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The temperature within the circle of Willis versus tympanic temperature in resting normothermic humans

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Summary. We measured the temperature of arterial blood within the circle of Willis (T_{Willis}) in seven normothermic patients undergoing carotid arteriography. We found this temperature to be lower by 0.13 to 0.30° C than tympanic temperature and by 0.30 to 0.55° C lower than rectal temperature. By imposing this data on calculated cerebral heat balance it can be suggested that the average cerebral temperature of a resting subject is somewhat higher than tympanic temperature. These findings would also support indirectly the thesis that temperature gradients may exist within the brain.

Key words: Arterial blood temperature – Brain temperature – Cerebral thermoregulation

Introduction

It has been suggested that one of the main functions in cerebral thermoregulation is the elimination of the large amounts of metabolic heat produced by the brain (Narębski 1985; Rasch et al. 1991). It is accepted that brain temperature is maintained at a relatively low level by continuous removal of heat by circulating blood. The temperature of arterial blood entering the skull cavity is known to be lower than that of the brain (Aschoff 1973; Hayward and Baker 1969; Narębski 1985). This difference in temperature, crucial for cerebral thermoregulation at least in normothermy, has not however been measured directly in humans (Narębski 1985). For obvious reasons, it is almost impossible to find an opportunity to determine exactly both of the temperatures in a human subject. We took advantage of carotid angiography in neurosurgical patients to measure the temperature of the blood within the circle of Willis (T_{Willis}) and compare it to the rectal (T_{re}) and tympanic temperatures (T_{ty}). The last of these has been believed to approximate most closely to the temperature of the brain among non-invasively accessible temperatures of the body (Benzinger and Taylor 1963; Brinnel and Cabanac 1989).

Methods

Subjects. Seven patients were selected for the temperature measurements. Five of them underwent minor subarachnoid haemorrhages (SAH), I° according to Botterel's scale (no loss of consciousness, no neurological deficit at the onset of SAH). One patient was suspected of having harboured a caverno-carotid fistula; eventually this was not confirmed. The patients were examined at least 10 days following SAH. All of them were fully conscious, with no neurological deficit and free of any distress at the time of investigation. There were six men and one woman, aged 24–47 years. The subjects were fully informed of the procedure and gave their consent. No intracranial abnormality was found in three cases, a minor arterio-venous malformation was discovered in one patient and an aneurysm in each of the remaining three.

Procedure. Commercially available copper-constantan thermocouples (Physitemp, USA) were used for temperature measurements. The T_{ty} was measured with a 0.2-mm thermocouple placed on the anterior lower quarter of the tympanic membrane under visual control (Brinnel and Cabanac 1989). The T_{re} was measured from a thermocouple placed 3–4 cm into the rectum. The temperature was read with a BAT 3 thermometer (Physitemp, USA), at an accuracy of 0.1° C in absolute temperature reading and 0.01° C in differential mode. The carotid artery was entered with a Venflon needle, the stylet was removed and a teflon sealed, flexible thermocouple (diameter 0.6 mm) was introduced through the catheter. Once the tip of the probe was in a position compatible with that of the circle of Willis (fluoroscopic control), the temperature was read and the thermometer switched to differential mode. The difference between T_{ty} and T_{Willis} could then be read directly with a resolution of 0.01° C. Having completed this, the probe was slowly withdrawn with continuous, precise reading of temperature changes along the artery.

We were reluctant to introduce an oesophageal probe in most cases, to avoid any distress to the patients with the potential danger of a rupture of the aneurysm. When it was applied, the probe was introduced through the nose, to a distance 0.49 m below the nares (Caputa 1980).

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Table 1. Rectal (T_{re}), tympanic (T_{ty}), carotid (T_{Willis}) and oesophageal temperature (T_{oes}) measurements (°C)

Patient	T_{re}	T_{ty}	T_{Willis}	T_{oes}	Difference	
					T_{ty}—T_{Willis}	T_{re}—T_{Willis}
I	37.2	36.9	36.8	36.5	0.18	0.40
II	36.9	36.8	36.7	—	0.13	0.27
III	37.4	37.1	37.0	—	0.15	0.40
IV	36.7	36.4	36.2	—	0.20	0.36
V	36.9	37.0	36.6	—	0.30	0.30
VI	37.2	36.7	36.4	36.1	0.21	0.55
VII	37.1	36.8	36.7	36.5	0.08	0.34
				Mean	0.18	0.37
				SD	0.07	0.09

Results

The intention of our work was to select a group of patients undergoing cerebral angiography, who differed from healthy subjects as little as possible. Table 1 shows that all patients were virtually normothermic at the time of examination. The T_{ty} was lower by 0.24 (SD 0.19)° C than T_{re}. In three subjects oesophageal temperature (T_{oes}) measured was on average lower than T_{ty} by 0.43° C. The temperature of carotid blood at the level of the circle of Willis was lower than T_{re} by 0.30 to 0.55° C and by 0.13 to 0.30° C lower than T_{ty}. The readings of differential temperatures during withdrawal of the probe revealed that the temperature at the level of internal carotid bifurcation did not differ by more than 0.02 to 0.03° C from the one recorded in lower segments of the artery. It would to confirm suggestions made that no significant heat exchange takes place within the cavernous sinus during normothermia (Hayward and Baker 1969).

The T_{oes}, recorded in three patients of our series, was lower than the temperature of arterial blood by 0.2 to 0.3° C. This finding would seem to indicate that T_{oes}, considered to be the best approximation of arterial blood temperature, is in fact somewhat "contaminated" by the lower temperature of mixed venous blood, returning from the splanchnocranium and upper limbs (Shiraki et al. 1986).

Discussion

The brain-blood temperature gradient is the main mechanism for the removal by convection of the large brain metabolic heat production. Cerebral heat production has been estimated to be 4.7 cal$\cdot$s^{-1}, or 20 W (Rasch et al. 1991). Assuming the specific heat of blood at close to 1.0 kcal$\cdot$l^{-1} (4.2 kJ$\cdot$l^{-1}) and cerebral blood flow at 0.55 l$\cdot$kg$^{-1}\cdot$min^{-1}, it can be calculated that the amount of heat produced by a brain would raise the temperature of incoming arterial blood by 0.35 to 0.5° C (Shiraki et al. 1988; Rasch et al. 1991). Such a range of difference is to be expected between the temperature of the brain and that of the arterial blood, as it has been assumed that no additional heat sink influences cerebral thermoregulation during normothermia (Cabanac and Caputa 1979; Narębski 1985; Rasch et al. 1991). In our series of experiments the difference between T_{ty} and T_{Willis} amounted only to 0.18 (SD 0.07)° C. This finding would suggest, that the average temperture of the brain is somewhat higher than temperature recorded on the tympanic membrane. Information regarding this subject is very sparse (Mellergard and Nordstrom 1990; Shiraki et al. 1988). Unpublished data of ours has suggested that the temperature in the subdural space lies within 0.1° C difference from T_{ty}, being actually lower in some normothermic subjects. The ventricular temperature (T_{ventr}) has been reported to be about 0.5° C higher than T_{ty} [(Shiraki et al. 1988) this value also showed up in our preliminary investigations]. The mean offset between T_{ventr} and T_{Willis} can therefore be estimated at 0.7° C, which means it is greater than the one calculated from a theoretical cerebral heat balance. This calculation would support the thesis that centrifugal thermal gradients may exist in the normothermic human brain (Mellergard and Nordström 1990) and the temperature corresponding to the balanced heat exchange prevails somewhere between the ventricles and the surface. What mechanism is responsible for producing such a gradient in normothermy is a very intriguing question, especially if we remember that the flushing of the surface of the brain by cool blood, coming back from the scalp and splanchnocranium (selective brain cooling) has been supposed to occur only in hyperthermia (Cabanac and Caputa 1979; Cabanac and Brinnel 1985).

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