Heat loss from the upper airways and through the skull: studies of direct brain cooling in humans

Background

This research began from attending a lecture on stress management in which it was mentioned that breathing through the nose for relaxation purposes also cooled the brain. I immediately wondered whether being unable to nose breathe had an adverse effect on brain temperature in intubated, brain-injured patients.

Increased temperature is common after brain trauma and stroke and considered to be detrimental to outcome [Polderman, 2008]. It is usually treated with systemic cooling but targeting cooling interventions at the head may be more logical because the brain is the site of injury [Harris and Andrews, 2005].

The brain is cooled by arterial blood from the body, but cooling also occurs by heat loss from the upper airways and through the skull by delivery of blood cooled in the nose and head skin to the brain, through changes in the direction and rate of venous blood flow in veins of the face, scalp and skull [Zenker and Kubik, 1996;Harris and Andrews, 2005]. There was very little clinical research on the effect of heat loss from the upper airways and through the skull on intracranial temperature in humans, apart from one small study showing that brain temperature reduced when patients were extubated and able to nose breathe again [Mariak et al., 1999].

Aims

- To advance knowledge and understanding of mechanisms of heat loss from the head in humans.
- To explore whether these mechanisms might be utilised therapeutically to reduce brain temperature after brain injury.

Methods and results

This research was exploratory with findings at each stage suggesting the next avenue of investigation. Two randomised controlled trials in patients and a healthy volunteer study were undertaken. I tested all the interventions on myself before using them for research.

The first trial aimed to find out if restoring ‘normal’ airflow through the upper respiratory tracts of intubated, brain-injured patients reduced brain temperature. There were no relevant pilot data therefore the power calculation was defined as a multiple of the unknown standard deviation. Air at room temperature and humidity, replicating normal resting minute volume, was continuously administered nasally to 15 patients. After a 30 minute baseline, they were randomised to receive airflow or no airflow for 6 hours and then crossed over for a further 6 hours. The airflow did not produce significant reductions in intracranial temperature (Mean -0.13 °C, SD 0.55 °C, 95% CI -0.43 to 0.17 °C). However, my continuous presence with each patient during the trial meant that unusual brain temperature fluctuations in one of them were noticed, the cause investigated and identified as intermittent air conditioning inducing heat loss through the skull.

This led to a formal investigation of heat loss through the skull, using head fanning, in a factorial trial which also included nasal airflow with enhancements intended to

overcome some of the possible reasons for the neutral results with 'normal' airflow. One likely reason was increased sympathetic tone after brain injury, which inhibits heat loss from the nose. After a 30 minute baseline, 12 intubated, brain-injured patients received enhanced nasal airflow (unhumidified air at twice minute volume, with 20 ppm nitric oxide gas to reduce sympathetic tone locally), bilateral head fanning (total flow 8 m/s), both together, and no intervention in randomised order. Each intervention was delivered for 30 minutes followed by 30 minutes washout. Mean brain temperature was reduced by 0.15 °C with nasal airflow (p=0.001, 95% CI 0.06 to 0.23 °C) and 0.26 °C with head fanning (p<0.001, 95% CI 0.17 to 0.34 °C). The estimate of the combined effect of airflow and fanning on brain temperature was 0.41 °C. Physiologically, this study demonstrated that heat loss through the upper airways and through the skull can reduce parenchymal brain temperature in brain-injured humans, that the effects are additive and onset of temperature reduction is rapid.

Heat loss through the skull seemed the most promising mechanism for therapeutic purposes. Therefore a convective head cooling device was developed and assessed in a non-randomised pilot study in healthy volunteers. Intracranial temperature was measured non-invasively across the brain by magnetic resonance spectroscopy (MRS). After a 10 minute baseline, five volunteers received 30 minutes head cooling followed by 30 minutes head and neck cooling, via a hood and neck collar delivering 14.5 °C air at 42.5 L/s. The net MRS brain temperature reduction with head cooling was 0.45 °C (SD 0.23 °C, p=0.01, 95% CI 0.17 to 0.74 °C) and with head and neck cooling 0.37 °C (SD 0.30 °C, p=0.049, 95% CI 0.00 to 0.74 °C). There was no significant reduction in cooling with progressive depth into the brain, i.e. core brain was cooled.

Discussion and contribution to nursing scholarship, innovation and health care
Temperature management is an important part of intensive care nursing and a legitimate, if in this case unusual, field of study for nurses.

This research is work in progress and has not yet significantly affected intensive care practice. However it has contributed to knowledge and understanding of the physiology of heat loss from the head and been cited in that context. Among physiologists, a key controversy regarding human brain cooling mechanisms centres on the difficulty of measuring intracranial temperature in healthy people [White et al., 2010]. Cross-sectional MRS brain temperature measurement was a novel approach to assessing heat loss from the head which we are continuing to research, with two studies in progress.

Clinically, factors which enhance or inhibit heat loss from the upper airways and through the skull can have an effect on brain temperature, but the therapeutic potential of these heat loss mechanisms requires further research, which is part of my postdoctoral work. This thesis forms part of a small but growing body of pioneering head cooling research in brain injury [Christian et al., 2008]. Methods vary but our common aims are to target the damaged organ – brain – and reduce the complications of cooling. My hope is that eventually non-invasive convective head cooling will provide a comfortable, practical means of reducing brain temperature suitable for patients with a range of brain injury acuity.

(1000 words)

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