The Great Brain Drain

A controversial theory takes ancestral brain growth in vein

By BRUCE BOWER

Question: How is an automobile engine like the human brain?

Answer: Both get only as big as their radiators can cool.

This mechanical metaphor has generated plenty of heat among anthropologists and physiologists since Dean Falk proposed her "radiator theory" of brain expansion in June. Falk insists it offers an important insight into human evolution, a contention some researchers support and others vigorously challenge.

Accumulating evidence suggests that an evolving cerebral "radiator" enabled brain size in the *Homo* lineage—including modern *Homo sapiens* — to double over the last 2 million years, says Falk, an anthropologist at the State University of New York at Albany. Her metaphor refers to a dense network of veins that, in her opinion, cools the heat-sensitive brain during intense exercise or heat exposure.

The burgeoning brain of successive species leading to modern humans has long intrigued anthropologists. Many have suggested that one key behavior, such as language, hunting or throwing, served as a critical influence on the evolution and growth of our ancestors' brains. However, the causes of brain growth in humans and other mammals remain unclear.

Into this murky milieu strides Falk with her radiator theory, which manages to stoke ongoing debates in both anthropology and physiology.

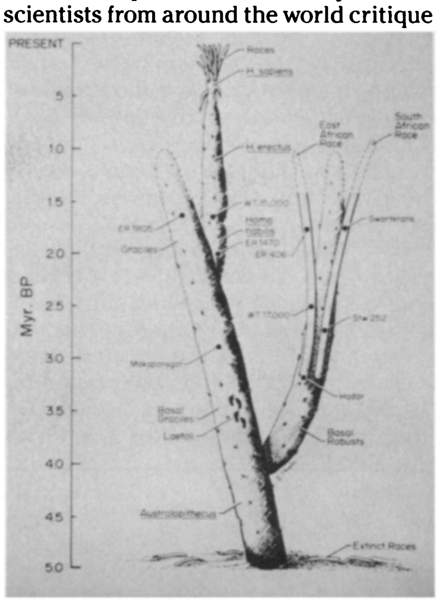
Much of the controversy emerges in the June BEHAVIORAL AND BRAIN SCIENCES, where Falk presents the theory and 26 scientists from around the world critique her proposal. Physiologists skirmish over the contention that a special venous thermostat automatically cools the brain when body temperature rises. Falk's theory also fires up anthropological arguments over lines of descent among human ancestors and flushes out conflicting versions of how our evolutionary forerunners made a living in Africa.

Falk's scenario of human brain growth begins 4 million to 5 million years ago, when hominids — members of the evolutionary family that includes modern humans — abandoned knuckle-walking for an erect posture and a two-legged gait. Prior to this ambulatory innovation, in Falk's view, blood returned from the brain to the heart through the jugular vein, which today provides the main thoroughfare for cerebral blood drainage in reclining humans. But in an upright position, blood streaming straight downward in a gravity-induced rush would damage jugular walls, she maintains.

To lighten the jugular load, two new drainage systems for the brain evolved in early hominids, Falk contends. Both divert cerebral blood to the vertebral plexus, an extensive network of veins running down the torso that returns blood to the heart. Analyses of bony grooves on the inside of fossilized hominid crania, performed by Falk and several other investigators (SN: 7/2/83, p.8), reveal the two venous patterns.

Fossil evidence of one drainage system appears in the famous "Lucy" and other members of *Australopithecus afarensis* discovered at the Hadar site in Ethiopia, who lived about 3.2 million years ago. "Robust" australopithecines, consisting of several small-brained hominid species dating to between approximately 2.5 million and 1 million years ago, display the same drainage setup.

A pair of channels for venous blood at the back of the head — the occipital and marginal sinuses — show considerable enlargement in these species and feed into the vertebral plexus. They would have helped to slow the outward flow of cerebral blood among the upright hominids, Falk argues. This arrangement appears in all 13 crania of Hadar *A. afarensis* and robust hominids with identifiable bony grooves, she says.



On the left side of Dean Falk's controversial hominid family "cactus," gracile australopithecines (with Makapansgat representing A. africanus*) extend up and branch off to the Homo line. The right side contains only robust australopithecines including basal robusts, Lucy and her Hadar companions. Most anthropologists place Hadar and Laetoli specimens in one species.*

In contrast, large occipital and marginal sinuses rarely appear in "gracile" australopithecines and members of the *Homo* lineage, Falk argues. The graciles include 3.5-million-year old fossils from Laetoli, Tanzania—placed alongside Lucy in the species *A. afarensis* by many other anthropologists — and the more than 2-million-year-old South African species *A. africanus*.

Another pair of venous channels, known as the transverse and sigmoid sinuses, fans out across the back of the cranium in gracile and *Homo* species, Falk points out. Moreover, many of these hominid fossils have two small openings for "emissary" veins penetrating the skull at the top and back. Anatomical studies of humans indicate that the emissary veins belong to a dense web of microscopic veins draining blood from the brain to the vertebral plexus.

Emissary veins apparently served double duty in the gracile-*Homo* lineage, says Falk, by helping to drain blood out of the cranium and by cooling the brain when vigorous exercise or heat exposure warmed up blood flowing into cerebral tissue. A rise of only 4°C or 5°C above normal brain temperature disturbs cerebral function and can cause convulsions. In modern humans under conditions of heat stress, the flow of relatively cool venous blood through the two emissary veins charted by Falk in fossil crania actually reverses direction, going back into the brain, according to several recent studies directed by physiologists Michel Cabanac of Laval (Quebec) University and Heiner Brinnel of Hôpital-Maternité in L'Arbresle, France.

Cabanac and Brinnel placed the tips of ultrasonic probes on the heads of bald male volunteers at sites where emissary veins poke through their tiny cranial conduits. The probes recorded the direction of blood flow.

When the men were at rest, emissary blood flowed out of the cranium. But after a substantial increase in arterial blood temperature, caused by intense exercise, venous blood from the scalp and forehead — which had been cooled in dilated veins — traveled back into the cranium, the physiologists say. As this occurs, the temperature inside the cranium drops, Brinnel contends.

Falk also contends that the evaporation of sweat from the scalp, a little of which enters the braincase, helps cool emissary blood as it returns to the brain.

Since the few emissary veins with impressions remaining on fossil skulls link up to an extensive network of microscopic veins in the cranium, Cabanac and Brinnel's data support her theory that a venous "radiator" cools the human brain, Falk says. This cerebral radiator — represented in fossils by grooves in cranial bones and openings for emissary veins — expanded as brain size increased in gracile australopithecines and the *Homo* lineage, while small-brained Hadar hominids and robust australopithecines lacked the cooling network of veins.

But why was the radiator confined to the gracile-*Homo* lineage?

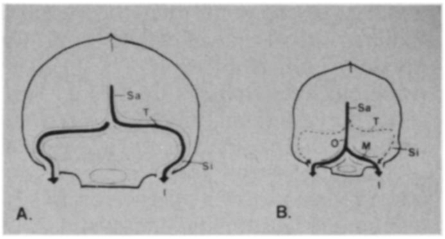
For Falk, the answer lies in how the two hominid branches conducted their daily business. Studies of the types and numbers of animal species in the fossil record, led by paleontologist Elisabeth S. Vrba of Yale University, combined with pollen and oxygen isotope analyses, indicate global cooling caused an expansion of open, grassy savannas in southern and eastern Africa about 2.5 million years ago. Falk argues that the robust australopithecines avoided the hot expanses of savanna and instead frequented wooded areas near lakes and rivers, where they mainly munched nuts and seeds (SN: 7/2/88, p.14).

Conversely, *A. africanus* and later human ancestors worked up a sweat under the hot savanna sun by hunting and scavenging for meat and by trekking long distances in search of edible leaves and fruit, Falk says. Sustained exercise on the savanna helped to promote the evolution of brain-cooling emissary veins, as well as copious sweat glands in the face and scalp, dark skin and reduced body hair, she notes.

Then, with an adjustable cerebral radiator in place, hominid brain size blossomed. The survival and reproductive advantages of increasingly "intelligent" behavior by savanna-dwellers living in cooperative groups multiplied rapidly about 2 million years ago, and the offspring of successful hominids gradually developed larger brains, Falk speculates. Although scientists have no consensus definition of intelligence, Falk says crucial forms of ancestral intelligence undoubtedly included social skills involved in obtaining food and mates, the development of language and the ability to think about the future and make plans.

But her notion that a network of veins evolved as a brain radiator and paved the way for hominid brain enlargement comes under fire from several physiologists.

Falk has no clear evidence for her contention, argues George L. Brengelmann of the University of Washington in Seattle. Cerebral blood drains through emissary veins and their smaller companion veins into "collecting sinuses" just beneath the skull, he says. Once there, the blood no longer cools the brain and does not reenter the cranium until it makes its way back as arterial blood, Brengelmann contends, disputing the findings of Cabanac and Brinnel.



Rear view shows typical cranial sinus systems for draining blood from the brain to the internal jugular veins of modern humans (A) and fossil robust australopithecines (B).

The brain's "radiator" encompasses the entire body surface, he adds. High blood flow in the skin couples with evaporation of generous amounts of sweat to cool the blood and thus cool the brain and other organs.

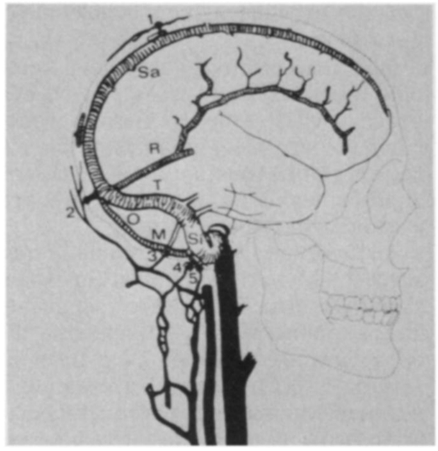
Furthermore, drainage from the brain depends more on the blood pressure of arteries feeding into tiny vessels inside the cranium than on any venous arrangement, assert Alan R. Hargens and J.-Uwe Meyer of NASA's Ames Research Center in Mountain View, Calif. Giraffes provide an extreme example, they note in the Sept. 3, 1987 NATURE. Naturally elevated arterial blood pressure at the giraffe's heart level (just below its elongated neck) maintains normal blood pressure and flow at head level, they say.

Blood pressure stays quite low in the giraffe's jugular vein, apparently allowing blood to cascade from the head down the neck with no siphoning of cerebral blood into a dispersed venous network, according to Hargens and Meyer.

Falk's proposed cerebral radiator has no clear structure, says Arnold B. Scheibel of the University of California, Los Angeles, because emissary vessels and other veins vary tremendously in appearance and organization from one person to another. He adds that researchers eventually may use brain-imaging techniques, such as magnetic resonance imaging, to trace the shunting of blood through the human skull while individuals rest or exercise.

The radiator theory attracts criticism from anthropological quarters as well.

Emissary veins — Falk's cardinal sign of a brain-cooling system — show no regular pattern in the crania of hominids living prior to about 1.6 million years ago, contends William H. Kimbel of the Institute of Human Origins in Berkeley, Calif. Kimbel has performed an independent comparison of grooves and marks inside hominid brain cases.



Numbers mark tiny openings for emissary veins in a modern human cranium. Letters designate different venous sinuses.

The two venous drainage plans observed among early hominids probably resulted from random genetic changes as new hominid species emerged; neither arrangement would draw off cerebral blood better than the other, Kimbel holds.

Thus, he argues, Falk inappropriately uses only one anatomical feature — venous drainage patterns — to group Lucy and other Hadar hominids with robust australopithecines. Kimbel and his colleagues — including Lucy co-discoverer Donald Johansen of the Institute of Human Origins — argue that numerous anatomical similarities unite the Hadar and Laetoli specimens into a single species, *A. afarensis*, from which all later hominids evolved.

Kimbel also agrees with physiologist Brengelmann that emissary veins play a minor role in brain cooling. He says most cerebral-temperature regulation takes place in the cavernous sinus just below the brain, where arteries with warm blood come in contact with veins containing blood cooled by evaporation from nasal mucus and facial sweat.

To top it off, Falk's scenario of robust australopithecines who put down roots in moist, wooded areas, while their gracile counterparts roamed the savannas and developed bigger brains, presents an unsupported, "cartoon-like" picture of hominid evolution, Kimbel contends. A 1988 review of available evidence by Tim D. White of the University of California, Berkeley, concludes that robust australopithecines inhabited a range of African habitats, from wooded regions bordering water sources to open stretches of grassy savanna.

Indeed, says Vrba, South African robust australopithecines may have occupied more arid, open stretches of savanna than did gracile australopithecines. The numerous bones of grass-grazing antelopes found deposited with robust australopithecine remains support this conclusion, the Yale paleontologist asserts.

East African robusts have been found only near rivers and lakes, but no evidence suggests they preferred wetter habitats over drier habitats, Vrba observes. Both robust and gracile australopithecines lived in relatively open savanna regions, she adds.

Furthermore, Vrba says, climatic data suggest that much hominid brain expansion took place at times of significant global cooling, when heat stress on the open savanna may not have been as severe as Falk assumes. For example, a noticeable increase in australopithecine brain size occurred somewhere between 2.7 million and 2.1 million years ago, when cooler temperatures led to savanna formation and the emergence of many new animal species, Vrba says. Moreover, cold extremes in the global climatic cycle — which develop about every 100,000 years — dropped temperatures an average of nearly 6°C beginning approximately 900,000 years ago, a critical evolutionary period for archaic and modern *H. sapiens.*

Not all investigators see disturbing leaks in the radiator concept. Harry J. Jerison, a brain researcher at the University of California, Los Angeles, says he welcomes Falk's contribution as "delightful, original and superbly documented . . . almost above criticism." He emphasizes, however, that the cerebral radiator merely opened the door for hominid brain expansion. The need to communicate symbolically through language, says Jerison, most likely pushed brain size and anatomy through that door.

"Language is the Rolls Royce of brain adaptations, run by a massive brain system unique to humans," he says.

According to anthropologist Adrienne Zihlman of the University of California, Santa Cruz, Falk presents a "plausible theory" that should spark further research. But she adds that all investigations of our fossil ancestors, including Falk's studies, face serious obstacles. Specimens in proposed hominid family trees rarely fit together neatly because investigators know little about anatomical variation within different species, Zihlman notes (SN: 8/18/90, p.106). For instance, although Falk groups Lucy and her Hadar companions with the robust australopithecines, the shape of Lucy's limb and pelvic bones nearly matches *A. africanus* specimens, which Falk considers gracile australopithecines.

Moreover, Zihlman says, the diets of modern gorillas, chimpanzees and other nonhuman primates often overlap, hinting that robust and gracile australopithecines did not always select their meals from different menus.

An independent theory complementing Falk's proposal comes from psychologist Robert Zajonc of the University of Michigan at Ann Arbor. Zajonc asserts that muscles used in facial expressions alter venous blood flow and help regulate both brain temperature and emotional state (SN: 7/6/85, p.12).

Preliminary studies in dogs suggest that when body temperature rises, cool venous blood in the face heads back into the brain, he says. In humans, facial veins may assist the cavernous sinus in cooling the brain, he says.

Human facial expressions regulate the flow of blood through facial veins and, in turn, influence brain temperature, Zajonc contends. At the annual meeting of the American Psychological Association in August, he described research indicating that happy facial expressions generate cooler forehead temperatures — reflecting cooler brain temperatures — while sad and angry expressions fan hotter forehead temperatures.

Moreover, Zajonc says, rat studies suggest that positive emotions arise as the temperature drops in a small, inner-brain structure called the hypothalamus, whereas hypothalamic heating stirs up negative emotions.

Scientists seem far from a consensus on the cooling powers of cranial and facial veins. But Falk's scenario of brain expansion serves as a lightning rod for future investigations.

"Right or wrong," says Scheibel, the radiator theory "is not likely to be forgotten." □