LETTER TO THE EDITOR

Blood Flow, Slip, and Viscometry

Dear Sir:

In their recent Letter to the Editor Zamir and Roach (1) discuss my paper (2). I am in agreement with the writers that the slip hypothesis is "one possible explanation" of blood flow behavior, among others. I believe nevertheless that its significance lies in its capability of accounting for several apparently unconnected flow properties observed under various conditions, and of unifying their interpretation within one concept. In the paper I tried to bring out this point. Other possible explanations were not "ignored"; on the contrary, a number of the more important ones were mentioned, briefly discussed, and further referenced (see p. 255) (2).

The writers are not justified when they allude to "curve fitting" in the formulation of the slip hypothesis. No such attempt was made, no more at any rate than for any other physical law where the form of a function is postulated from basic requirements, and the magnitude of coefficients determined from available data.

Paragraphs *a* and *b* are not clear. They seem to suggest that viscosity be handled as "fourth order *tensor*," as a property varying from point to point in the fluid. This would have little meaning here, since flow equations of the Navier-Stokes type are exceedingly difficult, if at all possible, to set up for blood, because of its lack of homogeneity and isotropy. In the paper (2) I view viscosity as a macroscopic fluid characteristic in the manner of, say, density, temperature, etc. This is prevalent practice for flow studies such as this one.

Paragraph *c* indicates a misunderstanding of slip as defined (2). Using the writers' illustration, the "skidding of a solid body over an oily surface" may imply slip, since slip is by definition a finite velocity of a fluid at a boundary or in its immediate vicinity (2).

The fifth paragraph does not seem very relevant, and suggests that slip has been misinterpreted.

It is difficult to follow the sixth paragraph, and arguments such as "different implications biologically" and the "obvious biological purpose" of slip are not helpful. If there is indeed such a "purpose," it might just as well be to expedite flow in blood vessels, rather than "to reduce the shear force at the wall of arteries," as the writers assert, or some other biological end. The shear force at the wall of blood vessels does not become "undefined," and the writers are, I believe, in error in denying that it is independent of slip. Nor is this independence a "hypothesis" of the paper, as they think; it is instead a fact derived from simple mechanics, and implies no assumption as to flow, except that it is steady (3).

The writers are quite correct in asserting that slip is not "demonstrated" in blood vessels. However, in light of what has been learned about the flow of blood in fibrin-coated glass tubes, slip may be strongly suspected in blood vessels because of the presence of a coating of fibrin on the vessel walls (4).

Finally, it is not quite true that "the no-slip condition is so well established experimentally" as the writers believe. On the contrary, recent studies suggest that there may be serious grounds for reconsidering it. Numerous comments and references to this effect are to be found in the paper (2).

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REFERENCES

1. ZAMIR, M., and M. R. ROACH. 1972. *Biophys. J.* **12**:703.
2. NUBAR, Y. 1971. *Biophys. J.* **11**:252.
3. PRANDTL, L., and O. G. TIETJENS. 1957. Applied Hydro- and Aerodynamics. Dover publications, Inc., New York. 19.
4. COPLEY, A. L. 1960. *In* Flow Properties of Blood. A. L. Copley and G. Stansby, editors. Pergammon Press, Inc., Elmsford, N. Y. 97.

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