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# SELECTIVE BRAIN COOLING IS IMPAIRED IN REM SLEEP

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In mammals, the arterial blood perfusing the brain is primarily cooled through the cool venous blood returning from the systemic heat exchangers of the body (upper airway mucosa, ear pinna, horn, glabrous skin, tail) to the heart (systemic brain cooling).

In some species (e.g., cat, dog, sheep, and goat), there is, in addition, a mechanism for selective brain cooling (Fig. 1) in which the carotid blood supply to the brain is thermally conditioned prior to entering the circle of Willis (6, 11). Countercurrent heat exchange is achieved by a network of fine vessels (the carotid rete) in contact with cranial venous plexuses receiving cool venous blood from the systemic heat exchangers of the head (nasal mucosa, ear pinna, horn). In this selective heat exchanger, heat is transferred from the warmer arterial blood (aortic arch temperature) to the cooler venous blood returning from heat dissipating systemic heat exchangers of the head.

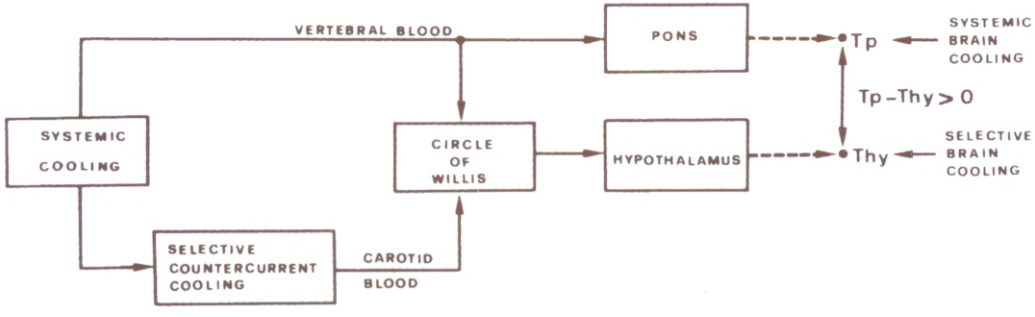


Fig. 1. - *Schematic diagram showing the mechanism of selective brain cooling in the cat, a species which has a carotid rete.*

Only the routes of blood flow thermally relating systemic and selective heat exchangers with the encephalon are indicated. Vertebral arterial blood is warmer than the carotid arterial blood perfusing the brain since the latter is additionally cooled by countercurrent heat exchange (selective cooling).

In contrast, vertebral artery blood is not thermally conditioned by selective heat exchange and enters the circle of Willis at the same temperature as the blood leaving the aortic arch. The difference between vertebral blood temperature (systemic cooling only) and carotid blood temperature (both systemic and selective cooling) is determined by selective heat loss and is, therefore, a quantitative indicator of the intensity of selective brain cooling. Practically, this difference may

be also appraised by recording pontine and hypothalamic temperatures since, under analogous conditions of metabolic heat production, their difference is determined primarily by the difference in the temperature between the carotid and vertebral artery blood (3, 4).

Recent experimental results show that selective brain cooling is fully operative during NREM sleep but impaired during REM sleep.

The increased pontine-hypothalamic temperature difference associated with the decrease in both temperatures, found during NREM sleep with respect to wakefulness, are effects of a state-dependent increase in systemic heat loss. This increase enhances secundarily also selective heat loss, as shown experimentally by inducing changes in heat loss from the ear pinna during NREM sleep in the cat (3). Moreover, the difference between pontine and hypothalamic temperatures was studied in the cat as a function of head heat exchanger vasomotion appraised by the difference between hypothalamic and ear pinna temperature during the wake-sleep cycle and under different thermal loads (15). The results show that in wakefulness and NREM sleep the pontine-hypothalamic temperature difference is an useful indicator of selective brain cooling since it is positive and inversely correlated with the intensity of vasoconstriction of systemic heat exchangers. This conclusion does not apply to the pontine-hypothalamic temperature difference during REM sleep, as experimentally induced changes in heat loss from systemic heat exchangers exert only a weak effect on the spontaneously occurring decrease in such difference in the cat (3). On this basis, the mechanism underlying the changes in the pontine-hypothalamic temperature difference in REM sleep deserves further consideration.

A study in cats of the pontine and hypothalamic temperature changes produced by transient drops in carotid blood flow, as the result of short (100 s) bilateral common carotid artery occlusion, shows a transient rise in hypothalamic temperature decreasing the pontine-hypothalamic temperature difference during wakefulness and NREM sleep (3). This is due to systemic baroreceptive reflexes and autoregulation of cerebral blood flow buffering such drops in carotid blood flow by increasing the flow of vertebral blood (7). Since the latter is warmer than carotid blood, hypothalamic temperature is raised. The rise in hypothalamic temperature does not depend on metabolic heat production, as on long lasting (300 s) bilateral common carotid artery occlusion a plateau of hypothalamic temperature is early attained (3). In contrast, bilateral common carotid artery occlusion during REM sleep scarcely enhances the marked spontaneous increase in hypothalamic temperature reducing the pontine-hypothalamic temperature difference. This indicates that during REM sleep carotid flow is spontaneously decreased with respect to the amount of vertebral blood flowing into the circle of Willis. Thus, a decrease in the efficiency of selective brain cooling explains the hypothalamic temperature rise and its plateau during REM sleep in several species regardless of the exposure to a wide range of ambient temperatures (1, 3, 10, 14, 17, 18) above and below ambient thermal neutrality (2).

The influence of carotid blood flow on the pontine-hypothalamic temperature difference across NREM and REM sleep has also been studied in cats by consid-

ering the effect produced by a chronical bilateral ligature of the common carotid artery (16). The changes in the pontine-hypothalamic temperature difference were found to be correlated with changes in ear pinna temperature (systemic heat loss) during NREM sleep before ($p < 0.003$) but not after bilateral common carotid ligature. In contrast, the changes in the pontine-hypothalamic temperature difference were correlated with the changes in ear pinna temperature (systemic heat loss) during REM sleep before ($p < 0.007$) and after ($p < 0.011$) bilateral common carotid ligature. This shows that the pontine-hypothalamic temperature difference is mainly influenced by carotid blood flow (selective brain cooling) during NREM sleep and by vertebral blood flow (systemic brain cooling) during REM sleep.

On the basis of the experimental data presented above, the mechanisms underlying brain cooling during the behavioral states of the wake-sleep cycle may be summarized as follows (13).

During wakefulness, the high tonic vasoconstrictor sympathetic outflow to systemic heat exchangers and the head-up posture (negative hydrostatic load decreasing transmural pressure) reduce both systemic and selective brain cooling: vertebral and carotid artery blood temperatures are higher than during NREM sleep and their difference is decreased (4). From wakefulness to NREM sleep, the state-dependent decrease in tonic vasoconstrictor sympathetic outflow (5) and the head-down posture (decrease in negative hydrostatic load and the raising of transmural pressure) enhance systemic and selective brain cooling: vertebral and carotid blood temperatures are lower than during wakefulness and their difference is increased (4). In fact, a sharp decline in hypothalamic temperature (occurring in 2-4 min), which is steeper at low ambient temperatures, is observed immediately in cats when the head is lowered to assume the sleep posture (14). During REM sleep, however, the autonomically regulated balance between transmural pressure and vasoconstriction is disturbed in several vascular beds (8-10, 12, 17). The resulting alteration in the balance between carotid and vertebral blood perfusion of the circle of Willis, which receives an increased supply of vertebral blood to replace a relative decrease in the supply of carotid blood, weakens the influence of selective brain cooling on hypothalamic temperature which rises to approach the temperature of the vertebral blood (3). In conclusion, during REM sleep hypothalamic temperature is primarily influenced by the temperature of vertebral blood which, as described previously, is only dependent on the heat loss from systemic heat exchangers.

## SUMMARY

There are systemic and selective mechanisms for brain cooling in mammals. The difference between the temperatures of the vertebral and the carotid blood perfusing the brain is determined by selective heat loss and is, therefore, a quantitative indicator of the intensity of selective brain cooling. Across the wake-sleep cycle systemic and selective brain cooling are affected by state-dependent autonomic changes. In REM sleep selective brain cooling is impaired.

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