20 years with their lawyers patenting everything of interest. There will have to be a compromise. We are all aware of the problem, but we have to get big sequencing under way before we get the answer."

The genome center has had a committee looking into the data release issue for about a year now and expects to come out with a policy soon. The bottom line, says Joseph Sambrook of the University of Texas Southwestern Medical Center in Dallas, who chairs the committee, is that once a reasonable chunk of sequence is finished and checked, it should be released as quickly as possible, within some outside deadline. Sentiment is strong, says Sambrook, for making that a condition of funding. But so far, committee members haven't yet decided what that outside date should be. Meanwhile, in the absence of guidelines—and after much wrangling and some peer pressure—a consensus is starting to emerge that sequence data should be deposited within 3 to 6 months of completion.

Gilbert believes the problem will essentially disappear over the next few years anyway. At the moment, the handful of researchers doing large-scale sequencing are passionately interested in the information the DNA encodes. But eventually, he predicts, "There will be a split between those who actually get the sequence and those who analyze it." In the interim, the community will come to some truce that will give investigators one first—and probably brief—look at their long-sought data. ■ LESLIE ROBERTS

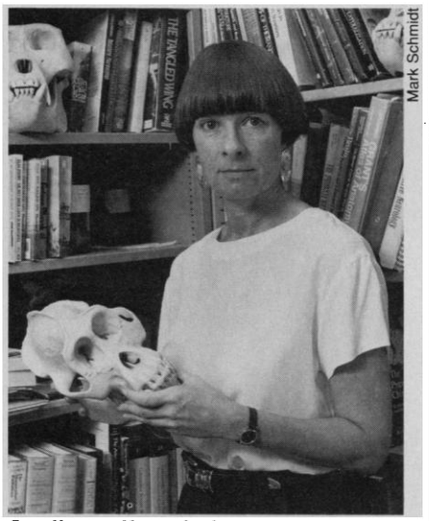
Did Cooler Heads Prevail?

A tenacious paleoanthropologist has set the pot boiling with her theory that hominid brains needed a special cooling system before they could expand to their present size

ALTHOUGH SCIENTIFIC INSPIRATION IS known to come from diverse sources, few scientific theories have been inspired by auto mechanics. Yet that was just the source of anthropologist Dean Falk's recent controversial notion of brain evolution. As her mechanic was explaining her engine's cooling system, Falk realized that a car engine and the human brain might have something crucial in common: a radiator. Falk theorized that the brain's size, like the engine's, is restricted by the capacity of the cooling system to keep it running within a certain temperature range. That insight led Falk to propose a "radiator theory" of brain evolution, an idea that has been generating a lot of heat lately among anthropologists and physiologists.

In a report published last summer in *Behavioral and Brain Science*, Falk proposed that the development of the "radiator"—in the form of a vast network of hair-thin veins that drain heat-carrying blood—was a crucial preadaptation that enabled the human brain to swell from slightly larger than the size of a chimp's to its current weight in just 2 million years. Falk also claims she can trace the evolution of this radiator from its origins in some species of early hominids to its complex form in modern humans. Indeed, she thinks certain hominid species may have hit evolutionary deadends largely because they lacked the brain radiator.

Few anthropologists or physiologists have been able to keep a cool head over Falk's theory since she published it last summer. Her backers express wild enthusiasm, claiming the radiator theory offers an entirely new perspective on brain evolution. "Falk's evidence is convincing. Her paper will be a classic in paleoanthropology," says Harry Jerison, a professor at the University of California at Los Angeles Medical School and author of a classic text on brain evolution.



Cooling off period. *Dean Falk, who theorizes that the capacity to drain away heat was crucial to brain evolution.*

The critics are equally extreme. They argue that Falk hasn't mastered brain physiology and therefore doesn't appreciate that the network of veins she describes has no significant role in brain cooling. "I think she's dead wrong," says Ralph Holloway, an anthropologist at Columbia University and a well-known specialist in brain evolution. "The radiator theory has too many leaks to be taken seriously."

Falk, a respected anthropologist who is known for tenacity, isn't fazed by the roller coaster of praise and criticism, much of which emerged in 26 commentaries by other scientists that were published along with her paper. "Paleoanthropologists are a contentious lot," she says. "It was what I expected."

One reason for all the overheating is that Falk has jumped into an area that has a long history—but few hard results. Many attempts have been made to explain how and why the human brain expanded so rapidly, with most theories attributing the explosive growth to changes in behavior: walking erect, hunting, using language and tools. But those theories are speculative, because there is no way to prove that coincident changes in behavior caused brain expansion. Which is one reason paleoanthropologists have long looked for direct evidence of anatomical changes in the brain over time.

Falk begins her case with physiology. A growing brain would need a radiator, she argues, because its tissues would be exquisitely sensitive to heat. A change of only 4 degrees Celsius, for example, begins to disturb the functions of the contemporary human brain; in children, high fevers can cause convulsions—a sign that the orderly coordination of neurons has been disrupted. But, in general, the body is cooled by the skin and the sweat glands. Does the brain have a special vascular radiator? Falk argues that it does by citing recent studies of brains of human corpses by Michel Cabanac of Laval University in Quebec.

Cabanac's work shows that the network of so-called emissary veins is spread throughout the skull. He thinks this system cools the brain during hyperthermia because its veins bring blood from the brain to the face and the surface of the skull where it is cooled by evaporation of sweat before being returned to the deeper recesses of the cranium.

Falk draws on Cabanac to postulate the existence of the "radiator" as a significant brain-cooling mechanism. The evidence hasn't convinced many physiologists, how-

ever, because it goes against long-standing theories about how blood is cooled in the human body. "I have great respect for Dr. Falk as an anthropologist, but not as the designer of radiators," says University of Washington physiologist George L. Brengelmann. "She might as well send the effluent of a car's radiator down the dipstick hole." There is no need for a special cooling system for the brain, says Brengelmann—the skin and sweat glands are enough.

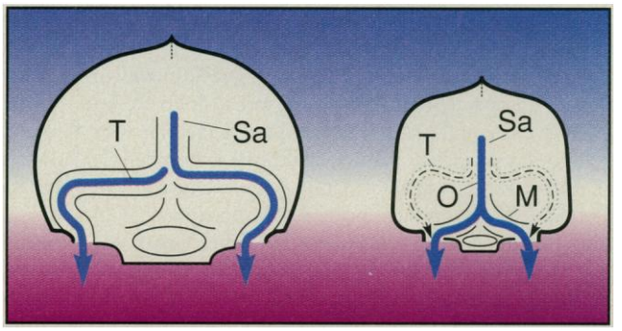
But other experts aren't nearly so quick to dismiss the idea. Arnold Scheibel, who has appointments in the departments of anatomy and cell biology, psychiatry, and the brain research institute at the UCLA Medical Center, says increased veinage might very well contribute in a special way to brain cooling. Scheibel says that as a research problem, the existence of the brain radiator is "not trivial," and he suggests it could be answered noninvasively by PET scanning or NMR measurements.

But Falk doesn't stop at arguing for the existence of the radiator. She goes well beyond Cabanac, extending the existence of the radiator back in evolutionary time, and making it a precondition for brain expansion. Her evidence comes from endocasts (detailed internal casts) and skulls of hominids who lived in Africa 3.5 million to 1 million years ago. She studied vein tracks in their brain cases and found that their circulatory systems were different from those of their knuckle-walking ancestors. In the apes, blood rushed from their heads directly into their jugular veins on their way to the heart (as it does in reclining humans).

But when the first hominids started running around on two legs instead of four, gravity put a heavy load on the blood flowing into the jugular. Falk reasons that these erect hominids developed modified vasculature that allowed blood to drain rapidly from the brain without putting undue stress on the jugular vein.

Falk finds that there were two different solutions to this problem in hemodynamics. One group of hominids—those not ancestral to modern humans—developed unusually large sinuses at the back of their heads (the occipital and marginal sinuses). When the hominids stood up, blood flowed into their sinuses, and then out of the skull to veins that surround the spinal column. Blood flowed from the brain down a pair of channels through these enlarged sinuses where it was slowed before rushing into the jugular. This system was found in skulls from several early hominid species: *Australopithecus afarensis, A. robustus,* and *A. boisei.*

But a different drainage pattern exists in other *Australopithecines* and in members of the *Homo* lineage, which leads directly to modern humans. In these specimens there are much smaller occipital and marginal sinuses. When these creatures stood up, most blood flowed instead by way of the emissary network, which feeds veins that drain to the spinal column.



Brain drain. *In modern humans (left) blood drains from the rear of the skull by way of the superior sagittal sinus (Sa) and the transverse sinus (T). In some hominids (right), most drainage was by way of the occipital and marginal sinuses (O and M).*

This second system, says Falk, is more efficient, and it gave our ancestors a clearcut evolutionary advantage in hot regions. "The network of veins in the lineage leading to *Homo* acted as a radiator that released a thermal constraint on brain size," says Falk. She stresses that the radiator wasn't the cause of larger brains but a preadaptation that allowed other behaviors, such as language, to enlarge the brain.

And why would the groups ancestral to human beings have developed a better radiator? Falk goes out on a limb and speculates that they lived under the broiling African sun in the savanna, while the robust *Australopithecines* huddled in the shade of the forests, where they could make do with less efficient cooling systems.

Some of the criticisms of this view have to do with Falk's database: the endocasts she and her colleagues studied. Columbia's Holloway, for instance, complains that most early cranial remains are in a "sorry state," making it difficult to observe emissary veins or sinus drainage patterns accurately. Anthropologist William H. Kimbel of the Institute of Human Origins, who has studied the grooves inside hominid brain cases, thinks there's so much variation from individual to individual that it's dangerous to draw any conclusions about species. Furthermore, he says, Falk has studied too few specimens to make general statements about veins and sinuses.

In addition, Holloway goes beyond the database to attack Falk's central premise that a radiator lifted a fundamental constraint on brain expansion. "No empirical evidence exists that brain size is limited by a thermal constraint (beyond metabolism), either within, between or among species," he says.

Falk is willing to admit that her data are far from perfect, but she turns that argument on her critics: "Yes, the sample sizes are small, and I wish I had 100 *Australopithecine* skulls to score," says Falk. "What's interesting is [that] the people who raise that issue haven't let it stop them (from drawing their own conclusions)." And although the fossil skulls are "grungy," she concedes, "the trends are there," and they are consistent with what has been found in modern apes and humans.

Although Falk's radiator model may have some paleoanthropologists in danger of boiling over, she does have her champions in the field. "If the venous radiator is not the prime mover for hominid cerebral expansion, it is an important accompaniment," says C. L. Brace, an anthropologist at the University of Michigan Museum of Anthropology. "Falk, in bringing attention to this, bids fair to be remembered for having given an entirely new connotation to the phrase 'the brain drain.'"

And she has supporters in other fields as well. M. Maurice Abitbol, a physician at University Hospital at the State University of New York at Stony Brook who is also a specialist in the changes in the vascular system that accompanied upright walking, praises Falk and her colleagues for putting the question of changes in cranial circulation during evolution on a more empirical footing. "A new approach to anthropology has been described," Abitbol claims, "namely vascular anthropology—and it will play a role."

But whether Falk's radiator proves sound or leaky, she has for the moment set the theory of brain evolution upon its head. "Clearly the Falk hypothesis is audacious, and, at first sight, even counterintuitive," says UCLA's Scheibel. "All the more reason to try to put it to the test. Of one thing we may be sure. Right or wrong, it is not likely to be forgotten." ■ ANN GIBBONS