

riod. In three of the subjects, in whom the period of observation was extended 30 minutes, plasma TSH continued to fall to 3.1 μ U/ml (3.2, 2.3, and 3.8 μ U/ml) while plasma T_3 remained constant at 163 ng/100 ml (148, 200, and 140 ng/100 ml). The temporal relationship between elevations in plasma TSH and plasma T_3 , and the known effects of TSH on thyroid function suggest that the T_3 rise is in response to the elevated TSH concentrations, although a direct effect of TRH on the thyroid gland cannot be entirely excluded. In contrast to the clear-cut elevation in plasma T_3 , the increase in plasma T_4 , though statistically significant, was quite small. This may explain the conflicting reports of effect, or lack of effect, of TRH on serum T_4 (3, 5, 6).

The dose of TRH employed in this study probably exceeds the concentrations achieved endogenously in the pituitary portal system. Therefore, studies are needed to establish whether the observed T_3 response reflects a rapid physiological adjustment of the TRH-TSH axis to the body's changing needs or whether it represents a pharmacological response.

However, many of the endocrinological tests in common use, such as the TSH and ACTH stimulation tests, have proved to be of considerable clinical value despite the pharmacological doses of hormone administered. In addition, the radioimmunoassay for T_3 in unextracted serum is sufficiently simple, sensitive, and accurate to permit its use for routine clinical testing, and the TSH radioimmunoassay is now available in many medical centers. Moreover, despite the observed rise in T_3 and TSH, the intravenous administration of TRH has been associated with only minor and tolerable side effects such as mild nausea and flushing (11). Therefore, whatever the physiologic import of these observations, short-term serial measurements of TSH and T_3 after administration of TRH may prove of clinical value in simultaneously assessing the ability of the pituitary and thyroid glands to respond to their trophic hormones.

CHARLES S. HOLLANDER

TERUNORI MITSUMA

LOUIS SHENKMAN, PAUL WOOLF

MARVIN C. GERSHENGORN

Department of Medicine,
New York University School of
Medicine, New York 10016

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Interfacial Organisms: Passive Ventilation in the Velocity Gradients near Surfaces

Abstract. *A variety of animals, including certain sponges, tube-dwelling worms, tropical termites, and prairie dogs, either are themselves arranged or construct domiciles arranged to permit flow of fluid inside the system driven by a velocity gradient in an external stream of fluid.*

Where fluid flows along an unmoving surface, a velocity gradient ("boundary layer") exists in the fluid adjacent to the surface. Thus the many organisms living at a solid-fluid interface are exposed to such gradients; for these organisms the possibility exists of using the potential differences of the gradient to assist in their energy-requiring activities. We suggest, in particular, that the structure of certain animals and their lodgings is appropriate for exploiting

the gradient in the external medium to augment flow within animal or burrow. For littoral organisms attached to solid substrata or for animals in burrows with multiple openings the existence of a gradient may be more certain than the direction of flow. It is therefore noteworthy that mechanisms exist which permit unidirectional internal flow, irrespective of the direction of the external stream.

One mechanism makes use of a

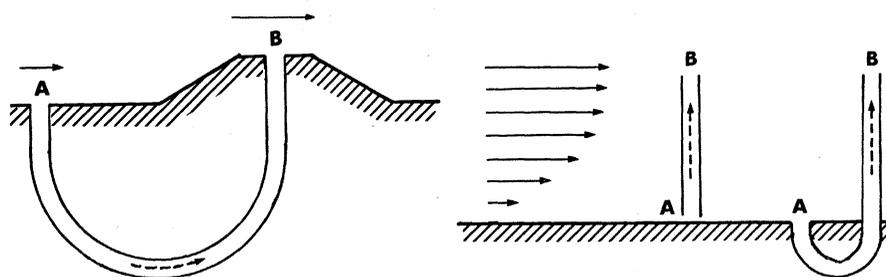


Fig. 1. Two arrangements which produce unidirectional flow in tubes. The lengths of the solid arrows are proportional to the local velocity; dashed arrows give the direction of flow in the tubes. At left, fluid moves from A to B when the free-stream velocity near B is greater than that near A. At right, fluid moves from A to B in either tube when opening A is sufficiently close to the wall so that the velocity near A is substantially less than that near B. In our model systems of this type, tubes were 2 to 3 cm long, 3 mm in internal diameter, and 4.75 mm in external diameter, in a long water-filled channel about 10 cm wide with mid-channel velocities of about 10 cm/sec.

change in the dimensions of the channel (or stream tube if the flow is unbounded above) to produce a difference in velocity and, by Bernoulli's principle, a pressure gradient (Fig. 1, left). Viscosity need not be invoked to produce the pressure difference. By contrast, a second mechanism emerges from the viscosity, or resistance to rapid shear rates, of real fluids. Unidirectional flow (as from *A* to *B* in the tubes on the right in Fig. 1) may result from greater viscous entrainment at the orifice exposed to greater external velocity. Bernoulli's principle cannot explain this latter case, since no pressure gradient is associated with the velocity gradient across a boundary layer. Instead, the phenomenon is a manifestation of the "viscous sucking" mentioned (1) for situations where fluid is drawn from a small tube into a more rapid stream crossing its orifice.

In general, then, the physical requirements for passive ventilation systems based on these mechanisms are as follows: (i) distinct incurrent and excurrent openings and (ii) incurrent opening or openings in a region of lower velocity than that near the excurrent opening or openings. The latter may be due to differences in free-stream velocity near the openings, differences in the height of the openings within a boundary layer, or some combination of the two. Cases in which these requirements appear satisfied are numerous; among them we may cite the following.

Simple intertidal sponges, such as members of the genera *Grantia*, *Leucosolenia*, and *Sycon*, have tiny incurrent pores on their external surfaces connecting, through a network of channels, the external medium and the main internal cavity. At the point farthest from the attachment to the substratum, a large excurrent opening, the osculum, returns fluid to the outside. Although Bidder (2) and others have investigated currents in sponges due to flagellar action, we find that a *Sycon*-sized plastic model in a velocity gradient (Fig. 2) shows the same unidirectional flow. The significance of such passive flow in nature is consistent with observations that the total water flow through sponges varies directly with the ambient water velocity, that the oscular chimneys of the same species are higher in slowly moving than in rapidly moving water, and that sponges developing from reaggregated cells have higher oscula if the ambient velocity is low (3).

A variety of worms of intertidal mud

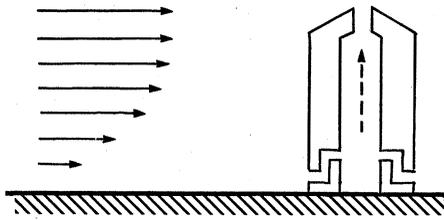


Fig. 2. Longitudinal section of cylindrical model "sponge," about 2 cm high, in the boundary layer of a substratum. Inner and outer rings of radial holes connect through a circumferential slot.

or sand flats live in burrows communicating with the water above through holes or porous channels at either end. A burrow of the lugworm, *Arenicola*, for example, connects a depression in the substratum at one end with a somewhat conical elevation at the other. The anterior end of the worm faces the depressed end at the bottom of the usually sand-filled "head-shaft" (4). Thus, whenever the water above is in motion, there will be passive flow from the anterior to the posterior end of the worm. In tanks of still water the worms pump vigorously but intermittently in the opposite (anterior) direction (4). Perhaps these movements normally serve to prevent excessive packing and loss of porosity of the sandy material in the head-shaft.

Passive ventilation is possible in certain terrestrial situations as well, since similar velocity gradients occur near the ground whenever air is in motion. Lüscher (5) has called attention to the oxygen requirements and consequent need for ventilation of the large (3.5 m high) termite (*Macrotermes natalensis*) mounds in central Africa. He proposed a convective circulation system driven by the heat of the central brood chamber; we would also suggest that the existence of incurrent openings near the base and excurrent openings near the apex permits wind-driven ventilation as well. Indeed, Lüscher noted that these openings are features of the open country mounds near Kampala, Uganda, whereas mounds in the forest of the Ivory Coast have a peripheral recirculating system instead.

Prairie dogs (*Cynomys ludovicianus*) dig long, deep burrows in the semiarid plains of North America; a typical burrow has openings at opposite ends of a principal passage about 15 m long, 2 to 3 m deep, and 100 cm² in cross-sectional area (6). Neglecting gas exchange with the soil, we estimate that a single dog in a typical burrow has a 5-

to 10-hour oxygen reserve and that diffusion alone could not supply its needs even in a burrow one-tenth as long. Bulk flow should be necessary; it is noteworthy that the height and shape of burrow openings are quite variable, ranging from ones with sharp crater-like walls, through low domes, to openings nearly level with the surrounding terrain. And the prairie dogs give considerable attention to shaping and repairing these mounds, often gathering dirt from several meters around to add to that from the original excavation (6). Rough calculations, based on Bernoulli's equation and Poiseuille's law (1), indicate that a wind of 20 cm/sec (0.5 mile per hour) over one opening and 10 cm/sec over the other should replace the air in the burrow every 10 minutes (7).

We suggest, finally, that water and air movements are more important factors in the lives of attached or burrowing organisms than is commonly recognized, that much of the structure of such organisms appears adaptively significant when fluid movement is considered, and that the relative dimensions of organisms and velocity gradients are of considerable consequence in determining habitat suitability.

STEVEN VOGEL

WILLIAM L. BRETZ

Department of Zoology,
Duke University,
Durham, North Carolina 27706

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7. Clearly, not all passive ventilatory systems need to operate by means of the mechanisms described above. In particular, either unidirectional free-stream flow or apertures whose orientation can be rapidly changed permit an animal to direct the incurrent opening toward the oncoming fluid. The animal can thereby take advantage of the difference between the dynamic (stagnation) pressure of the incurrent opening and the static pressure at the excurrent opening. For example, scallops (*Pecten maximus*) in unidirectional tidal currents usually orient so that their incurrent openings are directed upstream and their excurrent openings downstream [R. G. Hartnoll, *Helgoländer Wiss. Meeresunters.* **15**, 523 (1967)].
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