds, CPB was instituted with roller pumps and membrane oxygenators to achieve extracorporeal flows of 2.5 L/min/m<sup>2</sup>. Subsequent doses of unfractionated heparin were repeated to maintain ACT > 450 seconds. Urine output was maintained at 0.5-1 ml/kg/hr. Myocardial protection was carried out in all cases with cold blood cardioplegia (St. Thomas Hospital solution) (~ 4<sup>0</sup> C) administered antegrade into the aortic root or coronary ostia at twenty-minute intervals following the induction dose. Packed red blood cells were added to maintain the hemoglobin above 7 gm% during CPB.

After the institution of CPB, the TOE probe was put in standby mode and the temperature display on the top right of the monitor was used for monitoring the oesophageal temperatures. The arterial perfusate temperatures were monitored by inserting a temperature probe at the arterial outlet of the membrane oxygenator. The probes were supplied with their respective oxygenators (Terumo FX25® or Liva Nova Inspire 6®). Hypothermia was as per the surgeon's preference. During cooling and rewarming, the temperatures at each of the three sites were monitored and recorded simultaneously every five minutes until the end of 20 minutes, and then at thirty minutes.

In 50% of patients, the TOE probe was pulled to the upper oesophageal level (denoted by the aortic arch in long axis at 0<sup>0</sup>) and left at that position to record the temperatures at the arch level. In the remaining 50% patients, it was left at the mid-oesophageal level (denoted by the 4-chamber view at 0<sup>0</sup>) to record the temperatures at that level. This was carried out to determine the correlation of the temperatures recorded by the TOE probe in the upper oesophageal position vs. the mid-oesophageal position with the arterial outlet temperatures; since cooling of the heart by cardioplegia can potentially affect the temperatures recorded at the mid-oesophageal level. After the study period was over, the TOE probe was used to assess the adequacy of de-airing and/or evaluate the ventricular/valvular function. CPB was terminated when the nasopharyngeal temperatures reached 37<sup>0</sup> C. After termination of CPB, core temperatures were maintained by active surface warming with forced air warmers and with the use of warm intravenous fluids.

## Statistics

The performance of the TOE probe and the nasopharyngeal probe in terms of agreement against the standard (arterial outlet probe) was evaluated using intra-class correlation. The sample size was calculated assuming an intra-class correlation of 70% between the reference standard and the investigational (nasopharyngeal and TOE) methods. To achieve this goal, a sample size of 21 was required for accommodating an alpha error of 1%. A total of 30 participants were recruited to achieve a greater precision, and the sample size was powered to 90%. The continuous variables were expressed as mean (SD), and the categorical variables were expressed as proportions. Bland-Altman analysis was performed to measure the bias of measurement between the standard and investigational methods of temperature measurement. Bland-Altman plots were constructed to depict the bias (along with the lower and upper limits of the agreement values) between the standard and the investigational methods. Data were analysed with R (R studio, Geneva, Version 3.5).

## Results

The study was carried out from 07.10.2020 to 22.01.2021. The proportion of males was 43.3%, mean age was 47.2 (13.6) years, and mean weight was 59.8 (14.5) kg. Cases were mostly performed with mild-moderate hypothermia (~ 28–32<sup>0</sup> C). During cooling, mean values of both the TOE probe and the nasopharyngeal probe readings lagged behind the arterial outlet temperatures [TOE vs. nasopharyngeal vs. arterial outlet temperatures; 35.2 (1.8) vs. 35.1 (0.9) vs. 34.2 (2.1)<sup>0</sup>C at 5 minutes; 33.5 (1.5) vs. 33.9 (1.5) vs. 32.7 (1.9)<sup>0</sup>C at 10 minutes; 32.8 (1.9) vs. 33.4 (1.3) vs. 31.8 (2.1)<sup>0</sup>C at 15 minutes; 32.2 (2.1) vs. 32.6 (1.3) vs. 31.4 (1.9)<sup>0</sup>C at 20 minutes; and 31.5 (1.5) vs. 31.9 (1.2) vs. 30.9 (1.7)<sup>0</sup>C at 30 minutes]. Even after 30 minutes of cooling, the mean temperatures recorded by the TOE probe and nasopharyngeal probe were 0.8<sup>0</sup>C and 1<sup>0</sup>C higher respectively compared with the arterial outlet temperatures.

However, the intra-class correlation of the temperatures recorded by the TOE probe with the arterial outlet temperature was better at all temperatures compared with the nasopharyngeal vs. the arterial outlet temperatures (Table 1) with a lesser degree of bias (Fig. 1). Of note, the intra-class correlation was > 70%

between the TOE and arterial outlet temperatures at 20 and 30 minutes of cooling, but never reached 70% between the nasopharyngeal and arterial outlet temperatures at any cooling time points.

Table 1

Intra-class correlation (ICC) of TOE and nasopharyngeal temperatures vs. arterial outlet temperatures at different cooling and rewarming time points

Sl.	Time points	ICC (99% CI) (TOE vs. arterial outlet temperatures)	P (TOE vs. arterial outlet temperatures)	ICC (99% CI) (Nasopharyngeal vs. arterial outlet temperatures)	P (Nasopharyngeal vs. arterial outlet temperatures)
1	Cooling 5 minutes	0.58 (0.28 to 0.81)	< 0.001	0.46 (0.003 to 0.76)	0.005
2	Cooling 10 minutes	0.47 (0.17 to 0.73)	< 0.001	0.31 (-0.12 to 0.66)	0.02
3	Cooling 15 minutes	0.66 (0.19 to 0.87)	< 0.001	0.48 (-0.16 to 0.82)	0.04
4	Cooling 20 minutes	0.71 (0.35 to 0.88)	< 0.001	0.57 (-0.11 to 0.85)	0.02
5	Cooling 30 minutes	0.74 (0.37 to 0.90)	< 0.001	0.62 (-0.10 to 0.87)	0.013
6	Rewarming 5 minutes	0.74 (0.50 to 0.88)	< 0.001	0.73 (0.10 to 0.91)	0.002
7	Rewarming 10 minutes	0.72 (0.25 to 0.90)	< 0.001	0.62 (-0.16 to 0.90)	0.04
8	Rewarming 15 minutes	0.50 (0.21 to 0.75)	< 0.001	0.35 (-0.08 to 0.68)	0.02
9	Rewarming 20 minutes	0.51 (0.06 to 0.80)	0.001	0.40 (-0.15 to 0.76)	0.04
10	Rewarming 30 minutes	-0.15 (-0.29 to 0.12)	0.94	-0.16 (-0.46 to 0.28)	0.84
TOE- transoesophageal echocardiography; P < 0.01 is significant					

During rewarming, the mean nasopharyngeal temperatures lagged behind the mean arterial outlet temperatures. However, the performance of the TOE probe was significantly better than the nasopharyngeal probe at all rewarming points in terms of the mean temperature values [TOE vs. nasopharyngeal vs. arterial outlet temperatures; 32 (1.9) vs. 31.6 (1.5) vs. 32.3 (1.4)<sup>0</sup>C at 5 minutes; 33.4 (1.8) vs. 32.5 (1.6) vs. 33.7 (1.6)<sup>0</sup>C at 10 minutes; 34.4 (1.4) vs. 33.4 (1.6) vs. 34.2 (1.4)<sup>0</sup>C at 15 minutes; 35.6 (0.9) vs. 34.5 (1.5) vs. 35.5 (0.9)<sup>0</sup>C at 20 minutes; and 36.3 (0.5) vs. 35.8 (0.6) vs. 36.3 (0.5)<sup>0</sup> C at 30 minutes]. At 15 and 20 minutes of rewarming, the performance of the TOE probe significantly improved and it even tracked ahead of the arterial outlet temperature probe readings, and with a difference of ~ 1<sup>0</sup>C

more than the nasopharyngeal probe. At 30 minutes of rewarming, the TOE and the arterial temperature probe readings were similar, while the nasopharyngeal temperatures still lagged behind by 0.5<sup>0</sup>C.

The intra-class correlation of the TOE probe was considerably better with the arterial outlet temperatures compared with the nasopharyngeal probe (Table 1) with lesser bias (Fig. 2). The intra-class correlation was > 70% between the nasopharyngeal and arterial outlet temperature only at 5 minutes of rewarming, while it was > 70% between the TOE and arterial outlet temperatures at 5 and 10 minutes of rewarming.

With regards to the position of the TOE probe (upper vs. mid-oesophageal), there was no difference in the intra-class correlation with the arterial outlet temperatures, i.e., the performance of the probe for arterial perfusate temperature monitoring at each of the position was acceptable (Table 2).

Table 2  
Intra-class correlation (ICC) of mid and upper oesophageal TOE temperatures with arterial outlet temperatures

Sl. number	Time points	ICC (99% CI) (mid-esophageal position vs. arterial outlet)	ICC (99% CI) (upper esophageal position vs. arterial outlet)
1	Cooling 5 minutes	0.61 (0.32 to 0.83)	0.55 (0.24 to 0.81)
2	Cooling 10 minutes	0.47 (0.16 to 0.75)	0.48 (0.18 to 0.77)
3	Cooling 15 minutes	0.65 (0.23 to 0.88)	0.68 (0.33 to 0.88)
4	Cooling 20 minutes	0.74 (0.41 to 0.89)	0.70 (0.39 to 0.88)
5	Cooling 30 minutes	0.72 (0.39 to 0.89)	0.78 (0.49 to 0.92)
6	Rewarming 5 minutes	0.69 (0.43 to 0.87)	0.79 (0.58 to 0.92)
7	Rewarming 10 minutes	0.69 (0.22 to 0.88)	0.76 (0.46 to 0.91)
8	Rewarming 15 minutes	0.38 (0.08 to 0.68)	0.59 (0.31 to 0.82)
9	Rewarming 20 minutes	0.31 (0.02 to 0.63)	0.61 (0.22 to 0.85)
10	Rewarming 30 minutes	-0.18 (-0.32 to 0.11)	-0.11 (-0.26 to 0.21)
TOE- transoesophageal echocardiography			

## Discussion

The findings of this study show that oesophageal temperatures monitored with the TOE probe during CPB reliably approximate the arterial outlet temperatures at the membrane oxygenator, especially during rewarming. The performance of the TOE probe was considerably better than the nasopharyngeal probe during both the cooling and rewarming periods.

In humans, the basal cerebral metabolic requirement for oxygen (CMRO<sub>2</sub>) is 3.5 ml/100gm/min, of which 60% is used for electrophysiological function (functional CMRO<sub>2</sub>), and 40% is for maintenance of structural integrity (structural CMRO<sub>2</sub>) [6]. While anaesthetics reduce only the functional CMRO<sub>2</sub>, temperature affects both functional and structural CMRO<sub>2</sub>; and total CMRO<sub>2</sub> reduces by 6–7% per degree centigrade drop in temperature [6]. Apart from neuroprotective effects through reduction of metabolism, the institution of hypothermia has multiple pleiotropic benefits such as free radical suppression, inhibition of destructive enzymatic reactions, and inhibition of synthesis and release of putative excitatory neurotransmitters [7]. However, hypothermia is associated with risks like coagulopathy, prolongation of bypass duration due to an increase in the time for rewarming, postoperative shivering due to after drop of temperatures, and infections. Rewarming to reverse the hypothermia is equally critical. Cerebral hyperthermia may account for 50–80% of the neurophysiologic decline following cardiac surgery [11, 12].

Although the nasopharyngeal site is commonly monitored during CPB [13], nasopharyngeal temperature lags behind standard reference sites during rewarming [7, 8, 14, 15]. Nussmeier and colleagues [7], found that the nasopharyngeal temperature lags around 1.6 (1.2)<sup>0</sup>C at 15 minutes of rewarming compared with jugular bulb temperature. Similarly, Johnson and colleagues [14], found a poor correlation between the arterial outlet temperature probe and the nasopharyngeal temperature probe. In general, the mean arterial line temperatures were 3.6<sup>0</sup> C higher than the nasopharyngeal temperatures [14]. In fact, they suggested that the sole reliance should not be on nasopharyngeal temperature probe only [14]. Furthermore, nasopharyngeal temperatures also do not correlate well with brain temperatures during induction of deep hypothermia as well as its reversal [16]. In addition, massive epistaxis has been reported by the use of reusable nasopharyngeal temperature probes in a patient undergoing cardiac surgery [17].

The correlation with brain temperature is worse for other sites such as the bladder and rectum. At a rectal or bladder temperature of 37<sup>0</sup>C, the brain temperature is 2-4<sup>0</sup>C higher [7]. This puts the brain at higher risk for strokes since cerebral embolization occurs when the brain is warm or rewarming, after removal of the aortic cross-clamp. Other sites like the tympanic membrane are not commonly used for temperature management. A significant amount of wax may preclude accurate temperature measurements with probes inserted near the tympanic membrane [16, 18]. Studies have also shown that the tympanic membrane temperatures are lower than hypothalamic temperatures and can change in opposite directions [19]. Although the arterial outlet temperatures have been shown to correlate well with jugular bulb temperatures, in a survey of cardiac surgeons in the United Kingdom, only 33% rely on the arterial outlet temperature, and thus, it is not universally used [20]. While pulmonary artery catheters and jugular

bulb catheters have excellent intra-class correlation (> 90%) and are considered to approximate brain temperatures best, they are invasive catheters and are currently not the standard of care [19].

Oesophageal temperatures are commonly measured with a thermistor or thermocouple placed approximately 45 cm from the nose. Oesophageal temperatures have a good correlation with brain temperatures [16], but the degree of accuracy is less in patients undergoing aortic arch surgeries [21]. Other authors have found that oesophageal temperatures also lagged behind jugular bulb temperatures by around 1.3 (1.2)<sup>0</sup> C during rewarming [7]. This may be because oesophageal temperature probes being passive thermistors, probably are not designed to track surrounding temperatures rapidly. The use of oesophageal probes for monitoring core temperature is not very common (around 6.3% in a Canadian survey) [22], and probably even less so in the present context because of the routine use of TOE probes intraoperatively.

The intra-class correlation of the core temperatures recorded by the TOE probe with the arterial outlet temperatures in this study were at best modest (> 70% at 20 and 30 minutes of cooling and 5 and 10 minutes of rewarming). Despite this, its performance as a temperature monitor was superior to the nasopharyngeal probe. Although cold cardioplegia solutions may impact the temperatures and thus the accuracy of the oesophageal temperatures vs. the brain temperatures during cooling [18], we did not find a difference between the upper and mid-oesophageal positions of the probe, reflecting the fact that leaving the probe in any position would correlate with the arterial outlet temperature.

A possible reason for the poor intra-class correlation between the TOE and arterial outlet temperatures at 30 minutes following rewarming could be due to the fact the correlation is measured across individual values; and there may have been more variations in the individual measurements, despite similar average temperatures and bias measurements.

During the time the echocardiography machine is kept in standby mode, the TOE probe will reflect the temperature of the surroundings, in this case, the perfusate temperatures. The probe can be affected by the surrounding temperature, even without being used. In a patient with chronic liver disease, atrial fibrillation, poor hemodynamics, and hyperthermia (axillary temperatures 39<sup>0</sup>C), immediate shut down of the TOE probe on insertion into the oesophagus was reported by the authors [23]. At the time of the shutdown, the echocardiography monitor showed a temperature of 42.5<sup>0</sup>C [23].

Following the removal of the aortic cross-clamp after adequate rewarming, the TOE probe can be used as a cardiac monitor to evaluate the presence of intracardiac air as well as the results of surgery. The machine in standby mode also allows the prebypass images to be analysed without impacting the temperature readings.

One possible disadvantage is that in many centers, the aortic cross-clamp is removed at 32–34<sup>0</sup> C, at which time, operators often use the TOE probe to “look” at the heart. Once used, the probe will immediately start warming and not be reflective of the arterial perfusate temperatures anymore. However, this can be avoided by allowing the heart to rewarm completely along with the rest of the body, before

any cardiac interrogation is performed. Another disadvantage is that after termination of CPB, the nasopharyngeal probe can continue to monitor the core temperatures, and thus allow for treatment of “after drop”, while the TOE probe would be mostly used as a cardiac probe and thus, would not detect the drifts in the body temperature.

## Limitations

Temperature monitoring was not continuous but conducted mostly over 5-minute epochs in our study. Comparisons with oesophageal probes were not carried out as it is impractical to use both an oesophageal temperature probe and a TOE probe in the same patient. Our results are valid for only moderate hypothermia and more research needs to be conducted on the performance of the TOE probe during deep hypothermia. We used the membrane oxygenator arterial outlet temperatures and not jugular bulb temperatures, which has been considered the gold standard by many workers. But given the observational nature of the study, this additional intervention of inserting a catheter into the jugular bulb was not possible. We did not correlate the various factors that could have influenced the magnitude of temperature differences like age, body weight, hematocrit, CPB duration etc. Finally, the results of this study are specific for the GE E95 probe and needs to be validated with TOE probes of other vendors and even different models for the same vendor.

To conclude, the TOE probe can be used to monitor arterial perfusate temperatures during CPB. The performance of the TOE probe as an oesophageal temperature probe fared better than the nasopharyngeal probe during both cooling and rewarming on CPB.

## Declarations

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## References

1. Cook DJ, Huston J III, Trenerry MR, Brown RD Jr, Zehr KJ, Sundt TM III (2007) Postcardiac surgical cognitive impairment in the aged using diffusion-weighted magnetic resonance imaging. *Ann Thorac Surg* 83:1389-95. [https:// doi: 10.1016/j.athoracsur.2006.11.089](https://doi.org/10.1016/j.athoracsur.2006.11.089)
2. Neville MJ, Butterworth J, James RL, Hammon JW, Stump DA (2001) Similar neurobehavioral outcome after valve or coronary artery operations despite differing carotid embolic counts. *J Thorac Cardiovasc Surg* 121:125-36. [https:// doi: 10.1067/mtc.2001.111378](https://doi.org/10.1067/mtc.2001.111378)

3. Borger MA, Ivanov J, Weisel RD, Rao V, Peniston CM (2001) Stroke during coronary bypass surgery: principal role of cerebral macroemboli. *Eur J Cardiothorac Surg* 19:627-32. [https:// doi: 10.1016/s1010-7940\(01\)00649-2](https://doi.org/10.1016/s1010-7940(01)00649-2)
4. Nussmeier NA. A review of risk factors for adverse neurologic outcome after cardiac surgery (2002) *J Extra Corpor Technol* 34:4-10.
5. Bucerius J, Gummert JF, Borger MA, Walther T, Doll N, Onnasch JF, et al (2003) Stroke after cardiac surgery: a risk factor analysis of 16,184 consecutive adult patients. *Ann Thorac Surg* 75:472-8. [https:// doi: 10.1016/s0003-4975\(02\)04370-9](https://doi.org/10.1016/s0003-4975(02)04370-9)
6. Grigore AM, Murray CF, Ramakrishna H, Djaiani G (2009) A core review of temperature regimens and neuroprotection during cardiopulmonary bypass: does rewarming rate matter? *Anesth Analg* 109:1741-51. [https:// doi: 10.1213/ANE.0b013e3181c04fea](https://doi.org/10.1213/ANE.0b013e3181c04fea)
7. Nussmeier NA, Cheng W, Marino M, Spata T, Li S, Daniels G, et al (2006) Temperature during cardiopulmonary bypass: the discrepancies between monitored sites. *Anesth Analg* 103:1373-9. [https:// doi: 10.1213/01.ane.0000242535.02571.fa](https://doi.org/10.1213/01.ane.0000242535.02571.fa)
8. Kaukuntla H, Harrington D, Bilkoo I, Clutton-Brock T, Jones T, Bonser RS (2004) Temperature monitoring during cardiopulmonary bypass- do we undercool or overheat the brain? *Eur J Cardiothorac Surg* 26:580-5. [https:// doi: 10.1016/j.ejcts.2004.05.004](https://doi.org/10.1016/j.ejcts.2004.05.004)
9. Eltzschig HK, Rosenberger P, Löffler M, Fox JA, Aranki SF, Shernan SK (2008) Impact of intraoperative transoesophageal echocardiography on surgical decisions in 12,566 patients undergoing cardiac surgery. *Ann Thorac Surg* 85:845-52. [https:// doi: 10.1016/j.athoracsur.2007.11.015](https://doi.org/10.1016/j.athoracsur.2007.11.015)
10. Choudhury M, Chauhan S (2016) Hyperthermia and malfunction of transoesophageal echocardiography probe. *Indian J Crit Care Med* 20:380-1. [https:// doi: 10.4103/0972-5229.183902](https://doi.org/10.4103/0972-5229.183902)
11. Engelman RM, Pleet AB, Rousou JA, Flack JE III, Deaton DW, Pekow PS, et al (1999) Influence of cardiopulmonary bypass perfusion temperature on neurologic and hematologic function after coronary artery bypass grafting. *Ann Thorac Surg* 67:1547-1555. [https:// doi: 10.1016/s0003-4975\(99\)00360-4](https://doi.org/10.1016/s0003-4975(99)00360-4)
12. Seco M, Edelman JJ, Van Boxtel B, Forrest P, Byrom MJ, Wilson MK, et al (2015) Neurologic injury and protection in adult cardiac and aortic surgery. *J Cardiothorac Vasc Anesth* 29:185-95. [https:// doi: 10.1053/j.jvca.2014.07.026](https://doi.org/10.1053/j.jvca.2014.07.026)
13. Rajek A, Lenhardt R, Sessler DI, Brunner G, Haisjackl M, Kastner J, et al (2000) Efficacy of two methods for reducing postbypass afterdrop. *Anesthesiology* 92:447-56. [https:// doi: 10.1097/00000542-200002000-00027](https://doi.org/10.1097/00000542-200002000-00027)
14. Johnson RI, Fox MA, Grayson A, Jackson M, Fabri BM (2002) Should we rely on nasopharyngeal temperature during cardiopulmonary bypass? *Perfusion* 17:145-51. [https:// doi: 10.1191/0267659102pf536oa](https://doi.org/10.1191/0267659102pf536oa)
15. Grocott HP, Newman MF, Croughwell ND, White WD, Lowry E, Reves JG (1997) Continuous jugular venous versus nasopharyngeal temperature monitoring during hypothermic cardiopulmonary bypass for cardiac surgery. *J Clin Anesth* 9:312-6. [https:// doi: 10.1016/s0952-8180\(97\)00009-3](https://doi.org/10.1016/s0952-8180(97)00009-3)

16. Stone JG, Young WL, Smith CR, Solomon RA, Wald A, Ostapkovich N, et al (1995) Do standard monitoring sites reflect true brain temperature when profound hypothermia is rapidly induced and reversed? *Anesthesiology* 82:344-51. [https:// doi: 10.1097/00000542-199502000-00004](https://doi.org/10.1097/00000542-199502000-00004)
17. Sinha PK, Kaushik S, Neema PK (2004) Massive epistaxis after nasopharyngeal temperature probe insertion after cardiac surgery. *J Cardiothorac Vasc Anesth* 18:123-4. [https:// doi: 10.1053/j.jvca.2003.10.030](https://doi.org/10.1053/j.jvca.2003.10.030)
18. Ali MS, Harmer M, Kirkham F (2005) Cardiopulmonary bypass temperature and brain function. *Anaesthesia* 60: 365-72. [https:// doi: 10.1111/j.1365-2044.2005.04112.x](https://doi.org/10.1111/j.1365-2044.2005.04112.x)
19. Akata T, Setoguchi H, Shirozu K, Yoshino J (2007) Reliability of temperatures measured at standard monitoring sites as an index of brain temperatures during deep hypothermic cardiopulmonary bypass conducted for thoracic aortic reconstruction. *J Thorac Cardiovasc Surg* 133:1559-65. [https:// doi: 10.1016/j.jtcvs.2006.11.031](https://doi.org/10.1016/j.jtcvs.2006.11.031)
20. Browne LP (2021) Temperature management on cardiopulmonary bypass: Is it standardised across Great Britain and Ireland? *Perfusion* 267659121995996. [https:// doi: 10.1177/0267659121995996](https://doi.org/10.1177/0267659121995996)
21. Yan TD, Bannon PG, Bavaria J, Coselli JS, Elefteriades JA, Griep RB, et al (2013) Consensus on hypothermia in aortic arch surgery. *Ann Cardiothorac Surg* 2:163-8. [https:// doi: 10.3978/j.issn.2225-319X.2013.03.03](https://doi.org/10.3978/j.issn.2225-319X.2013.03.03)
22. Belway D, Tee R, Nathan HJ, Rubens FD, Boodhwani M (2011) Temperature management and monitoring practices during adult cardiac surgery under cardiopulmonary bypass: results of a Canadian survey. *Perfusion* 26:395-400. [https:// doi: 10.1177/0267659111409095](https://doi.org/10.1177/0267659111409095)
23. Saluja V, Singh G, Pandey CK (2016) Transoesophageal echocardiography probe shutdown in a patient with hyperthermia. *Indian J Crit Care Med* 20:50-1. [https:// doi: 10.4103/0972-5229.173692](https://doi.org/10.4103/0972-5229.173692)

## Figures

### Figure 1

Bland-Altman plots showing the bias of the temperature readings of nasopharyngeal and transoesophageal echocardiography probe vs. arterial outlet temperatures during cooling. Continuous line is the zero (reference) point, the middle-dotted line is the average bias across all temperatures, upper and lower dotted lines indicate the upper and lower limit of agreements.

### Figure 2

Bland-Altman plots showing the bias of the temperature readings of nasopharyngeal

and transoesophageal echocardiography probe vs. arterial outlet temperatures during rewarming. Continuous line is the zero (reference) point, the middle-dotted line is the average bias across all temperatures, upper and lower dotted lines indicate the upper and lower limit of agreements.