BODY TEMPERATURE REGULATION IN REPTILES, BIRDS, AND MAMMALS

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Homeothermic birds and mammals maintain a constant body temperature by behavioral and physiological adjustments. The latter includes changes in heat production, blood flow, and evaporative water loss. Poikilothermic reptiles also maintain a stable body temperature (often higher than that of mammals) when environmental conditions allow, by using behavioral and physiological mechanisms. Both modes of life have advantages and disadvantages. Neither poikilothermism nor homeothermism is unquestionably advantageous under all conditions; therefore, neither group of animals is indisputably better suited for survival than the other. God created all animals equally fit to live in their respecitve niches.

Introduction

Evolution is thought to be a continual process of improvement. It supposedly is powered by the ever present over production of offspring and a subsequent harvesting of the less fit by natural selection. Each species is thought to be in a race for perfection.

The rates of supposed advancement, however, vary greatly from species to species, certain groups changing little throughout geologic time while others make great "progress." (It always has seemed paradoxical to the author that any "primitive" form could compete for long periods of geologic time with more "advanced" contemporaries, but this is not the issue here.) This "advancement" in contrast to "primitiveness" is a nebulous concept but seems to involve specialization, diversity, and increased complexity in form and function.

Classic examples of so-called advanced phyla are the arthropods and chordates. Protozoa and Porifera would be placed at the opposite extreme in the animal kingdom. Even within a more restricted group—the vertebrates—considerable variation is said to exist, with certain fish cited as "primitive" examples and birds and mammals representing the most "advanced" forms known.

If some organisms have "evolved" toward a higher state of perfection, while others remained at some "primitive" level, degrees of perfection should be observed in nature. That is, assuming the rates of evolutionary change are different from group to group, then certain "advanced" groups should be unequivocally and irrefutably better suited for survival than other less advanced groups in a particular environment. Let us compare in some detail certain aspects of differences found between "primitive" reptiles and "advanced" birds and mammals.

One of the most striking differences between these groups is maintenance of body temperature. Birds and mammals generally are classified as being "warm blooded" or more descriptively, homeothermic, while the reptiles are "cold blooded" or poikilothermic. Homeothermism of birds and mammals is considered to be one of the most significant "advances" made from presumed reptilian ancestry. Let us look closely at this so-called advancement and see if it is unequivocally and irrefutably an improvement over poikilothermism.

Homeothermic Temperature Regulation Mechanisms

Birds and mammals generally are able to maintain a constant body temperature in spite of wide fluctuations in their environmental temperatures (see Figure 1). Most birds and mammals are covered with insulating feathers or hair. Although insulation aids in the conservation of body heat, the major difference between homeothermic and poikilothermic animals is at the tissue level, homeotherms consuming up to 10 times the energy per gram of tissue that a poikilotherm consumes.

This increased metabolism (even at identical temperatures) provides the source of heat for regulation of body temperature. The terms endotherm and ectotherm also are used. Endotherms or homeotherms have the source of heat within; conversely ectotherms or poikilotherms rely on external heat. Actually, neither of these terms is fully adequate.

Regulation implies control, and several mechanisms of control have been elucidated. The mechanisms may be placed under two headings: control of heat production and control of heat loss.

Control of Heat Production

Rates of biochemical reactions, like other chemical reactions, are temperature sensitive. Higher temperatures result in faster reactions. Many biochemical reactions are approximated by the familiar van't Hoff generalization: that increasing the temperature by 10°C doubles the reaction rates.

Rates of biochemical reactions inside poikilothermic animals appear to be passively controlled by the prevailing body temperature. When the energy consumed is compared as a function of temperature for both homeothermic and poikilothermic animals, strikingly different results occur as are illustrated diagramatically in Figure 2.

As expected for poikilotherms, increased temperature results in increased energy consumption. In the homeothermic animal however, the opposite effect results. Referring to Figure 2, if the temperature is decreased below point A, energy consumption increases.

In most biochemical transformations for example: $A \rightarrow B$ energy is lost as heat. This "loss" of energy is the source of heat for homeothermic animals and is called non-shivering thermogenesis. Apparently in non-shivering thermogenesis metabolic pathways are shifted to "less efficient" pathways increasing the energy "lost" to heat and thereby maintaining thermal homeostasis. Brown fat is especially important in the production of metabolic heat and is utilized extensively in the arousal of small mammals from hibernation.

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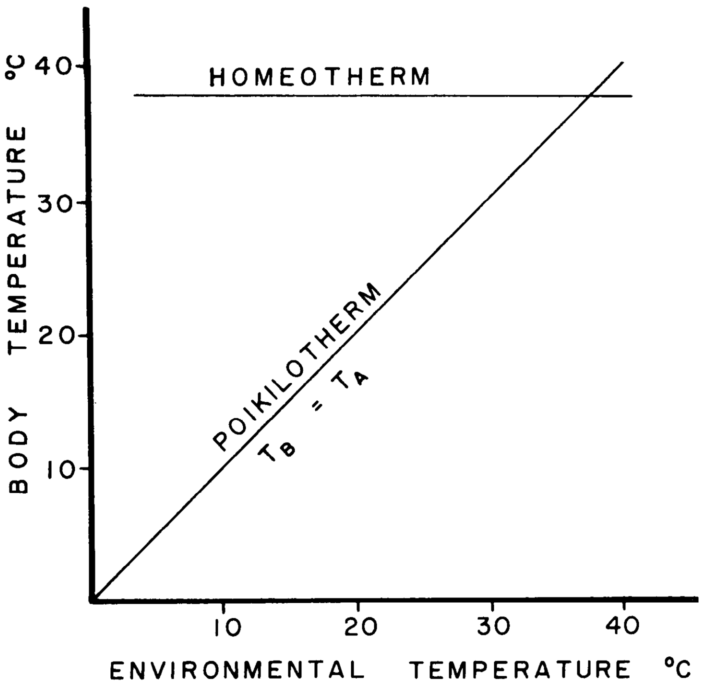

Figure 1. Relationship of the body temperature of homeotherms ("warm blooded") and poikilotherms ("Cold blooded") to environmental temperatures. This is a generalized diagram showing trends. Evaporative cooling and/or endogenous heat production would slightly alter the poikilotherm's body temperature and of course the homeothermic animal's body temperature is not completely independent of environmental temperature.

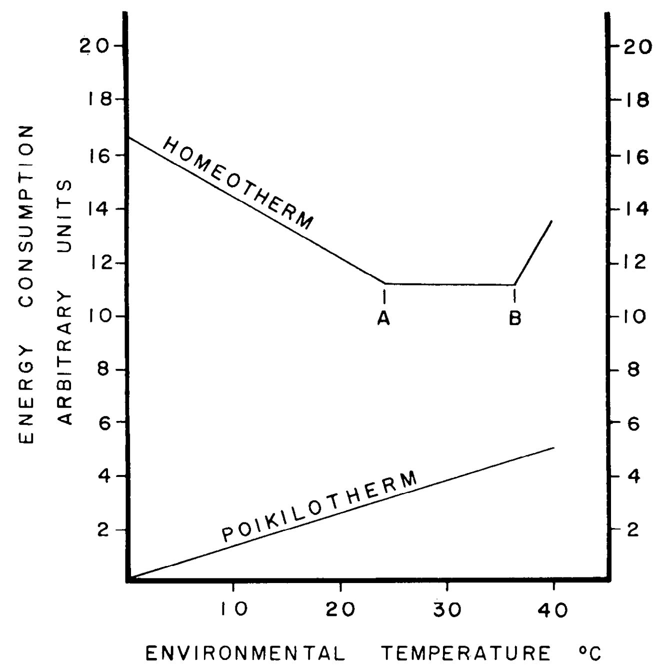

Figure 2. Relationship of energy consumption of homeotherms and poikilotherms to environmental temperature. Again this is only a first approximation. The slopes are not constant but increase sharply at warmer temperatures.

Besides, non-shivering thermogenesis, chilling temperature also induces shivering. This involuntary flexing of skeletal muscles results in great amounts of metabolic heat, and helps to explain both increased heat production and increased energy consumption with decreasing temperature.

The heat production that enables such a high level of environmental independence of homeotherms is not free. Approximately 90% of the food required by homeotherms goes to the maintenance of body temperature. Homeotherms living in cold regions must never be far from food.

Referring again to Figure 2, it is apparent that the energy consumption is constant for a portion of the range of changing environmental temperatures from A to B. This thermal neutral zone implies that some mode of control other than changing the rate of energy consumption must be working to maintain thermal stability.

Changes in Insulation

For animals with hair or feathers the effective insulation can be changed considerably by varying the thickness or degree of erection of the pelage or feathers. A bird with its feathers fluffed out has considerably more insulating trapped air than does the same bird with its feathers drawn tightly against its body. A similar situation exists for most mammals with hair erect.

In addition to changes in insulative quality caused by position of hair or feathers, changes in blood flow can cause great changes in the amount of heat flow from or into an animal. A hot animal flushes blood to the surface resulting in rapid heat loss to the outside. A cool animal reduces peripheral blood flow and shunts the blood deep inside its body thus minimizing heat loss.

Finally, many homeotherms can pant, lick themselves, or sweat thus aiding maintenance of their body temperature below that of the environment. Water secretion is metabolically expensive and energy consumption rises sharply as seen in Figure 2 beyond point B.

Mammals and birds, then, have the ability physiologically to regulate their body temperatures by varying heat production by changing their effective insulation, by adjusting blood circulation, and by evaporating water.

Behavioral Mechanisms

In addition, mammals and birds behaviorally select protected nest sites and more hospitable microhabitats in the environment. Grazing animals feed with their backs to the wind on cold windy days. Most animals seek shade when hot.

Some animals, when hot, dig to expose cool moist soil on which to lie. Many smaller animals seek shelter from both heat and cold by going underground. Some mammals escape cold weather by hibernation, and many birds and some mammals migrate to milder wintering quarters.

Reptilian Thermoregulation

Biologists long have known that, when a fish, frog, or snake is placed into a cold environment, the body temperature soon approximates that of the new environment (Again see Figure 1). In contrast the body temperature of a bird or mammal varies little even when exposed to rapid and extreme environmental temperature changes. The body temperature of poikilotherms was thought always to approximate that of the environment.

The early work of Cowles and Bogert[1] on temperature regulation in reptiles began to change the picture. Certain small diurnal lizards were found to regulate body temperature simply by moving about in the natural environment. When cool, lizards crawl into the sunlight; when warm, they seek shade. By behavioral thermoregulation some desert lizards have been found to regulate their body temperature to ±3°C during the day.

In the intervening years many investigators have continued to study reptilian thermoregulation. All reptiles studied have been found to possess thermoregulatory behavior and are able to minimize fluctuations in body temperature. Several excellent reviews of the literature are available[2-5] and none is intended here.

Much of the early work with reptilian thermoregulation dealt largely with thermoregulatory behavior. Lizards were found not only to seek the sun when cool, but also to align themselves in such a way that the sun fell on the larger surface area of the animal, and the animal usually aligned itself perpendicular to the rays of the sun. Furthermore, in order to gain heat from a warm substrate, reptiles would lie flattened out and increase conductive heat gain. Conversely, heat conduction could be minimized by standing high above the substrate.

By simple exposure to the sun's warming rays, lizards can elevate their body temperature considerably. Certain small lizards living at high altitudes have been found to maintain body temperature as much as 30°C higher than the surrounding air.[6, 7] These measurements demonstrate the utility of basking. Many reptiles gain the advantages of high temperatures without high energy consumption.

Not only can the body temperature of terrestrial poikilotherms be higher than the air, but also there are examples of lizards having temperatures higher than the body temperatures of some mammals.[8] Monotremes, for example, lose the ability to thermoregulate at 32.5°C; 35°C is lethal for the platypus and 37°C kills echidna.

In contrast the preferred body temperature of most species of *Sceloporus,* the spiny lizards, is between 34 and 36°C. Many *Cnemidophorus,* whiptailed lizards, are active with a body temperature of 35-44°C. Certain lizards can operate at temperatures harmful or even lethal to some mammals. Obviously the term "warm blooded" and "cold blooded" are inappropriate, and should be discontinued.

While thermoregulatory behavior no doubt plays an important part in reptilian thermoregulation, recent studies indicate that many of the physiological thermoregulatory mechanisms used in the "advanced" birds and mammals are used by the "primitive" reptiles.

Endogenous heat production is significant in the thermoregulation of the lace monitor[9, 10] and even for the more aquatic alligator.[11] Frair observed that body temperature of a large marine turtle was 18°C higher than the water from which it was taken.[12] Just as mammals and birds regulate body temperatures by changes in blood flow so do many reptiles.[13, 17]

Not only has total blood flow been found important for the regulation of body temperature of reptiles, but also local cutaneous vasomotor responses to temperature variations were found to play a part in the thermal stability of the Galapagos marine iguana[18] and spiny-tailed iguana.[19] That reptiles can cool by evaporation has been well established.[20]

It appears, then, that birds, mammals and reptiles, while active, all utilize both behavioral and physiological mechanisms to maintain a relatively stable and often high body temperature.

What are the advantages of a high body temperature? Higher temperatures cause increased rates of chemical reactions. An increase in temperature causes food to digest and to be assimilated more rapidly. Higher temperatures increase the speed of nervous impulse transmission and the rate of muscular activity resulting in greatly improved coordination, speed of movement, and consequently the ability to elude a predator or to capture prey.

While assets of a high body temperature are many, there also are liabilities. Increased metabolic rates mean the fuel that enables such luxurious living quickly is consumed and must be replaced or starvation results. This is especially true for smaller organisms. How is the high rate of metabolism to be maintained during periods of food shortage?

In many cases it is not. Many homeotherms hibernate, with the onset of colder weather; and, in so doing, drop their body temperature, thereby reducing their food requirements. Many tiny humming birds, with usually high body temperature and extremely high rate of metabolism, avoid nightly starvation by turning down their thermostat and letting their body temperature drop to near that of the environment.

Temperature Regulation and Creation

Using the above brief introduction to temperature regulation let us return again to the question of homeothermy and survival suitability. Is homeothermy, as seen in birds and mammals, an "advance" in suitability for survival? Are these animals uniquely and irrefutably better suited for their environment than their more "primitive" peers? Obviously it depends on circumstances.

As temperatures fall, reptiles require less food and homeotherms require more. If food is a limiting factor the homeotherms are at a marked disadvantage. Yet a sluggish, cold reptile is easy prey for the ever alert homeotherm. Neither is irrefutably and unequivically better suited for its environment.

Instead of viewing homeothermism as a step "upward" in complexity and fitness it is more logical to view the two modes (and all intermediate steps) as equally useful methods of exploiting particular niches. In some ways the hiberating mammal and lizard that become active on warm days are exploiting a habitat more efficiently than can the homeotherm that must eat, starve or hibernate during less hospitable days.

Instead of viewing partial homeothermism in reptiles as developing nascent homeothermism on the way to becoming full-fledged homeothermism, it is more logical and consistent with nature to view partial homeothermism as a special (and fully developed) method of exploiting a particular niche.

Similarly, hibernation should not be viewed as a "return to reptilian poikilothermy," but as a highly refined mechanism enabling its user to exploit the advantages of both poikilothermism and homeothermism.

Let us look briefly at an example of a "primitive" poikilothermic animal and see how it is suited for survival and how it competes with (more "advanced") homeotherms.

American Alligator: Specific Example

The American Alligator, *Alligator mississippiensis,* was once the dominant vetebrate in the Southeastern United States. It inhabited every available river, lake and marsh. Old hunters compared the number of alligator eyes seen reflecting automobile lights to the stars overhead.[21] It has been said that if the alligators in the Mississippi River would hold still, a man easily could have stepped from head to head across the river without wetting a shoe.

The abundant alligator was to Southeastern Indians what the buffalo was to the plains Indians. It provided food, clothing and tools. With the opening up of the wet lands to hunters and trappers during the first part of this century the numbers of alligators began to decline. McIlhenny has estimated over three million alligator hides were sold in Louisiana alone.[22] This "primitive" animal, then, was a dominant vertebrate, and obviously fared well with more "advanced" forms.

Anatomically the alligator has a four-chambered heart; but until recently it was thought that a shunt between the right and left aortic arches *(foramen Panizzae)* caused inefficient mixing of arterial and venous blood. Here again crocodilian circulation has been viewed as a kind of developing avian or mammalian circulation better than that found in "lower" reptiles, but not as good as the circulation of the homeotherms.

White[23] has recently shown that functionally there is no mixing of oxygenated and unoxygenated blood when alligators are breathing air. When submerged, however, increased pulmonary resistance induces a right to left shunt.

Instead of being inefficient and poorly developed, this system, along with other anatomical and physiological adjustments, enables the alligator to dive for extended times. During prolonged diving it would only waste energy to profuse the lungs with blood. It is the homeotherms that would be at a distinct disadvantage with their mandatory dual circulation.

Bradycardia in response to submergence, has been shown to occur in all air-breathing vertebrates studied.[24] In reference to the alligator it has been called diving bradycardia and was thought to be a reflex to submergence.[25] However, in a recent study of free-ranging alligators, using radio telemetry, Smith and coworkers[26] have found instead that bradycardia is fear-evoked, and not a response to submergence.

An alligator spends a great deal of time submerged and the profound bradycardia response, if present, would undoubtedly be harmful to normal alligator function. It does however, ably suit the animal for prolonged emergency dives. The author has timed dives exceeding one hour and fifty minutes, during which time the alligator was actively evading capture in clear water.

In terms of thermoregulation the alligator has been found to maintain a relatively stable body temperature by a combination of behavioral and physiological adjustments.[27] Endogenous heat production probably coupled with cardio-vascular adjustments enables the alligator to maintain a body temperature several degrees above the water even during the night time.

The alligator, thought to be a relic of the age of the dinosaur, seems optimally suited for a particular environment, and certainly competes well with more "advanced" forms. It is even considered necessary and helpful in shaping plant communities in the marshland, and important to the general ecology and maintenance of the wet land ecosystem.[28] In fact, it seems that a vicariate homeotherm might considerably upset the ecology in relation to migrating water fowl.

The alligator becomes less active and requires considerably less food when winter approaches. During cold weather most of the southern marshlands are teeming with migratory water fowl. A homeothermic carnivor, as abundant as the alligator once was, surely would upset the ecology as it is known today. Could it be that there actually is a purpose or plan in nature?

Snakes: Further Specific Examples

Additional evidence that another poikilothermic animal is well suited physiologically for a particular way of life comes from studies of a snake. Squamates possess a three-chambered heart with two atria and an incompletely divided ventricle. From anatomical evidence it was reasoned that the circulation was "primitive" and inefficient, involving mixing of venous and arterial blood. Physiological studies, however, revealed virtually no mixing, the pulmonary artery receiving only unoxygenated blood.[29]

Recent studies of the carpet python, *Moreila spilotes,* have shown a significant temperature difference of blood leaving the heart.[30] This suggests that the heart of snakes is functionally superior to the avian or mammalian heart, for it aids in thermoregulation, sending mostly cool blood from the posterior portion of the animal to the lungs. This helps to maintain head-body temperature gradients and minimize respiratory heat loss.

Once more the placing of squamate circulation in an "evolutionary" sequence has been unfruitful. Instead of possessing an inefficient nascent homeothermic circulation, snakes appear to have a highly specialized and perfected circulatory system, attending not only to oxygen transport but also to function in thermoregulation.

Reptiles can and do compete favorably with homeotherms. In some ways they are more suited for certain environments than more "advanced" forms.

Zoogrographically homeotherms predominate in cold regions. In the tropics both groups abound. Perhaps arctic regions, as they are found today, did not originally exist and have been filled secondarily in post flood times.

Conclusions

The precept that some organisms generally are more suitable or more nearly perfect is a part of "evolutionary" thinking, and is entirely unscriptural.

According to "evolution" (in the broadest sense), the earth before life was "primitive," relatively devoid of order, and lacking complexity or perfection. As time passed (and "evolution progressed") order and complexity supposedly increased.

This is contrary to the teaching of the Bible (to say nothing of the laws of thermodynamics), however, for the writer of Genesis uses the very same phrase, "And God said that it was good," to describe the formation of the dry land[31] that is used following the creation of birds[32] and cattle.[33]

In several scriptural passages various "kinds" of animals and plants are singled out, but never is it said (or implied) that some are more "advanced" than others, with the notable exception of man who was created in the image of God. God created many "kinds" of organisms rapidly, and all equally suited for survival. A lizard is no less designed (let us be theological, Moses was) for any particular niche than is a mouse. "And God saw everything that he had made, and, behold, it was very good."[34]

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Added Note: It may be remarked that there are other cases of thermoregulation besides those discussed in this paper. For instance, thermoregulation is found in some insects[35] and recent evidence indicates thermoregulation in the plant kingdom.[36] Indeed, thermoregulation may prove to be the rule, rather than the exception, among living things.

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