LETTERS TO THE EDITOR

Biophysics of pulsatile perfusion

To the Editor:

I was intrigued by the discussions on the long-standing controversies of pulsatile versus nonpulsatile flow perfusions by Drs. Runge and Trinkle (1994;107:642-3) and by Dr. Bartlett (1994;107:644-6) in this JOURNAL. Drs. Runge and Trinkle emphasized the importance of using "physiologic" pulsatile waveforms, particularly in relation to rate of pressure rise (dP/dt) and ejection time. Dr. Bartlett deduced from the existing literature that differences in "adrenergic response" at moderate flow rates can account for the reported advantages of pulsatile perfusion and that at very low or high flow rates such advantages become insignificant.

Although these insights shed much light on the controversy, I wish to propose that some of the mysteries may also be related to our neglect in considering one of the physical laws of rheology. We are used to thinking of flow F as $R = \Delta P/F$, where R is "resistance" and ΔP "pressure gradient." In fact, flow between two points is determined not by P alone, but by the total energy difference (ΔE), which has two components: potential energy and kinetic energy.¹ Potential energy is our familiar P , whereas kinetic energy depends on the flow velocity ($mv^2/2$) and acceleration (related to rate of pressure rise [dp/dt]). Pulsatile flow is associated with higher kinetic energy: witness the higher gasoline consumption of driving your car fast and slow in the city compared with that of steady speed driving on the highways. It has been repeatedly observed that pulsatile perfusion reduces peripheral resistance R . If flow is maintained constant, with higher kinetic energy in the pulsatile perfusion, a lower P will be recorded and decrease the calculated R . This may account in part for the reduced "adrenergic response" described by Dr. Bartlett, although I suspect baroreceptors² also may respond to E . In turn, if mean perfusion pressure P is held constant, pulsatile perfusion will result in higher F ; thus if the study is being done in the low to moderate flow range, pulsatile perfusion may demonstrate physiologic advantage. Finally, because the magnitude of kinetic energy depends on the waveform of the pulsatile flow (whereas the mean pressure does not), it may offer a theoretic basis for the observations of Drs. Runge and Trinkle and many other investigators.

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2. Minami K, Vyska K, Körfer R. Role of the carotid sinus in response of integrated venous system to pul-

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Reply to the Editor:

The comments of Dr. Chiu regarding the greater kinetic energy and, hence, the total energy of pulsatile flow compared with that of steady flow are of course valid. The concept derives from the law of conservation of energy: the greater the magnitude of energy delivered into a system, the greater the magnitude of energy released by the system, in one form or another.

Grossi and colleagues¹ quantitated the quality, the degree, of pulsatility necessary to significantly reduce hypoxic metabolic acidosis in dogs during cardiopulmonary bypass in 1985. These investigators originated a pulsatility scale that they termed the "Pulse Power Index." Their work is a must for investigators who would study pulsatile versus steady flow.

Other important in vivo data have been published by Trinkle and colleagues,² who showed that vigorous pulsatile flow in human subjects reduced hypoxic metabolic acidosis compared with steady flow, and by Jacobs and associates,³ who showed in dogs totally supported by pulsatile flow or steady flow that not only was metabolic acidosis diminished, but also that interstitial fluid accumulation (a routine accompaniment of human cardiopulmonary bypass today) treated with furosemide, hetastarch, mannitol, and human albumin in various centers was also diminished.

It is also possible to demonstrate in vitro several significant differences in pulsatile flow of physiologic morphology versus steady flow. We have done this with standard hemodialyzers, dialyzing water spiked with urea. At identical flow rates (1) mean pressure is significantly higher with pulsatile flow, (2) ultrafiltration volume is significantly greater with pulsatile flow, and (3) urea clearance is significantly greater with pulsatile flow.⁴

On occasion it has been stated that it is not possible to "define" physiologic pulsatile flow, but certainly it is possible to define pulsatile flow of physiologic morphology. We stand by the numbers previously published in this JOURNAL in February 1994⁵: (1) physiologic rate of pressure rise (dP/dt) of the waveform within the subject's arterial tree (1000 mm Hg/sec or greater); (2) physiologic intraarterial ejection time (no greater than 415 msec - $1.7 \times$ heart rate, after Weissler⁶); (3) physiologic pulse pressure; (4) physiologic rate; and (5) physiologic stroke volume.

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