called "minimum voluntary temperature" (*3*), which is the lower limit for activity as conventionally determined (*3, 4*). *Phrynosoma* spent much of the day active, above the surface of the sand, so relatively few data are available. Those that I have indicate day burials above the minimum voluntary temperature and within the basking and activity ranges.

The initial results for *Uma* were variable. While many voluntarily selected low temperatures at night, others were active at night and torpid in the day! Some lizards did not show any indication of the voluntary selection of temperatures below "normothermic" levels on any regular basis. A simple photoperiod appeared to be inadequate to simulate dusk and dawn for this group of individuals under conditions of ad libitum heat.

The procedure was then changed in an effort to reduce the individual variability. One of the two red-glass heat lamps was replaced by a clear-glass lamp and placed in the circuit with the room lights so that when the room lights would go off, the total area comprising the hot end of the gradient would become reduced. Thus, while the temperatures at the extremes of the gradient did not alter, dusk was simulated in that a sharp reduction in light intensity was associated with substrate cooling in some areas and with a reduction in the radiant environment in a part of the gradient.

Under the new conditions nearly all *Uma* selected low temperatures when burrowing at night (Fig. 2) but levels above the minimum voluntary temperature when buried during the day. Parts of the gradient shifted their boundaries at "dusk," but most lizards were found covered where the gradient was stable. A trap effect cannot, then, explain the results.

Only three *Sceloporus* were observed. They would remain active for days at a time, burrowing in cool sand (cloacal temperatures were 14.5° to 18.8°C) and becoming torpid only about once a week. This hypothermia was, of course, voluntary, even though it had no evident relation to photoperiod.

To summarize, the tendency to orient voluntarily to low temperatures has been demonstrated in several species of lizards under conditions that would permit the animals to maintain body temperatures constantly at activity levels. This generally occurs at night, but regular, periodic behavior may require simulation of dusk for certain species. Physiological benefits may well underlie the phenomenon, but the ecological advantage is more obvious at present.

It seems reasonable that the endothermic birds and mammals evolved from behaviorally thermoregulating ectotherms, and that the initial role of metabolic heat production was as an adjunct to an already sophisticated thermoregulatory system (*7*). These ancestral ectotherms might be assumed to have faced problems similar to those faced by modern behavioral regulators. With daily exposure to suboptimal temperatures, one would expect (using these modern lizards as a model) that they would develop mechanisms to protect them from inopportune thermally directed behavior and consequent exposure to hazards. Given a trend toward endothermy, voluntary hypothermia would gain the added protective function of energy and water conservation. It follows that active, periodic changes in the thermoregulatory system, or "thermostat," were probably part of the heritage of the birds and mammals from ectothermic ancestries and through the transitions to endothermy.

From this point of view it would appear that a hypothermic state such as daily torpidity is primitive, having been modified and retained wherever adaptive. Cade (*8*) has observed that torpidity appears in the phylogenetically conservative lines of rodents, and on this basis has come to the same conclusion.

The more orthodox view at present is that hypothermic states represent adaptive specializations and are advanced conditions in vertebrate endotherms (*9*). It is of course possible that thermostatic control became continuous and nonperiodic in the founders of the marsupial and placental lines of mammals, and that the hypothermic states of today represent secondary phenomena. This might have happened if ancestral forms were large at some stage well along toward endothermy. The energy expense of warming a large body every day could have resulted in continuous regulation becoming more practical (*10*). It is very difficult, of course, to determine if any particular fossil is directly ancestral or, indeed, endothermic.

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5. The semantics of biothermal studies can be confusing. I follow the ecological approach of R. B. Cowles as reviewed in *Science* **135**, 670 (1962). *Ectotherm* includes nearly all reptiles and signifies that thermal homeostasis is dependent upon heat available in the environment. *Endotherm* includes nearly all birds and mammals and signifies the importance of metabolic heat production in heat balance. The term *hypothermia* is unconventional when applied to ectotherms. In speaking of mammals, hypothermia is frequently a purely descriptive term and in clinical studies is even used to denote an induced state. My usage implies a judgment as to the natural operation of the neural control system. My data do not resolve the question of whether a thermostat is "turned off" or "set down," but they do suggest that more than simple inhibition of a thermoregulatory system occurs in lizards, since directed locomotor efforts are required to become cool in these gradients. Use of the word *preference* should not be taken to suggest a mechanism of regulation. Behavioral studies on lizards in nature and in the laboratory indicate, rather, that active lizards maintain body temperatures within a *range* by particular behavior patterns which are elicited toward the extremes of the range (*2–4, 11*).
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13. I thank Drs. G. Bartholomew, J. Heath, R. Lasiewski, and P. Licht for reading the manuscript, although their suggestions may not have been adopted. I thank Drs. R. B. Cowles, J. Heath, M. Lloyd, and K. Norris for their encouragement, and particularly Dr. Lloyd for his suggestions on the preparation of the manuscript. The work was completed in part while I was an NIH mental health trainee under PHS 5t1-MH-6415.

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Avena ventricosa: Possible Diploid Contributor to Hexaploid Oats

Avena ventricosa Balansa, with a diploid number ($2n$) of 14, is the least-known diploid oat species. Only two collections of this species have been reported (*1*), one from Algeria (subsp. *ventricosa*) and one from Baku (subsp. *bruhnsiana*). We have examined samples from both locations (*2*) and have found that *A. ventricosa* is distinct from other diploid *Avena* in that it lacks awns on the tips of its lemmas and has an extremely asymmetrical karyotype. It has six pairs of chromosomes with subterminal centromeres and only one pair of satellited chromosomes (Fig. 1). All other diploid oats

Fig. 1. Chromosomes of *Avena ventricosa*.

have rather symmetrical chromosomes and two pairs of satellited chromosomes (*3*).

In having these distinct morphological and cytological characters, *A. ventricosa* approaches closely the hexaploid oats (the group comprising *A. sativa* and *A. sterillis* and having $2n = 42$). Hexaploids have awnless denticulate lemmas. They also show seven pairs of chromosomes with subterminal centromeres (*4*). Since these characters are absent in other diploid *Avena* (as well as in the tetraploid oats), the hypothesis is advanced that *A. ventricosa* participated in the formation of the hexaploid oats.

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12 January 1967

Red Cell Slip at a Wall in vitro

Abstract. *Interferometric microscope observations of flowing blood indicate that the absolute number of red cells maintaining sliding contact with a wall is of the order 10^4 per square centimeter at low flow rates. Contacting cell oscillation and orientation results are given. The near wall local hematocrit is found to be relatively low.*

The purpose of this investigation was to explore the reality of blood slip, an issue significant to such matters as the local shear stress experienced by the containing vessel, the exchange of substances through the red cell membrane, and the total work performed by the heart.

It is generally accepted that real Newtonian fluids do not slip freely at a boundary, regardless of the flow velocity at some distance from the wall. Tested fluids include those that wet the wall, such as air (*1*) and water (*2*); and those that do not, such as mercury (*3*).

Unlike Newtonian fluids, the measured apparent viscosity of blood is sensitive to the roughness and chemical nature of a capillary wall (*4*) and to the vessel diameter (*5*), which suggests the possibility of slip. Velocity profiles taken several microns from the wall have been deemed (*6*) strongly suggestive of real slip, when the shear rate is low. Conversely, a number of hypotheses, with supporting evidence, have been advanced to explain the anomalous flow properties of blood without recourse to true slip. These include the sigma effect (*7*), the wall effect (*8*), the mechanical effect (*9*), and variable concentration (*10*).

To resolve the issue of slip it is sufficient to measure the velocity of blood, both plasma and cells, on planes of depth vanishingly close to a wall. Classic difficulties arising in such measurements are refraction and reflection of light, cell optical density variation as a function of velocity (*11*), and resolution limitations. The latter is particularly serious; the order of magnitude of lateral resolution with white light when employing practical lenses (in contrast to idealized values) has been given by Michelson (*12*) as 0.5 μ. Practical resolution in depth is further reduced, for additional error sources are introduced, such as the extent of accommodation within the eye and fine-focus backlash. Thus the results of Bloch (*13*), who reported red cells "in very close proximity to the wall, apparently touching the wall or 1–2μ from it," may be regarded as representing the limit of conventional microscopic depth perception. In order to establish the state of slip, a resolution improvement of at least one order of magnitude is necessary; an improvement of two orders of magnitude is useful.

The technique chosen employs a form of Newton's interference rings known as Fizeau bands. Widely known in metrology (*14*), minute differences in path length, within a thin film under test, are utilized to establish interference fringes of known separation in depth. Through a fringe counting procedure, absolute depth is established, based on the wavelength of light.

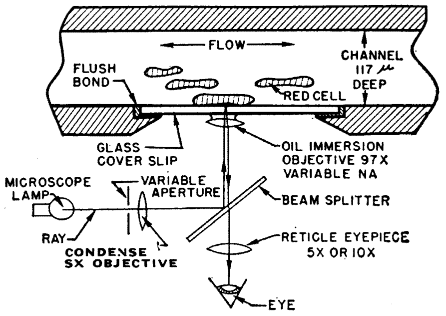

Fig. 1. Experimental arrangement schematic. Fizeau fringes are established on those cells within 1.4 μ of the channel floor.

Blood-flow conditions chosen are those that minimize optical problems and maximize the possibility of slip detection. Specifically, a two-dimensional channel, offering the same Newtonian fluid parabolic flow velocity distribution as that of a cylindrical vessel, but few refraction difficulties, was employed in preference to the latter. To assure nearly vertical illumination, I used only central rays from the microscope (*15*) lamp, by means of a small, variable aperture placed a considerable distance from the bulb, and a 5-power objective, serving as a condenser. Alignment proved critical; see Fig. 1. Rays entering the microscope are routed conventionally.

With the instrument focused on the underside of a red cell, a series of interference bands of alternate light and

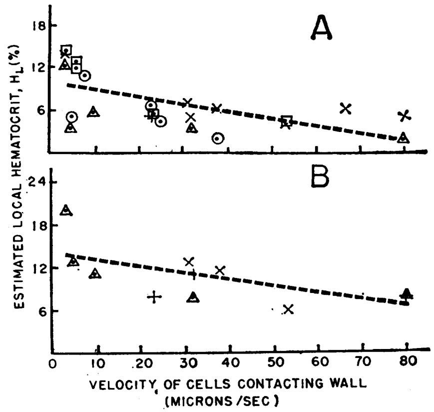

Fig. 2. Variation of estimated local hematocrit, H_L, with cell velocity at different depths from a wall. The dashed lines are least-squares regressions. Each symbol indicates a given blood donor. (A) Red cells in sliding contact with a wall. (B) Cells occupying some portion of the initial 1.4 μ depth with respect to a wall.