

A Brain-cooling System in Mammals

Carnivorous mammals and some of their mammalian prey endure lethal extremes of heat and exertion because they have a rete, or heat-exchange network, that keeps the brain from getting too hot

by Mary Ann Baker

On a hot day a dog can keep a rabbit on the run until the rabbit dies. How is this possible? The answer is that although running raises the temperature of both animals, the dog's brain has a cooling system and the rabbit's brain does not. If the rabbit cannot find a hiding place where it can cool off, the temperature of its brain soon reaches a lethal level.

Specifically what the dog has that the rabbit does not is a countercurrent heat-exchange plexus at the base of its brain, an anatomical feature found in some mammals but not in all. This plexus, consisting of a network of small blood vessels branching from the carotid arteries, was first recognized more than two millennia ago by the Greek physician Herophilus. As he was dissecting the head of an animal (probably a sheep) in about 300 B.C. he discovered a prominent network of blood vessels at the base of the brain.

Herophilus described the structure, but it was the anatomist Galen who made it famous nearly half a millennium later. Working in Rome in the middle of the second century A.D., he ascribed functions to the arterial network that appear to be responsible for the term that was soon applied to it: the *rete mirabile*, or wonderful net. Galen was not able to obtain human cadavers for dissection, and so his descriptive anatomy came mainly from the study of domesticated animals. In his view the carotid *rete* was a key anatomical structure: it acted to transform the "vital spirit," which was carried through the arteries, into the "psychic spirit." That spirit was then transported through the body by the nervous system, which Galen believed consisted of hollow tubes.

Galen had a profound influence on later anatomy and medicine. From his day until the time of the Renaissance, anatomists who had human heads to dissect were expected to find the wonderful net because Galen had described it, even though it is not present in man and other primates. The great Renaissance anatomist Vesalius, writing in about 1538, de-

scribes the dilemma: "I who so much labored in my love for Galen... never undertook to dissect a human head in public without that of a lamb or ox at hand, so as to supply what I could in no way find in that of man, and to impress it on the spectators, lest I be charged with failure to find that plexus so universally familiar by name."

Countercurrent heat-exchange networks are not limited to the brain of certain mammals; they are found in other parts of the body throughout the animal kingdom. They are responsible for the ability of wading birds to stand for long periods in cold water, for the ability of some sea mammals and fishes to live in polar seas and for the ability of such tropical mammals as sloths and anteaters to conserve body heat at night. Here, however, we shall be concerned only with the first wonderful net to be discovered, the carotid *rete*, and the role it plays in keeping the brain cool.

No carotid *rete* is found among the monotremes (the order that includes the platypus), the marsupials, the perissodactyls (the order that includes the horse, the rhinoceros and the tapir), the rodents, the lagomorphs (the order that includes rabbits and hares) and, as we have seen, the primates. For example, in man blood is supplied to the brain through the right and left internal carotid arteries and the right and left vertebral arteries. At the base of the brain the four arteries are connected in the circle of Willis, named for the English anatomist who described it in the 17th century. It is from this circle that all the major arteries supplying blood to the brain arise.

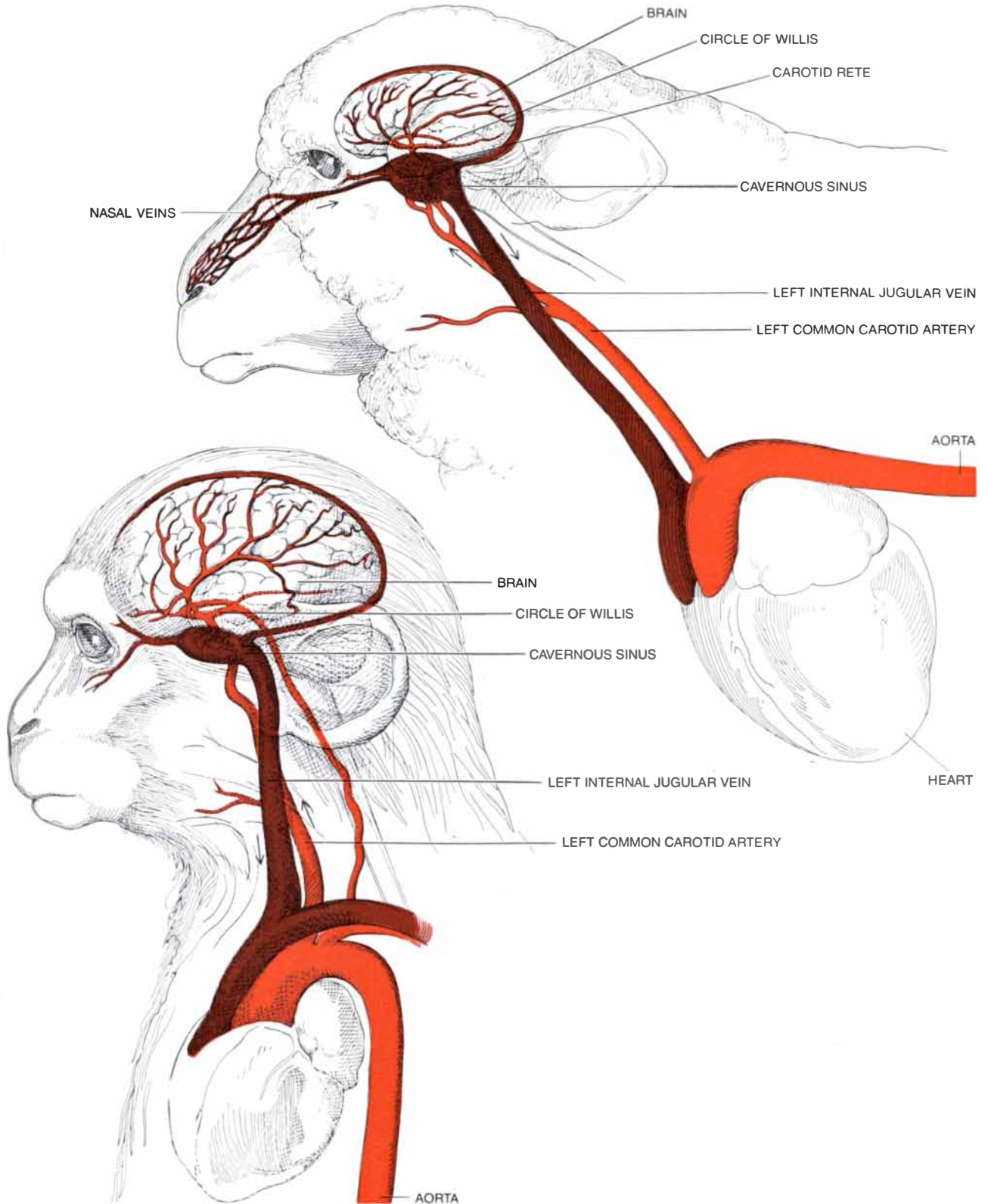
Among the artiodactyls (the order that includes cattle and the other hoofed mammals with even-numbered toes) and many carnivores the pattern of the blood supply to the brain is quite different. Instead of receiving blood from the two pairs of cranial arteries the circle of Willis in these animals is supplied mostly or entirely by the carotid *rete*. The *rete* in turn receives blood either from

branches of the left and right internal carotid arteries or from branches of the external carotid arteries or from both. The right and left vertebral arteries are present, but they are often very small. Thus the *rete* is interposed between the two common carotid arteries and the circle of Willis, and almost all the arterial blood that flows into the brain passes through it.

The size and shape of the carotid *rete* varies among the species of mammals that have it, although in some of these species the *rete* has not been examined in detail. For example, among the carnivores all members of the cat family have a well-developed *rete*: a network of vessels 200 to 300 microns in diameter. These are medium-size vessels, much smaller than the arteries that enter and leave the *rete* but much larger than the capillaries. Among dogs, wolves and hyenas and among some seals and sea lions the *rete* is small and consists of no more than a few twisting medium-size arteries.

All mammals, those with a carotid *rete* and those without it, show the same anatomical arrangement at the base of the brain. There, where the arteries that supply the brain with blood enter the cranial cavity, large reservoirs of venous blood are found. Known as the venous sinuses, the reservoirs receive blood from veins both outside and inside the skull. One of the reservoirs is known as the cavernous sinus; in mammals that have no *rete* the internal carotid arteries run through the cavernous sinus on their way to the circle of Willis. In animals that have a *rete* the arterial plexus either lies inside the cavernous sinus or is associated with a similar plexus of venous blood vessels that is connected to the cavernous sinus.

In both arrangements the arteries are bathed by venous blood but the arterial blood and the venous blood do not mix. That is not surprising with respect to the internal carotid arteries, which have normally thick walls. The walls of the *rete* arteries, however, are unusually thin, as I have determined in studies



SUPPLY OF BLOOD to the brain of a mammal moves from the heart in one of two basic ways, depending on whether or not the mammal has a carotid rete. As illustrated schematically here, the sheep (*top*) has a rete but the monkey (*bottom*) does not. In the sheep arterial blood is distributed to the brain from the network of vessels known as the circle of Willis. Some of the blood arrives at the circle via the vertebral arteries but most arrives via the common carotid arteries and their branches, detouring through the network of vessels that forms the carotid rete. This network, located within a pool of ve-

nous blood in a cavity known as the cavernous sinus, acts as a heat exchanger: the warmer arterial blood loses heat to the cooler venous blood. As a result most of the arterial blood that reaches the sheep's brain is at a lower temperature than it was when it was pumped from the heart. In the monkey the arterial blood travels from the heart via the vertebral and carotid arteries and their branches directly to the circle of Willis. The internal carotid arteries pass through the cavernous sinus with a minimum of heat lost to the pool of venous blood there, and so the blood is supplied to the brain at heart temperature.

conducted in collaboration with Wendelin J. Paule and Sol Bernick at the University of Southern California School of Medicine. Why is the barrier between the arterial blood and the venous blood so insubstantial? The answer to this question helps to explain the major function of the carotid *rete*.

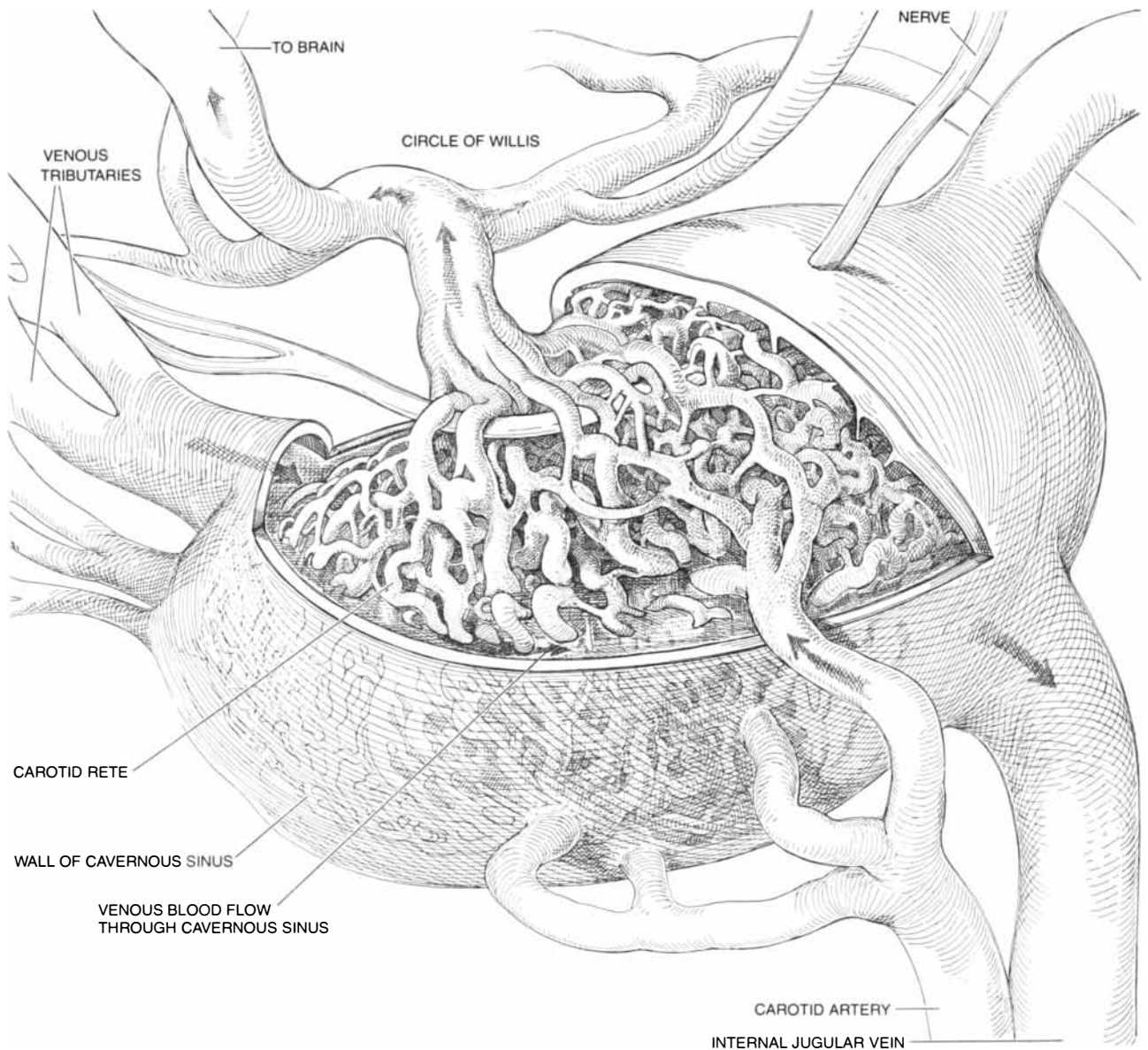
Since the supply of blood to the brain is of major physiological and clinical importance, the anatomy and physiology of the system have been studied in much detail. The metabolic processes of the brain operate at a high rate, and the organ must be supplied with blood at a rate of flow high enough to supply oxygen and nutrients and carry away waste products. If the supply is interrupted, the brain cells can be irreversibly dam-

aged; an interruption may be damaging within a matter of minutes or in no more than a few seconds, depending on the circumstances. It is not surprising that the carotid *rete*, intimately associated with the supply of blood to the brain, has intrigued investigators for hundreds of years.

The question of whether the *rete* does or does not play some role in regulating the rate of blood flow to the brain still remains unanswered. What is now understood, however, is its function in the quite different role of a heat exchanger for cooling the arterial blood destined for the brain. The work leading to an understanding of this role began for me some 10 years ago in the laboratory of James N. Hayward at the University of

California at Los Angeles. It was known that in vertebrate animals generally the temperature of the brain was important for the regulation of body temperature. As a result we were interested in finding out how brain temperature was controlled.

Our first studies arose from the observation that rather large changes in brain temperature, as much as one or two degrees Celsius, take place when mammals go from one behavioral state to another. For example, when a relaxed rabbit is suddenly alerted, its brain temperature rises, and when the rabbit relaxes again or goes to sleep, its brain temperature falls. Some investigators had suggested that such temperature



CAROTID RETE, located within a hollow known as the cavernous sinus at the base of a sheep's brain, is exposed in this cutaway drawing. Venous blood, draining from the nose and mouth, enters the sinus from the left, bathes the small arteries of the *rete* and leaves via

veins that enter the internal jugular vein at the right. At the same time arterial blood from the heart enters the *rete* via branches of the external carotid artery (*right*) and travels on to the circle of Willis (*top*) after losing some of its heat to the pool of cooler venous blood.

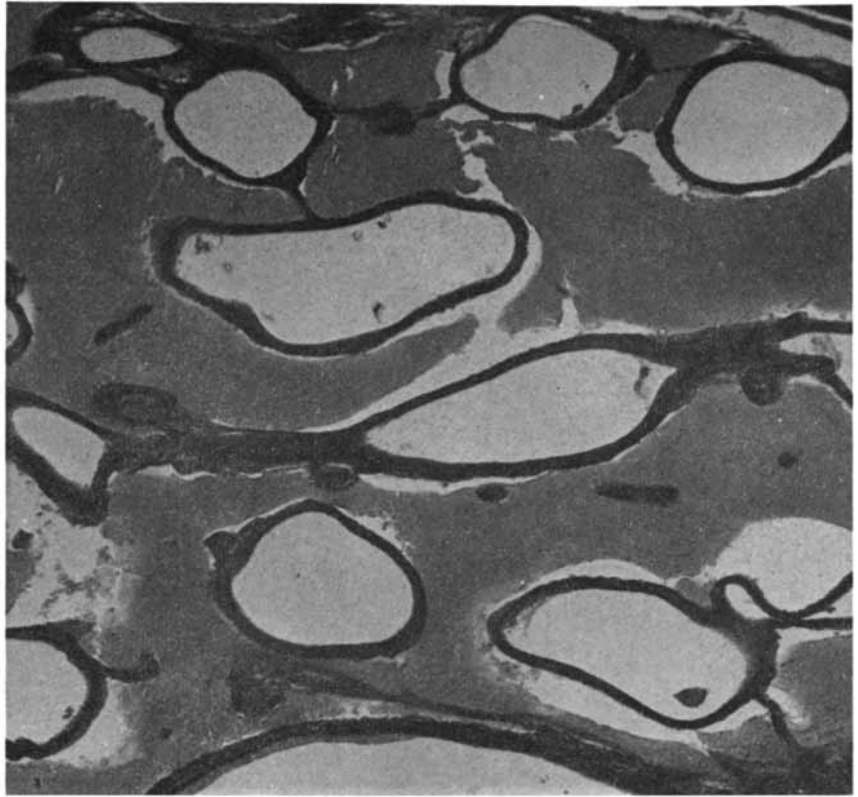
changes were caused by increases or decreases in the metabolic rate of the brain; our studies showed that this was not so.

Selecting monkeys and rabbits as our experimental animals, we implanted very small thermocouples in each subject: one thermocouple near the arteries of the circle of Willis, a second in the animal's brain and a third in a carotid artery near the aorta. The leads to the thermocouples were attached to plugs fixed to the animal's head; long wires led from the plugs to automatic temperature recorders, making it possible for us to monitor changes in temperature as we observed the animal's behavior. We found that all the changes in brain temperature were preceded by changes in the temperature of the arterial blood being supplied to the brain.

What caused the changes in the arterial blood temperature? We found that they were the result of changes in the rate at which heat was being lost from the animals' skin. When the flow of blood through the skin increases, so does the heat loss; when the flow decreases, the heat loss is reduced.

The dilation and constriction of the blood vessels of the skin are controlled by the autonomic nervous system, a system that is affected by emotion and activity. For example, when an animal is excited, the autonomic nerves cause constriction of the blood vessels in the skin; heat loss is reduced and the body-core temperature, including the temperature of the arterial blood, rises. Soon afterward so does the temperature of the brain. Conversely, when an animal relaxes, the autonomic nervous system allows the blood vessels in the skin to dilate, heat loss through the skin increases and the temperature of the body core falls. In rabbits one of the most important heat-exchange areas is the ear; the fur there is thin and the tissues are richly supplied with blood. In monkeys the hand and the foot are important heat-exchange areas; in human beings the hand is. Indeed, this same autonomic reaction occurs in human beings. When we are excited or upset, our hands tend to get cold. When we relax, they warm up.

While we were studying the brain and blood temperatures of rabbits and monkeys we found that the temperature of the arterial blood in the carotid artery and of the arterial blood in the circle of Willis were the same. We wondered whether the same pattern would be found in other species. Our next experimental animals were cats and sheep, species that unlike rabbits and monkeys have a carotid *rete*. We implanted three thermocouples in the new subjects. When either animal was in a relaxed state, we found that, as in rabbits and monkeys, the temperature of the brain was higher than the temperature of the



CAROTID RETE of a cat is seen in section in this micrograph. Varied in size, the thin-walled arteries lie in a lake of cool venous blood, secured in place by strands of connective tissue.

arterial blood at the circle of Willis. When the animals were active, the temperatures rose, as they also had in the rabbits and monkeys. We found, however, that during activity the arterial blood at the circle of Willis remained cooler than the blood at the third thermocouple, which was emplaced near the aorta. Somehow in cats and sheep the arterial blood was being cooled as it flowed from the heart to the brain. This was quite different from our findings in rabbits and monkeys.

The only major difference between the two sets of experimental animals as far as the blood supply to the brain was concerned was the absence of a carotid *rete* in monkeys and rabbits and the presence of the *rete* in cats and sheep. This fact suggested that in our new subjects the *rete* was functioning as a countercurrent heat exchanger. To test this hypothesis we implanted an additional thermocouple in the animals' cavernous sinus, where the venous blood surrounds the arteries of the *rete*. We found that the venous blood also underwent temperature changes: it was cooler when the animals were relaxed or sleeping and warmer when they were alert or excited. Regardless of the animals' state, however, the venous blood was cooler than the arterial blood entering the *rete*, and so a countercurrent heat exchange was taking place.

This led us to two further questions. What is the source of the venous blood

in the cavernous sinus? Why does the temperature of the venous blood change when the animal's activity changes? As to the first question, venous blood arrives at the cavernous sinus from several sources. Some of it comes from the base of the brain; we would expect this blood to be warmer than arterial blood because the brain has added heat to it. Much of the venous blood, however, comes from areas outside the cranial cavity. For example, anatomists have known for a long time that the venous blood draining from the nose and parts of the mouth can flow into the intracranial sinuses.

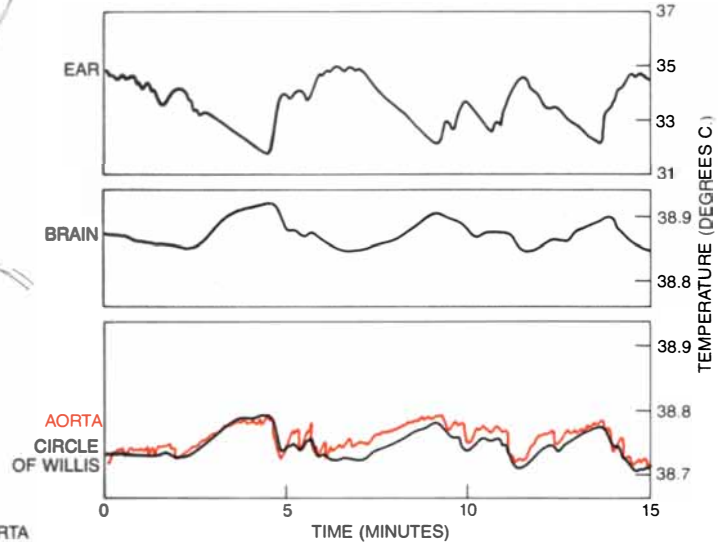
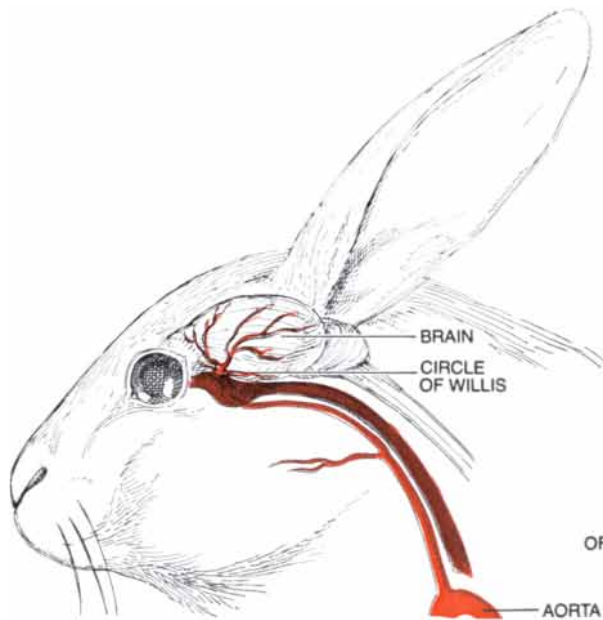
James H. Magilton and Curran S. Swift of Iowa State University have studied the venous drainage of the nose, with dogs as their subjects. They found that changes in temperature within a dog's nose will change its brain temperature by changing the temperature of the nasal venous blood that flows into the cranium. In an anatomical study of our own we traced a similar flow in sheep. Working with preserved sheep heads, we injected colored latex into the veins of the nose; we found that the latex filled the cavernous sinus at the base of the brain where the sheep's carotid *rete* is located.

Such studies enabled us to answer the first of our questions: the venous blood that was affecting the temperature of the arterial *rete* came from the animals' nasal passages. As for the question of

changes in temperature, these changes reflect the condition of the nasal mucosa: the moist lining of the nasal passages. The blood vessels of the nasal mucosa, like the blood vessels of the skin, are under the control of the autonomic nervous system. When an animal, including

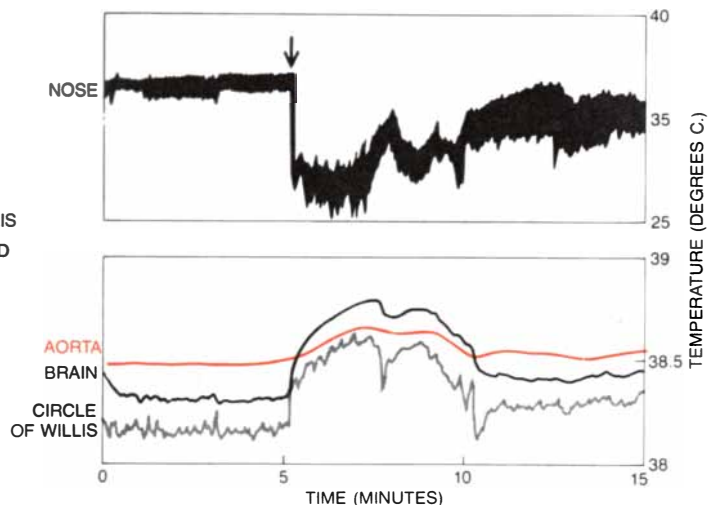
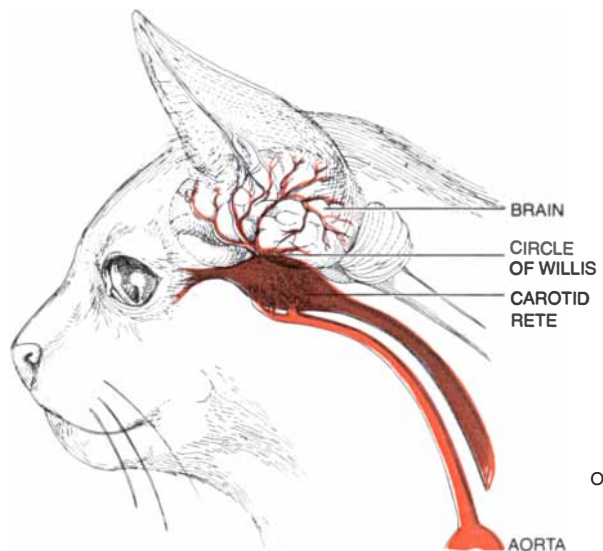
the human animal, is relaxed, the blood vessels of the nasal passages are dilated and the venous blood is cooled by the evaporation of moisture from the mucosa. When the animal is excited, the blood vessels of the nasal mucosa are constricted by the autonomic nerves.

The action decreases the amount of blood flowing through the nasal passages and also the amount of venous blood flowing from the nose to the cavernous sinus in the cranium. The decrease in the supply of cool venous blood diminishes the heat exchange be-



BLOOD-TEMPERATURE CHANGES in a rabbit proved to be correlated with changes in the heat loss from the ear. The dilation and constriction of the blood vessels in the ear of the rabbit, a major heat-exchange surface, are controlled by the autonomic nervous system. When the blood vessels of the ear are unconstricted and the air temperature is 25 degrees Celsius, the temperature of the ear is gen-

erally above 34 degrees. When the autonomic nerves constrict the blood vessels of the ear, the temperature of the ear drops. The drop is followed by a rise in the temperature of the arterial blood flowing from the heart through the aorta to the circle of Willis. The temperature of the brain, which is normally somewhat higher than the temperature of the blood at the circle of Willis, rises and falls similarly.



SIMILAR TEMPERATURE CHANGES in a sleeping cat that was wakened once during a 15-minute period are shown. The major heat-exchange surface, the mucosa of the cat's nose and mouth, is similarly under the control of the autonomic system. While the cat sleeps the heat loss through the nose is high and evaporation cools the venous blood draining into the cavernous sinus. There the warmer arterial blood moving from the aorta to the circle of Willis is cooled by the venous blood as it flows through the carotid rete. When the cat

wakes (arrow), the autonomic nerves constrict the mucosal circulation, the nasal heat loss is reduced, as is the heat exchanged through the rete. The temperature of the arterial blood at the circle of Willis rises to almost match the temperature of the arterial blood from the aorta, whereas the temperature of the brain, normally lower than that of the aortic blood, briefly exceeds it. When the cat returns to sleep, the dilation of the mucosal blood vessels enhances heat exchange in the rete, and the other temperatures decline accordingly.

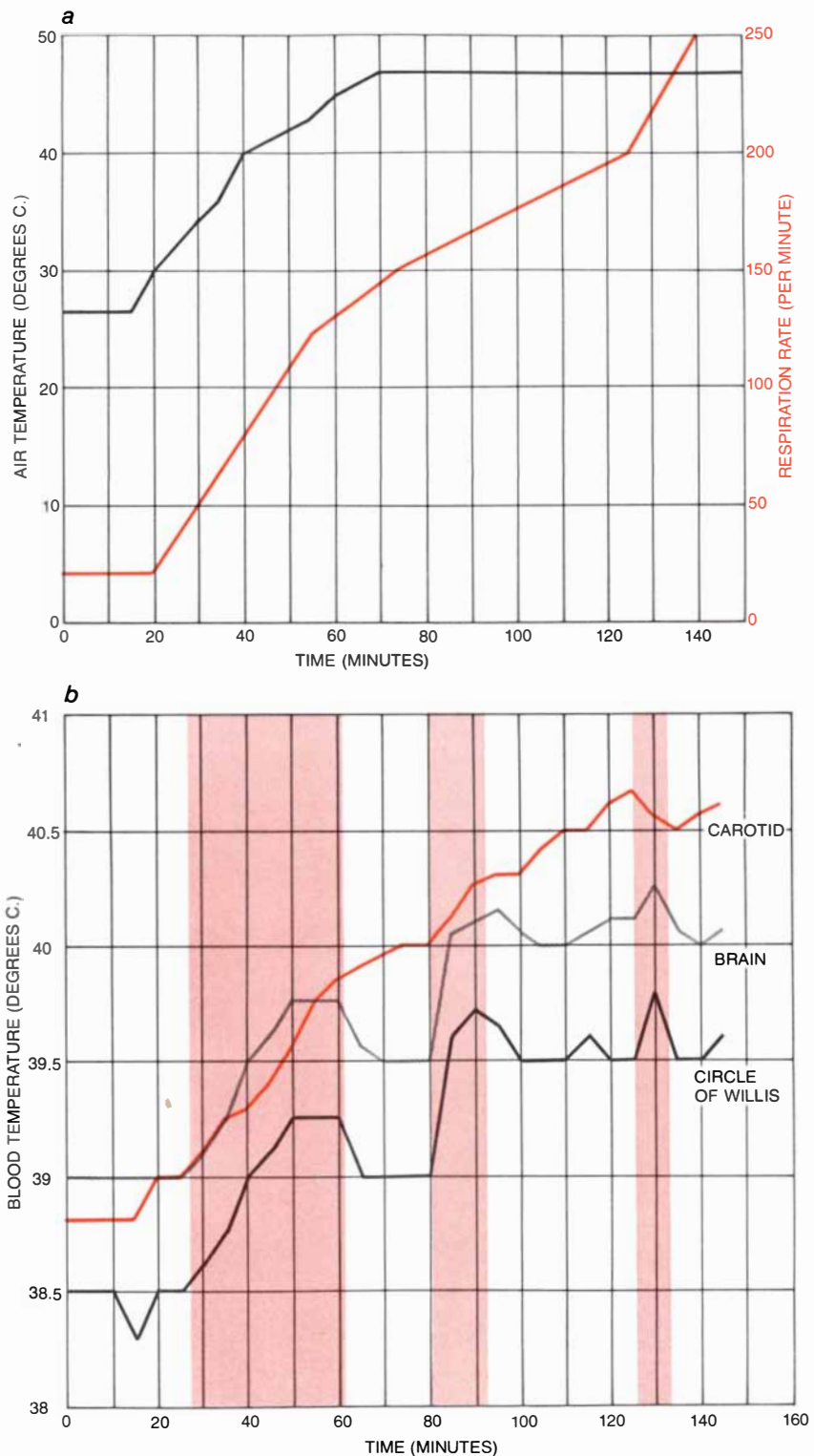
tween the venous blood and the arterial blood passing through the carotid *rete*. This results in a rise in the temperature of the arterial blood reaching the brain until this blood approaches a temperature equal to that of blood in the body core.

We confirmed the validity of this sequence of events by a series of experiments measuring the temperature of the nasal mucosa with thermocouples implanted in the nostrils of both cats and sheep. When the blood flow through the nasal mucosa increased, the temperature of the mucosa rose; when the blood flow decreased, so did the temperature of the mucosa. This exactly paralleled the changes in skin temperature we had observed in association with the constriction and dilation of the skin blood vessels. (It should be mentioned that the ambient air temperature and the animals' respiration rate remained constant during these measurements.)

Exactly how does evaporation cool the nasal mucosa? The mucosa is always moist. With each breath the animal draws relatively dry air across the moist surface, the moisture evaporates and the cooled mucosa cools the blood flowing through it. Therefore one could expect that an increase in the rate of evaporation would further decrease the temperature of the venous blood flowing from the nose and produce a consequent decrease in the temperature of the arterial blood in the carotid *rete*.

That is exactly what happened when we conducted a further experiment. We anesthetized cats and sheep and pumped air into their noses. The arterial blood supplied to the head by the heart remained constant in temperature, but the increased evaporation made the temperature of both the *rete* and the brain drop. When we repeated the experiment with a rabbit as the subject, there was no such rapid cooling. Instead the first drop in temperature took place in the carotid artery; it was followed by a lowering of the brain temperature. The sequence indicates that in the absence of a carotid *rete* the cooled venous blood from the nose must return to the heart and there cool the arterial blood moving from the heart to the brain before the temperature of the brain is affected.

Would an increase in respiratory evaporation have the same effect on animals in normal circumstances that it had on anesthetized animals? To find out we placed cats and sheep in a hot room; the flow of air through their nasal passages would naturally increase when they began to pant in response to overheating. By the time the animals were panting at a rate of 250 to 300 respirations per minute the rate of cooling of the arterial blood passing through the *rete* had also increased. Both the carotid arterial blood flowing to the input side of the *rete*



RESPONSE TO HOT ENVIRONMENT by a *rete*-protected mammal is shown in this pair of graphs. An unrestrained sheep was placed in a test chamber at an air temperature of 26 degrees C. Over a period of an hour the air was gradually heated to 47 degrees C. (117 degrees F.) and kept at that temperature for more than an hour (a); the respiration rate of the sheep, only 20 breaths per minute at the start, increased rapidly and continued to rise after the air temperature leveled off. The temperature of the blood in the sheep's carotid artery also rose steadily (b), but the animal's panting cooled the venous blood surrounding the *rete* sufficiently to keep the blood temperature in the circle of Willis below that of the blood in the carotid artery. As a result the sheep's brain, warmer than carotid blood to start, remained at or below the carotid temperature for most of the experiment. When the sheep stood up (colored bands) instead of lying down, both the brain and the blood at the circle of Willis became temporarily warmer.

and the cerebral arterial blood flowing from the output side showed a rise in temperature, but the rise was less for the blood that had passed through the *rete*.

As a result the difference in temperature between the arterial blood on the input side and that on the output side of the *rete* became greater. When the animals were kept at a normal temperature, the temperature of the input blood had been about .25 degree C. higher than that of the output blood. Now, when the animals were panting in a hot room, the input blood was a full degree warmer. The hot-room observations demonstrated the significance of the carotid *rete* as a heat exchanger. In conditions of heat stress the brain of a panting animal that has a carotid *rete* will remain cooler than the rest of its body.

The brain is particularly sensitive to abnormal temperatures. A rise of only four or five degrees C. above normal begins to disturb brain functions. For example, high fevers in children are sometimes accompanied by convulsions; these are manifestations of the abnormal functioning of the nerve cells of the overheated brain. Indeed, it may be that the temperature of the brain is the single most important factor limiting the survival of man and other animals in hot environments.

When the air temperature is higher than the body temperature, mammals would overheat rapidly if it were not for

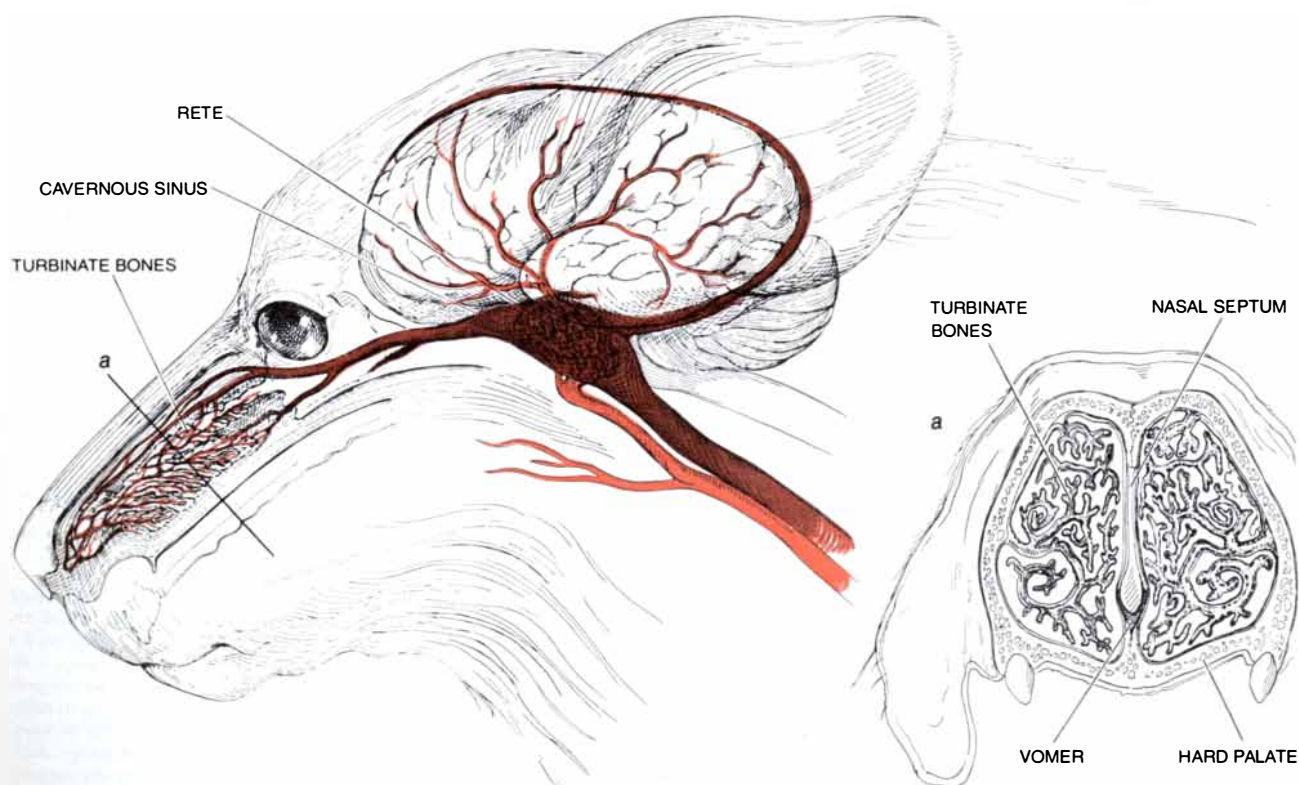
evaporative cooling. Some mammals cool themselves by both panting and sweating. Others, man and the rest of the primates included, depend exclusively on sweating. Still others rely entirely on the evaporation from the nasal and oral cavities that panting enhances. Of the mammals in this last group those with a carotid *rete* have the greatest advantage. This, we now realized, is because the venous blood that drains the evaporative surfaces of the nose and mouth almost immediately comes in close contact with the arteries of the carotid *rete*. Hence the blood supplying the brain receives the full benefit of the evaporative cooling. At the same time, when this venous blood returns to the heart to mix with venous blood from the rest of the animal's body, it provides further cooling for the circulatory system in general.

In most panting animals both the nose and the mouth are anatomically well suited to efficient evaporative cooling. The surface areas are large and moist, and the numerous connections between arteries and veins allow a high rate of blood flow. Considering the nose first, the complex infolding of the turbinate bones presents a very large surface area: in some mammals, such as dogs, the total surface of the nasal turbinates has been calculated as being larger than the rest of the body surface. The nasal interior not only is covered with mucosa richly supplied with interconnected veins and arteries but also houses an or-

gan unique to panting mammals: the lateral nasal gland. The gland secretes fluid onto the mucosa, providing a constant supply of water for evaporation. In dogs the rate of secretion of the lateral nasal gland, as studies by Charles Blatt, C. R. Taylor and M. B. Habal of Harvard University have shown, is directly proportional to the air temperature.

As for the other evaporative region, the mouth, water for cooling the mucosa that lines the oral cavity is provided by the salivary glands. These glands too increase their secretion when the ambient temperature increases. For the evaporative process to reach maximum efficiency the animal's rate of ventilation must increase at the same time the glandular secretions and the rate of blood flow through the mucosa increase; the act of panting produces the required increase in ventilation.

Does exposure to high air temperatures represent the most severe thermal stress a mammal can encounter? For most mammals the answer is no. For example, in mammals the size of cats, dogs and even sheep, Taylor has found that it is exercise rather than heated air that presents the most serious threat of overheating. In these medium-size mammals the very high rate of metabolism during heavy exercise causes an explosive rise in body temperature. For the purpose of comparison, consider our finding that when cats and sheep are at rest under conditions of abnormal



DOG'S NOSE, shown in side and front view, contains an array of complexly infolded turbinate bones that support the nasal mucosa, a

membrane that is cooled by evaporation. Cool venous blood, draining from the mucosa into the cavernous sinus, cools the dog's *rete*.

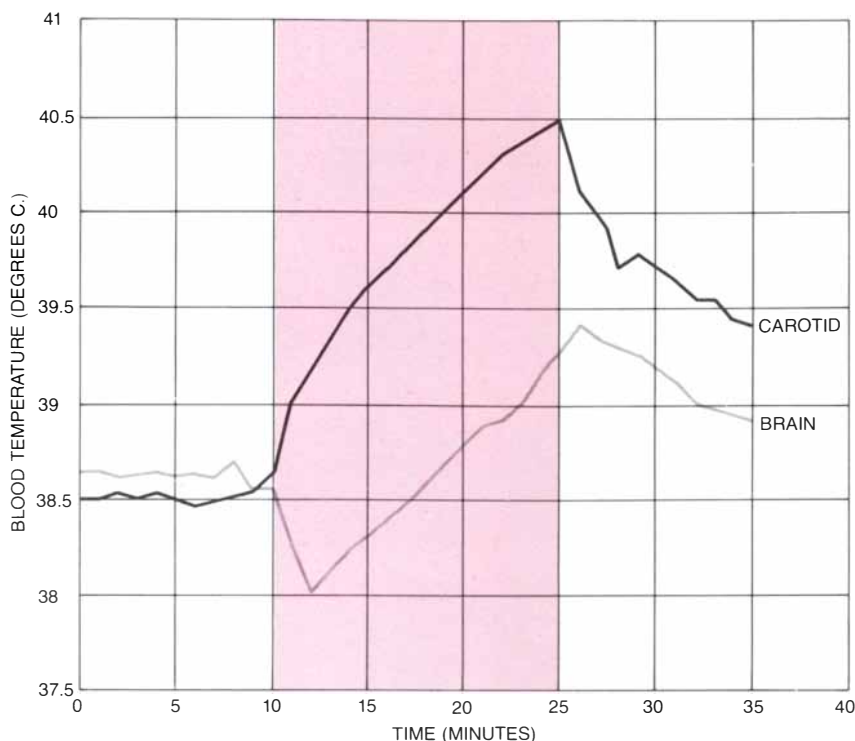
heat, they display a brain temperature one degree C. lower than their body temperature. Taylor and his colleague Charles P. Lyman made similar measurements of brain and body temperature in Thompson's gazelle (an African antelope with a carotid *rete*) when the animals were running at full speed. They found that the brain temperature dropped to almost three degrees C. below the body temperature.

This unexpectedly large cooling effect led me and my colleagues at the University of California at Riverside to suspect that the carotid *rete* might not reach its maximum efficiency as a heat exchanger except during exercise. Recent studies we have conducted with exercising dogs as subjects have confirmed the conjecture, even though dogs do not have a carotid *rete* as well developed as that of antelopes, sheep or cats.

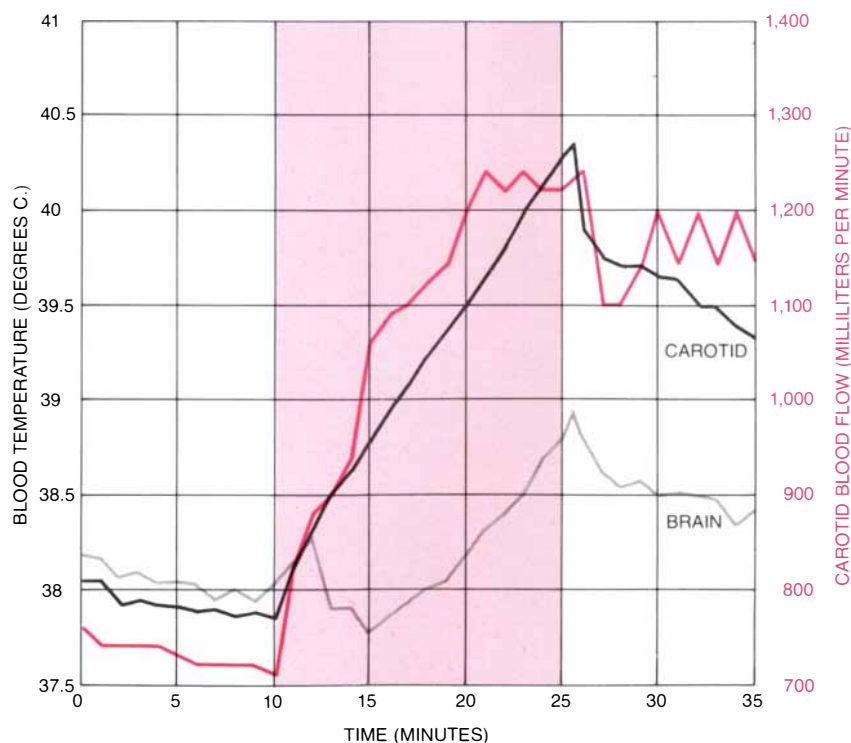
When the dogs were put in hot rooms, they reacted scarcely at all to the abnormal temperature. Both the body and the brain rose in temperature, and the brain remained only slightly cooler than the body. We found this puzzling, because dogs are known to be among the most heat-tolerant of mammals and to have a marked capacity for enduring long periods of exertion in extreme desert conditions.

We set up a treadmill in a warm, rather than hot, room and measured the dogs' brain and body temperatures as they ran on the treadmill. From the moment the dogs began to run their body temperature rose rapidly. Within the first few minutes of exercise, however, the brain temperature fell; it remained about 1.3 degrees C. below the body temperature throughout the run. That is almost three times the cooling we had observed when the dogs were at rest in a hot room.

Two of the physiological factors responsible for this high rate of brain cooling have recently been measured. The first is a large increase in the rate of ventilation when dogs exercise. R. Flandrois and his colleagues at the University of Lyons have found that a dog at rest breathes five to six liters of air per minute. In the first few seconds of hard exercise (about the same degree of exertion that is demanded of the dogs in our laboratory) Flandrois's dogs increased their rate of ventilation to 30 liters per minute. The rate thereafter rose less dramatically and reached 40 liters per minute after 15 minutes of exercise. When exercise was terminated, the rate of ventilation dropped abruptly. The primary purpose of the increase in ventilation, of course, is to deliver more oxygen and flush out more carbon dioxide in order to meet the physiological demands associated with exercise. At the same time the increase has the secondary effect of accelerating evaporation in the dogs' nasal and oral pas-



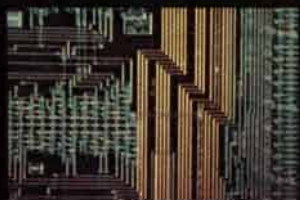
EXERCISING DOGS maintained a brain temperature significantly lower than body temperature during a 15-minute trot at 7.2 kilometers per hour (colored band) on a treadmill with a slope of 13 degrees. Warmer than the body while the dogs were at rest, the brain rapidly grew cooler at the onset of exercise and remained more than one degree C. cooler throughout the exercise period. The two traces show the mean values recorded for two dogs in four trials each.



INCREASED CIRCULATION during exercise is traced in another exercising dog, this one trotting on a treadmill with a slope of 18 degrees. At rest the blood flowed through the dog's left common carotid artery (color) at a rate of less than 800 milliliters per minute. During the 15-minute exercise period (colored band) the rate of blood flow increased to between 1.2 and 1.25 liters and remained at 1.1 liters or above for several minutes after exercise ended. The enhanced flow of blood to the nose and mouth caused an increase in the heat exchange in the carotid *rete*, as is evidenced by the consistently lower temperature of the animal's brain.

hexa·photo·cybernetic

Technology this advanced deserves its own word.



The incredible new Canon A-1. It's on the cutting edge of technology, with state-of-the-art electronics and computerized operation.

Yet, although the way we build it is complex, the way you use it is the ultimate in simplicity. If pushbutton-easy fine photography is what you're after, the A-1 can give it to you six ways.

1 Shutter Priority automation: You pick the speed to freeze or blur action or prevent camera shake, the A-1 picks the perfect aperture automatically.

2 Aperture Priority automation: Select the aperture you want for a soft back-

ground or total overall sharpness, the A-1 will give you the speed that's correct.

3 Programmed automation: On the A-1, this unique exposure mode picks both aperture and speed in ideal combinations depending on the light. You don't have to set anything.

4 Stopped-Down automation: This mode lets you get automatic exposure with any lens or accessory you can

mount on the camera. Great for astrophotography, photomicrography, close-ups.



5 Flash automation: The A-1 has the easiest elec-



tronic flash of any camera of its type. With special Canon flash units, your aperture and speed are set automatically. Just mount the flash, turn it on and shoot for perfect exposures every time.

6 For any type of photography that's not already covered, there's a manual.

There's more. Digital control and viewfinder display. Versatile control features. Accessories like a rugged motor drive, compact motorized film winder and interchangeable date/data back. Plus forty Canon FD lenses for unsurpassed image quality and scope.

You won't find another camera like it on the face of the earth. Because only Canon has the technology to make it. Luckily, you don't have to go to the ends of the earth to get an A-1. Only as far as your local Canon dealer.



THE OFFICIAL
35MM CAMERA OF
THE 1980 OLYMPIC
WINTER GAMES

Canon A-1
So advanced, it's simple.

Canon USA, Inc., 10 Nevada Drive, Lake Success, New York 11040
140 Industrial Drive, Elmhurst, Illinois 60126 • 123 Paularino Avenue East, Costa Mesa, California 92626
Bldg. B-2, 1050 Ala Moana Blvd., Honolulu, Hawaii 96814 • Canon Optics & Business Machines Canada, Ltd., Ontario

sages, thereby lowering the temperature of the venous blood.

The second brain-cooling factor to be measured is the increase in the rate of blood flow to the nasal and oral mucosa during exercise. Working in collaboration with Roland D. Rader and William Kirtland of the University of Southern California School of Medicine, we have measured the flow of blood through the common carotid artery in dogs during exercise, using an ultrasonic flow probe designed by Rader. In a large dog at rest the flow of blood through the common carotid artery is between 600 and 700 milliliters per minute. In our experiments we found that the rate began to rise at the onset of exercise and eventually reached a level in excess of 1,200 milliliters per minute.

There is no reason to believe the rate of blood flow to the brain increases during exercise. Accordingly we can assume that the additional blood flowing through the common carotid artery during exercise circulates to areas other than the cranium. Subtracting the flow destined for the brain (roughly 250 milliliters per minute), we can calculate that the flow destined for extracranial areas is about 400 milliliters per minute when the dog is resting and a full liter per minute when the dog is exercising. Since the arterial circulation passes through both common carotid arteries, the combined flow of two liters per minute represents about a sixth of the total output of the heart of an exercising dog.

Most of this extracranial flow of blood is destined for the mucosa of the dog's nasal and oral cavities, where the increased rate of ventilation during exercise has accelerated the process of evaporative cooling and the dog's lateral nasal glands and salivary glands are secreting increased amounts of water for evaporation. Hence the combination of physiological factors, by significantly cooling the brain of a panting mammal that has a carotid *rete*, provides an increased tolerance to exertion, particularly in a hot environment.

What about panting mammals that do not have a carotid *rete*? We have studied the brain and body temperatures of domestic rabbits while the animals were running. We found that their brain temperature increased in parallel with their body temperature. The animals' panting nonetheless can do something to offset the rise in brain temperature, as M. Caputa and his colleagues at Nicholas Copernicus University of Toruń in Poland have demonstrated. Measuring the temperature of venous blood returning from the nose of panting rabbits, they found that it was cooled by evaporation. As a consequence cooling by conduction lowered the temperature of regions of the rabbits' brain adjacent to the cool venous blood; these parts of the brain proved to be .5 degree C. lower in temperature than the rabbits' body.

In nature this offsetting factor appears to be trivial. Vaughan H. Shoemaker and his colleagues at Riverside have used radio telemetry to measure the body temperature of jackrabbits living unrestrained in the Mojave Desert. On a hot summer day a jackrabbit at rest has a body temperature of about 41 degrees C. When the animal is flushed from its resting place and chased, it shows a rapid rise in body temperature. Between five and 10 minutes of exertion can raise its body temperature above 43 degrees. Knut Schmidt-Nielsen and his colleagues at Duke University have demonstrated that if a jackrabbit's body temperature rises much above 44 degrees, the animal will die. It is therefore apparent that a jackrabbit unable to rest and cool off between brief periods of running cannot survive for long.

The study of the heat-exchange function of the carotid *rete* in panting mammals has raised intriguing questions about mammalian temperature regulation in general. It has long been known that there is a heat-sensitive region in the brain stem of mammals and that by sensing the temperature of the arterial blood flowing from the core of the body to the brain this region probably acts as a thermostat controlling the body-core temperature. This seems to be a valid assumption for mammals that lack the carotid *rete*; in those mammals the arterial blood does not change temperature as it passes from the body to the brain. What, however, does the brain-stem thermostat sense in a mammal that has a carotid *rete*?

What it senses is at the very least equivocal. For example, during exertion the temperature sensed by the thermostat is quite different from the actual temperature of the body core; the brain temperature and the body temperature change in opposite directions at the onset of exercise and remain at different levels during most of the exercise period. How, then, does the brain thermostat know what the body temperature is? In mammals that have a carotid *rete* are the temperatures of the brain and the body regulated independently?

We can speculate that in such animals temperature-sensitive nerve cells in parts of the body other than the brain are important in the regulation of temperature during exertion. For example, such sensors exist in the spinal cord and in the abdominal cavity and have been shown to play a thermoregulatory role in some mammals. In mammals with a carotid *rete* the input from these extracranial sensors to the region of the brain that controls body temperature may be more significant during a period of exertion than during a period of rest. What the right answers are to such questions will be learned from further study of thermoregulation in a wide variety of mammals.



Elvira



I began this series with some historical facts on how my family came to be winemakers and how our wines benefit from this heritage. I want to give due credit, also, to my grandmother Elvira - not a winemaker but a winemaker's wife.

In 1904, 16 year old Elvira Eraldi became Mrs. Samuele Sebastiani. That same year Samuele founded his long-dreamed-of winery in Sonoma and they began building our family business. While Samuele made his wine Elvira raised chickens and took in washing. She spent long hours over a scrub board to help meet expenses. Eventually, with her support, the winery grew and prospered. Samuele called her his Lady of the Vineyards.



She became an accomplished cook, laboriously making her own pastas and cheeses. Many enjoyed her culinary talents, among them, A.P. Gianini, founder of Bank of America and close friend of Samuele.

Unique was Elvira's love of birds. She raised song birds for years and stirred a similar interest in her son, August, my father, who has raised and bred rare game birds for over half a century.

I could go on but it's enough to say Elvira Sebastiani was an inspiration to her husband and to all of us who have followed.

Please write for our free monthly newsletter.

Sam J. Sebastiani



Sebastiani

VINEYARDS

EST. 1825

P.O. Box AA Sonoma CA 95476

H3