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Reliability of different body temperature measurement sites during aortic surgery

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Abstract

Objective: We retrospectively performed a comparative analysis of temperature measurement sites during surgical repair of the thoracic aorta.
Methods: Between January 2004 and May 2006, 22 patients (mean age: 63±12 years) underwent operations on the thoracic aorta with arterial cannulation of the aortic arch concavity and selective antegrade cerebral perfusion (ACP) during deep hypothermic circulatory arrest (HCA). Indications for surgical intervention were acute type A dissection in 14 (64%) patients, degenerative aneurysm in 6 (27%), aortic infiltration of thymic carcinoma in 1 (4.5%) and intra-aortic stent refixation in 1 (4.5%). Rectal, tympanic and bladder temperatures were evaluated to identify the best reference to arterial blood temperature during HCA and ACP.
Results: There were no operative deaths and the 30-day mortality rate was 13% (three patients). Permanent neurological deficits were not observed and transient changes occurred in two patients (9%). During re-warming, there was strong correlation between tympanic and arterial blood temperatures ($r= 0.9541$, $p<0.001$), in contrast to the rectal and bladder temperature ($r=0.7654$, p= n.s; $r=0.7939$, p= n.s., respectively).
Conclusion: We conclude that tympanic temperature measurements correlate with arterial blood temperature monitoring during aortic surgery with HCA and ACP and, therefore, should replace bladder and rectal measurements.

Keywords

aortic surgery; temperature monitoring; antegrade cerebral perfusion; hypothermia; circulatory arrest; tympanic; rectal; bladder

Introduction

Accurate monitoring of the core temperature during aortic surgery, especially with the application of deep hypothermic circulatory arrest (HCA), is an important component of routine perioperative care. Preservation of neurological function is one of the main goals in such patients. Increasing the tolerance of the brain to ischaemia by the application of systemic hypothermia allows for a safe period of circulatory arrest and has remained the mainstay of neuroprotection for decades[1,2] The safety of this procedure relies on adequate systemic cooling under strict control. If this control is incomplete or fails, neurological injury may occur during HCA.

Whereas hypothermia is neuroprotective, even mild hyperthermia is hazardous during cerebral ischaemia since it accelerates neuronal death.[3-7] This results from oxygen free radical production,[8] destabilization of the cytoskeleton,[9] intracellular acidosis[10] and increased blood-brain barrier permeability.[11] Thus, to estimate the actual brain temperature, different sites are used for perioperative temperature measurements, e.g., urinary bladder, oesophagus, rectum and tympanic membrane. Body temperatures measured on these alternative sites may, however, substantially deviate from the actual cer-

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Table 1. Preoperative patient characteristics.

Characteristics	
No. of patients	22
Male	12
Female	10
Mean age in years±standard deviation	63±12
Emergency operations	15
Indications	
Type A dissection	14
Degenerative aneurysm	6
Aortic infiltration of thymic carcinoma	1
Intra-aortic stent refixation	1
Hypertension	16
Preoperative ventilation	4
Preoperative renal insufficiency	3

ebral temperature. Adequate neuroprotection requires meticulous temperature management to avoid too low or too high temperatures leading to overcooling or overheating the patient due to inappropriate "slow responding" temperature monitoring. The aim of our study was to evaluate the reliability of the commonly used core body temperature measurement sites in contemporary aortic surgery performed with the aid of HCA and selective antegrade cerebral perfusion.

Patients and methods

Between January 2004 and May 2006, 22 patients (mean age: 63±12 years, 12 men and 10 women) underwent operations on the thoracic aorta. In all patients, a standard operative technique for acute aortic dissection or aneurysm resection was used at our institution. Cardiopulmonary bypass (CPB) was established via arterial cannulation performed on the concavity of the aortic arch and, during HCA, selective bilateral antegrade carotid perfusion was used. Indications for surgery included: acute type A dissection (n=14, 64%), degenerative aneurysm (n=6, 27%), aortic infiltration of thymic carcinoma (n=1, 4.5%) and intra-aortic stent refixation (n=1, 4.5%). Fifteen patients (68%) underwent emergency operations. Preoperative patient characteristics are given in Table 1.

Diagnosis was confirmed by contrast-enhanced computed tomography and intraoperative transoesophageal echocardiography (TOE) in all patients. Aortography or coronary angiography was not performed in emergency cases.

The standard operative technique for aortic dissection or aortic aneurysm at our institution is Dacron graft replacement of the ascending aorta and proximal aortic arch combined with inspection of the supra-aortic

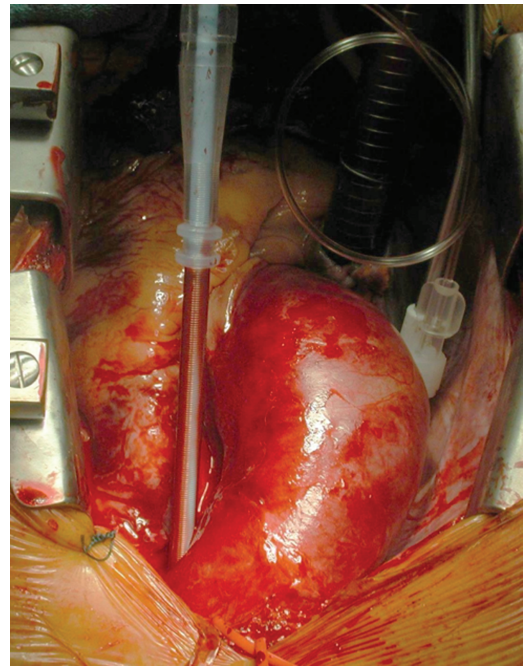

Figure 1. Showing direct aortic cannulation over arch concavity with the Seldinger technique.

vessels ± concomitant island transposition, depending on the supra-aortic status. The patients were placed in the standard supine position. Monitoring of arterial pressure was performed by routinely placing three lines in both radial and right femoral arteries. A median sternotomy was performed in all patients. Puncture of the proximal aortic arch concavity at the level of Botallo's ligament was followed by a minimal invasive cannulation, with dilation steps by the Seldinger technique (Fem-Flex Femoral Arterial Cannula®, 24 Fr TFA 02425H Edwards Lifesciences LLC, Irvine, CA, USA; Joline Special Dilatatorset®, Hechingen, Germany) (Figure 1). Correct position of the guide wire and cannula was confirmed by TOE of the aorta. CPB was instituted between this and a single, two-stage, right atrial venous cannula.

Patients were cooled down to a tympanic temperature of 19-20°C (Mon-a-therm® Thermistor YSI 400 Series tympanic temperature probe, Mallinckrodt Inc., St. Louis, MO, USA). Rectal (Thermocouple probe, Mallinckrodt Medical) and urinary bladder (Curity®, Degania, Israel) temperatures were simultaneously recorded throughout the procedures. Tympanic, rectal and bladder probes were connected to Mallinckrodt Model 6510 electronic thermometers which require no previous calibration and have an accuracy of around 0.1°C with disposable thermocouples, according to the user's manual. Prior to insertion of the tympanic probe, the cerumen-free status of the auditory channel was always controlled by otoscopic examination. The auditory channel was always

Table 2. Surgical procedures performed.

Surgical procedure	*n*
Ascending aorta + hemi arch	20
Ascending aorta + total arch	2
° David reconstruction	3
° Yacoub reconstruction	4
° Bentall procedure	4
° Coronary bypass grafting	4

° marks an additional procedure of aortic graft implantation.

insulated by a cotton swab, the probe securely fixed by a tape and a gauze bandage was additionally positioned over the external ear. Theatre temperature was continuously kept at 20-22°C throughout the operative procedures.

After cross-clamping, an ascending aortic incision was made and antegrade crystalloid cardioplegic solution (2000 ml Custodiol® HTK-Solution by Brettschneider, Dr. F. Köhler Chemie, Hähnlein, Germany) was administered through both coronary ostia. During HCA, selective ACP was provided through both carotid arteries (DLP Retrograde Coronary Sinus Perfusion Cannula with manual Inflating Cuff®, Medtronic Inc., Minneapolis, MN, USA) at a flow rate adapted to keep a constant cerebral O_2 saturation on each side with a perfusion pressure of 35-40 mmHg. Cerebral monitoring was performed with near infrared spectroscopy (INVOS® cerebral oxymeter, Somanetics Inc., Troy, MI, USA) and brain tissue oxygen saturation measured at 65-70% continuously during perfusion, which corresponded to the induction values.

Reconstruction of the aorta was performed with a woven Dacron side-branch vascular prosthesis (Hemashield Platinum Woven Double Velour Vascular Graft®, Boston Scientific Inc., Wayne, NJ, USA), including the island type reinsertion of all supra-aortic vessels, if applicable. The false lumen was eradicated with 45% bovine serum albumin-10% glutaraldehyde glue (BioGlue®, CryoLife International Inc., Kennesaw, GA, USA); aortic valve commissures were refixed with the resuspension suture technique. The valve was replaced if it was severely diseased. Composite valve graft replacement was applied in patients with Marfan syndrome or if severe local injury with aortic wall destruction was found intraoperatively. The decision whether or not a composite graft was implanted did not depend on the maximal diameter of the aortic root, but was based on the presence of Marfan syndrome or the severity of the wall destruction. Systemic reperfusion and re-warming were started through the graft side-branch. A summary of performed surgical procedures is presented in Table 2.

Table 3. Intraoperative data.

Intraoperative data	Mean±SD (Median)
Time to HCA (min)	25±12 (21)
CPB time (min)	176±63 (158)
HCA time (min)	46±21 (45)
ACP time (min)	36±18 (34)
ACP flow right start (ml/min)	216±55 (200)
ACP flow right end (ml/min)	199±40 (190)
ACP flow left start (ml/min)	224±55 (210)
ACP flow left end (ml/min)	230±61 (220)

CPB: cardiopulmonary bypass; HCA: deep hypothermic circulatory arrest; ACP: selective antegrade cerebral perfusion.

Statistical analysis

Statistical analysis for body temperature measurement sites was done using univariate analyses (Pearson's correlation and Student's t-test) with SPSS v17.0 (SPSS Inc., Chicago, IL, USA) to identify the best reference to arterial blood temperature during HCA and ACP. A p-value <0.05 was considered as significant.

Results

Perioperative data

There were no operative deaths; cumulative 30-day mortality rated 13% (n=3). The cause of death was multiorgan failure in all three patients. Eight patients (36%) stayed in the intensive care unit >5 days.

Direct aortic cannulation was safely performed in all cases; there was no need to switch to an alternative cannulation site. The adventitia of the dissected aorta was firm enough to support the cannula inserted by the Seldinger technique with staged dilatators and there was no case of complicated local massive haemorrhage at the cannulation site. TOE guidance was useful for aortic cannulation along with colour Doppler imaging, which provided information about the true lumen antegrade perfusion. No malperfusion or apparent thrombo-embolism due to the cannulation was observed. Malperfusion was defined by a cerebral saturation difference of 10% compared to preoperative values and/or pressure difference between the peripheral arteries >20 mmHg. There were no permanent neurological deficits, but two patients (9%) suffered from transient neurological dysfunction.

Mean CPB time was 176±63 minutes (median: 158), mean time to reach HCA was 25±12 minutes (median: 21), mean HCA time was 46±21 minutes (median: 45) and mean selective antegrade carotid perfusion time was 36±18 minutes (median: 34). Intraoperative patient data is shown in Table 3.

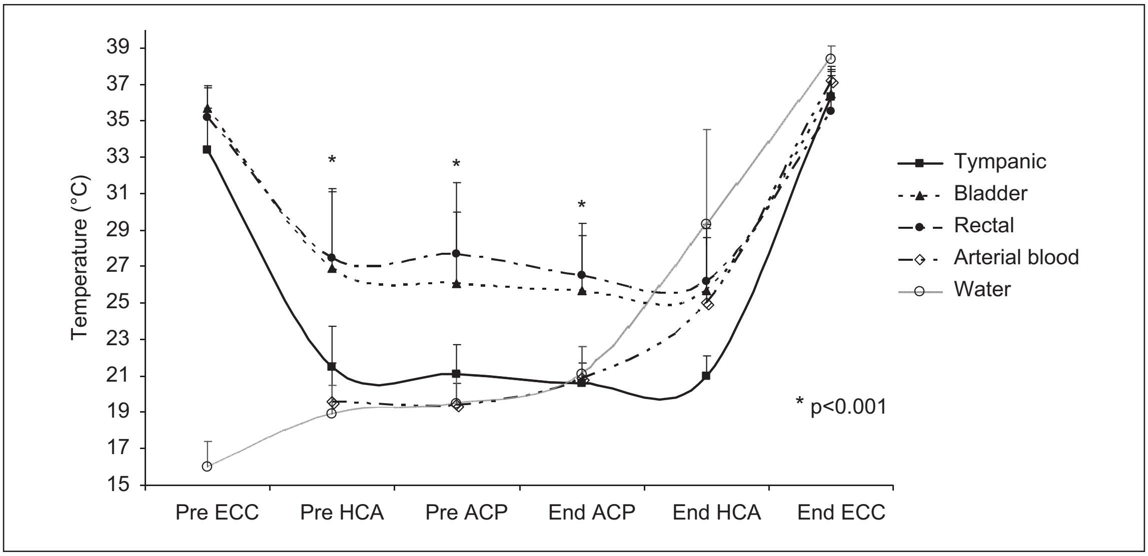

Figure 2. Temperature changes at different measurement sites during extracorporeal circulation (ECC), deep hypothermic circulatory arrest (HCA) and selective antegrade cerebral perfusion (ACP).

Temperature evaluation

Statistical analysis revealed a strong association between the tympanic temperature and the arterial blood temperature during HCA, while rectal and bladder values did not represent the core temperature adequately. The difference between rectal and arterial blood temperatures was significantly greater than the difference between tympanic and arterial blood temperatures [average temperature difference (rectal minus arterial): 7.9 (pre HCA), 8.3 (pre ACP), 5.6°C (end ACP); average temperature difference (tympanic minus arterial): 1.9, 1.7, 0.3°C, respectively; ($p<0.001$)]. There was a similar relationship between the bladder and tympanic temperatures (average temperature difference (bladder minus arterial): 7.3, 6.7, 4.8°C, respectively; average temperature difference (tympanic minus arterial): 1.9, 1.7, 0.3°C, respectively; ($p<0.001$)]. Figure 2 shows the temperature detected at the different sites during the course of the operation.

Analysis of the rewarming phase revealed strong correlation between tympanic and arterial blood temperatures ($r= 0.9541$; $p<0.001$) as well as between the arterial blood and heat exchanger water temperatures ($r=0.9879$; $p<0.001$). The urinary bladder and rectal values showed less correlation with the arterial blood ($r=0.7939$, p= n.s.; $r=0.7654$, p= n.s., respectively). Figure 3 shows the temperature detected at different sites during the re-warming phase.

Discussion

Our study demonstrates that tympanic measurements are reliable for intraoperative temperature estimation during aortic surgery performed under HCA. This may aid in improved postoperative outcomes due to a reduced cooling phase and adequate rewarming. Although the application of hypothermia has been an important contribution to patient management as a neuroprotective method from the dawn of cardiac surgery,[12,13] proper body temperature management relies on the accurate measurement of the temperature to enable adequate monitoring of changes during CPB and HCA. Oxygen consumption drops with lower body temperatures so that ischaemic tolerance is increased by cooling. Cerebral oxygen requirement decreases to approximately one-fifth of normothermic needs at 20˚C,[14] allowing a safe period of 45-50 minutes for HCA. In addition, hypothermia may contribute to neuroprotection by a variety of complex mechanisms, including decreased vascular permeability, reduced ion influx and decreased excitatory transmitter release.[15] During the rewarming phase of CPB, conventional temperature monitoring sites may not reflect true brain temperature, so cerebral hyperthermia may not be detected if conventional temperature monitoring underestimates the brain temperature or there is a delay with the arterial heat exchange.[16,17]

Monitoring rectal or urinary bladder temperature to control intraoperative core temperature is standard in many institutions all over the world. Rewarming, which aims to normalise the temperature after HCA, relies on measured data from the above sites. We have shown that temperature measurement at these sites could be misleading, possibly due to latency in the heat exchange process at these points. Clinicians are often concerned about the risks of postoperative hypothermia, such as shivering leading to increased myocardial oxygen

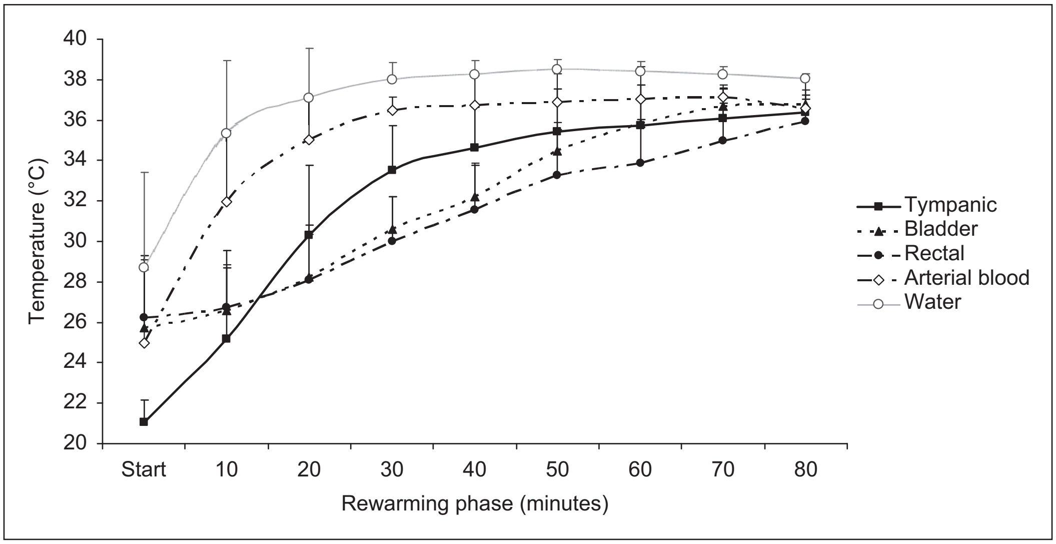

Figure 3. The temperature at various intervals during re-warming, following deep hypothermic circulatory arrest.

consumption, arrhythmias, coagulopathy, greater risk of wound infections and elongated hospital stay,[18-21] but the possible side effects of cerebral hyperthermia are rarely taken into account. Thus, the rewarming phase must be carefully monitored and managed to avoid cerebral hyperthermia, since it elevates the risk of post-ischaemic tissue injury[22,23] and intraoperative hyperthermia is well known to be associated with post-operative neurological impairment.[24,25]

Arterial blood temperature is considered to be the most accurate indicator of cerebral temperature.[26] This is not surprising as this is the medium for heat exchange for the brain during HCA and ACP. According to our results, tympanic temperatures correlate well with arterial blood temperatures and, hence, with cerebral temperatures, not only during HCA, but also during the rewarming phase of the operation. Urinary bladder and rectal temperatures lag behind arterial blood temperatures, therefore, these measurement sites cannot be relied upon to provide an accurate estimation of temperature change. This affects the management of these patients at various phases of cooling and re-warming.

The tympanic membrane is situated in the immediate vicinity of the internal carotid artery and is supplied by its branches. Thus, the tympanic temperature is well-placed to closely represent the cerebral thermal state. Although some authors consider tympanic temperature as a good standard for cerebral temperature monitoring by reflecting the hypothalamic status,[27,28] others have suggested that the tympanic temperature can be influenced by changes in ambient temperature.[29,30] If, prior to insertion of the tympanic probe, the debris-free status of the auditory channel is confirmed via otoscopic examination along with careful insulation by cotton swab and the probe is securely fixed by tape and a gauze bandage over the external ear, the ambient temperature influence on tympanic measurement can be effectively diminished. Variations in urinary flow, which is a normal phenomenon during CPB and, especially with HCA, may affect the bladder temperature sensors.[31] On the other hand, rectal probes can become lodged in faecal matter, which insulates them from the surrounding tissues.[32] The above factors contribute to the weak correlation of these temperature measurements with those of the arterial blood.

In our institute, we do not use nasopharyngeal/oesophageal temperature monitoring in HCA as standard measurement sites, as it has been shown in several studies to modestly, but significantly, over- and underestimating brain temperatures during the cooling and re-warming phases, respectively.[33-35] It is probable that this is a result of the suboptimal heat exchange environment as these probes are situated in larger, air-containing cavities. Although oesophageal probes are placed relatively close to the descending aorta, the open chest or eventually applied topical cooling in the pericardium could also influence measurement accuracy. Akata, et al. have, furthermore, demonstrated that pulmonary artery temperatures closely reflect changes in brain temperatures, but nasopharyngeal/oesophageal measurements could not be considered as a reliable index of brain temperature, at all, during rapid induction of moderate/deep hypothermia.[36]

Our study has some important limitations. It is an observational, retrospective study without randomisation and presents preliminary experience with a small number of patients. The good preliminary results have to be confirmed by further studies on larger patient groups.

Conclusion

We recommend multiple temperature measurement sites during aortic surgery with HCA and ACP to be able to assess homogenous cooling and rewarming of the patient. To achieve good postoperative neurological outcome, we believe that tympanic values are highly reliable as a guide to temperature changes of the brain during HCA and re-warming.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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