Correspondence of brain and rectal temperatures of guinea pigs in helium environments

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Unger, H., F. G. Hempel, and P. G. Kaufmann. 1980. Correspondence of brain and rectal temperatures of guinea pigs in helium environments. Undersea Biomed. Res. 7(1):27–34. — Brain and rectal temperatures were measured in guinea pigs exposed to helium-oxygen environments at pressures as high as 50 bars. Very high correlations ($r = .856, P << 0.001$) between the two values were observed, with an average difference of $0.47^\circ C$ (computed $sd = 0.31$). Brain temperature was usually higher than rectal. At a given ambient temperature, heat loss at 50 bars was more rapid than at 20 bars, which supports existing data for lower pressures. At 50 bars, normal equilibrium temperatures ($\sim 39^\circ C$) could be maintained only if ambient temperature was in the vicinity of $35^\circ C$. Lower ambient temperatures resulted in lower equilibrium temperatures. Between $33$ and $39^\circ C$, brain temperature can be predicted from rectal temperature, with an error of about $0.5^\circ C$.

Practical considerations of density and narcotic potency require that nitrogen be replaced by helium in some hyperbaric environments. However, the high specific heat of helium and its increased density at high pressures results in a breathing mixture with high thermal capacitance, and respiratory as well as convective heat loss become increasingly important in the thermal economy of homeothermic mammals (1, 2, 3). In humans, for example, the ambient temperature required for thermal comfort in a helium-oxygen atmosphere has been placed at $33.5–34.5^\circ C$, depending on the relative humidity (4), compared with $21–25^\circ C$ in air. Animals exposed to helium environments experience a similar temperature stress (5, 6, 7). Measurement and maintenance of adequate body temperature in such circumstances are therefore of considerable importance.

Because rectal temperature is the easiest to obtain, it has frequently been taken to represent core temperature (8) and implicitly been used as an indicator of brain temperature in studies of high pressure effects on the central nervous system (9, 10, 11). Rectal temperature may, however, not be representative of brain temperature, which is often higher (12). Rectal temperature may also be less than an ideal indicator because of the slowness of response to
temperature change of sites remote from the probe. For example, human divers who show no change in rectal temperature report chills when helium-oxygen breathing is initiated under isobaric conditions in a nitrogen-oxygen atmosphere (personal communication), which suggests that brain temperature changes before that of the core. Since the relationship between rectal temperature and that of the brain in helium atmospheres has not previously been studied, our goal was to determine to what extent these temperatures parallel each other.

**METHOD**

**Animal preparation**

Observations were made on 14 male Hartley guinea pigs weighing from 600–900 g. Nine animals were anesthetized with pentobarbital sodium (40 mg/kg, i.p.) and placed in a stereotactic apparatus. The skull was exposed. An opening 3 mm square was drilled at stereotactic coordinates: \( A = 6, \ L = 5 \) mm. These coordinates, derived from previously sectioned guinea pig brains, correspond to the location of the dorsal lateral geniculate nucleus of the thalamus at a depth 7 mm below the cortical surface. The dura was covered by a layer of gelfoam and left intact. A thermistor guide cannula was prepared by embedding a 6-mm length of 20-gauge hypodermic tubing in dental acrylic. Each end of the guide cannula was lightly packed with bone wax and cemented over the skull opening with dental acrylic, forming a cap. The skin was drawn against the cap by sutures and the animal was allowed to recover for 3 to 4 days before further experimentation. Data are also presented from five other animals who had no implanted brain thermistors but whose rectal temperatures were maintained near a constant level for an extended period at 50 bars’ pressure, and who were used in other studies.

**Temperature recording**

On the morning of the pressure exposure in helium, a single guinea pig was placed in a whole-body sling. A rectal probe (Yellow Springs Instruments No. 401) was lubricated and inserted to a distance of 6 cm. A 24-gauge hypodermic thermistor probe (Yellow Springs Instruments No. 524) was inserted through the implanted guide cannula into the dura and advanced into the brain to a previously prepared stop at a depth 7 mm below the cortical surface in the thalamus. The probe was secured with a drop of dental acrylic. A second hypodermic thermistor was inserted subcutaneously along the abdomen. Its primary function was to detect warming by the heating pad and to provide a framework for observing colonic and brain temperature recovery. Ambient temperature within the chamber was measured with a fourth probe (Yellow Springs Instruments No. 408). Animals were comfortably suspended in a 208-liter steel chamber, and connections were made through electrical chamber penetrators to a Yellow Springs Instruments telethermometer. Temperatures taken at the three body points (brain, rectum, skin) immediately upon inserting the thermistors were regarded as control values for each animal since these values began to decline soon after animals were placed in the sling. Actual compression did not take place for another hour while preparations for compression were completed.

**Compression in helium-oxygen**

At the beginning of compression, the oxygen content of the chamber was raised by adding 0.2 bars of oxygen (52 liters). Since a 1-kg guinea pig consumes less than 1 liter of oxygen
per hour (13), a liberal supply of oxygen was ensured for the duration of the experiment, allowing for the greatly increased metabolic demands caused by thermal stress. Helium was added through a venturi CO₂ scrubber at the rate of 1 bar/min to a maximum pressure of 50 bars. Since the course of recovery of brain temperature relative to rectal temperature could differ as a function of the amount of temperature drop experienced by the animal, we instituted two levels of cooling (Conditions 1 and 2), which allowed observation of the consequences of mild as well as more severe thermal change.

Condition 1

In three experiments, the animals were exposed to a helium-oxygen environment at 20–50 bars' pressure and 24°C. They were allowed to cool passively to about 32°C before rewarming with a heating pad and by external heating of the chamber.

Condition 2

In six experiments, external heating was applied as needed, beginning at several bars' pressure, to restrict body temperature loss to 2°C below surface control values up to 50 bars' pressure.

Condition 3

Additional data are presented for five animals whose rectal temperatures were maintained at different constant levels (±0.2°C) at 50 bars of pressure for a period of 1–1½ h.

RESULTS

In all experiments, the body temperatures of the guinea pigs began to drop soon after they were placed in a sling, sometimes by as much as 2.5°C. The average rectal temperature of 11 normal guinea pigs from our animal colony was 39.2°C (computed SD = 0.15; (14)), which corresponds closely with published values of 39°C (15), while the average rectal temperature of the guinea pigs at the beginning of this study was 37.3°C, (computed SD = 0.73). (One of the three animals in Condition 1 (No. 40T) was rewarmed to 38.5°C by a heating pad before compression). The lower body temperature under mild restraint is consistent with the finding that restraint results in hypothermia (16), and that freely moving mice maintain normal temperature more readily than partially restrained animals (6). However, we found no evidence that colonic temperature rises during the continuous presence of a rectal probe (8), perhaps because the influence of restraint is more prominent.

In the nine cases in which simultaneous brain and rectal temperatures were recorded (Conditions 1 and 2), they differed by an average of 0.47°C (computed SD = 0.31). During passive cooling in 25°C helium (Fig. 1), brain and rectal temperatures showed parallel changes, and the brain maintained its slightly higher temperature, as it did in room air. Subcutaneous temperature sometimes fell more rapidly, probably as a result of vasoconstriction of surface vessels. The rate of heat loss (reflected by the slopes of the curves beyond the indicated pressures) was always greater at 50 bars than at 20 bars.

The relationship between rectal and brain temperatures of nine animals is plotted in Fig. 2. In seven of the nine animals, the correlations were excellent, falling between .930 and .980. In the remaining two cases, r values were .700 and .600. The correlation coefficient between
Fig. 1  Brain, rectal, and subcutaneous temperatures of 3 male guinea pigs at pressures as high as 50 bars in helium-oxygen. Arrows indicate surface pressure (s), depth in bars (5, 10, 20, 30), and onset of heating (h).

These two temperatures for all animals is .856 (P < .001). On the basis of these data, brain temperature can be estimated from rectal temperature by the relationship

\[ T_b = .89 T_r + 4.2 \]

During severe cold stress, the temperature gradient was higher than in near-euthermic conditions: when rectal temperature dropped to 33°C, the thalamus was 0.57°C warmer, but it was only 0.02°C warmer when rectal temperature was 38°C.
Fig. 2. Comparison between brain temperature and rectal temperature measured in guinea pigs in helium-oxygen; at 38°C, the two are nearly equal. As body temperature drops, brain temperature is maintained at a somewhat higher level.

In the five experiments in which body temperature was maintained within narrow bounds (± 0.2°C; Condition 3) at 50 bars, the ambient temperature required to maintain this temperature increased with higher equilibrium rectal temperatures. Although the positive correlation (0.830) between ambient and equilibrium rectal temperature is statistically significant ($P < 0.05$, one-tailed, df = 3), it is based on only a few animals, and additional data might affect the position of the regression line of Fig. 3. Our data for the guinea pig, particularly the slope of the regression line relating rectal and ambient temperatures, are in close agreement with data for the mouse (7), included in Fig. 3 for comparison. Mice exposed to high pressure helium-oxygen tend to be considerably cooler than guinea pigs, perhaps due to the relatively greater stress placed on a small animal with a higher surface-to-volume ratio.

As the rectal temperature of guinea pigs at 50 bars approached the normal temperature for unrestrained animals (39.2°C), the chamber temperature necessary for thermal equilibrium was similar to the thermal comfort range for humans in helium atmospheres (4).

**DISCUSSION**

We have demonstrated a significant correlation (0.856, $P << 0.001$) between rectal and brain temperatures of guinea pigs in high pressure helium-oxygen environments for body temperatures between 33–39°C. The hypothermic effects of helium were greater at 50 bars than at 20 bars, extending Hart's data (17) at 1–6 bars and that of Gillmore and Eicher (6) at 7.5–35 bars. Our data suggest that between 30 and 35°C, each ambient temperature at a given pressure results in a unique point of thermal equilibrium and will be reflected by an adjustment of the core temperature of the animal. Gillmore and Eicher (6) have found ambient temperatures as high as 37–38°C necessary to maintain normal body temperature in guinea pigs at 35.5 bars in
Fig. 3. Relationship between stable rectal temperatures and the ambient temperatures required to maintain them. Each point represents 1 animal held to within ±0.2°C for at least 1 h. Dashed lines are regression lines for similar data for CD-1 mice, taken from Sheehan and Brauer (7) and provided for comparison.

He-O₂, but our animals at 50 bars required an ambient temperature of only 34–35°C. Their figure seems very high, since temperatures above 35°C result in greatly increased mortality rates in mice (10, 7), and it also conflicts with all other published data. It therefore appears that in mice (7), rats (5), guinea pigs (these data), and humans (4) exposed to He-O₂ atmospheres of 35 bars and higher, ambient temperatures of 33–35°C are required to maintain thermal balance, despite differences in the thermoneutral zones of these species in air (18, 15).

It is known that brain damage, particularly massive disruption of the anterior hypothalamic/preoptic region, can cause an increase in body temperature. This neurogenic hyperthermia is believed to be mediated by prostaglandins (19) which are released as a result of tissue injury. We therefore had to consider the possibility that our data were influenced by such events. This is unlikely for two reasons. The experiments that demonstrated such hyperthermia employed massive trauma, especially involving the hypothalamus. By contrast, the damage caused by our puncture of the brain by a 24-gauge needle probe to a depth of only 7 mm was slight. Furthermore, we never observed any spontaneous temperature increase after the brain puncture, either in our animals or in several other animals from other studies in which brain temperature was measured.

A significant temperature gradient exists between various sites in the brain, depending on their distance from the Circle of Willis, the entry point of arterial blood (12). The warmest parts of the brain in mammals occur toward the center of the cerebral hemispheres, the diencephalon, and the midbrain, which are warmer in some species by as much as 0.5°C. Similar gradients undoubtedly exist in the guinea pig as well, and generalizations should be
made with caution, particularly when differences of a few tenths of a degree are important. When errors of this magnitude are acceptable, rectal temperatures can serve as reliable estimates of brain temperature.

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