Effect of Hematocrit upon the Shift in Doppler Frequency[1] (35985)

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Since the introduction of the Doppler technique in 1961 by Franklin *et al.* (1), to measure blood flow velocities, this technique has gained in popularity for both clinical and laboratory studies (2). The basic equation which relates the Doppler shift in frequency to blood flow velocity is:

$$F_d = \frac{2 F_e (V) \cos a}{c},$$

where: F_d = Doppler shift in frequency = frequency excitation — frequency received (Hz) = $F_e \pm F_r$; F_e = 9.3 MHz; V = velocity of flow (cm/sec); a = angle between the acoustical axis and the flow of blood; c = velocity of sound in blood = 1.5×10^5 cm/sec. The audio output F_d fluctuates due to flow velocity variations and the number of scatters in the reverberation volume (3). Since the operation of the Doppler system is dependent upon the presence of suspended particulate matter within the fluid, it is conceivable that alterations in the particulate concentrate of an inhomogenous solution might alter the frequency of reflected sound, and thus the Doppler frequency. Such a shift in F_d as a function of changes in hematocrit (HCT) could result in an erroneous measurement in blood flow velocity.

This study was undertaken to evaluate the effects of a change in hematocrit on F_d under *in vitro* conditions of a constant flow velocity and temperature.

Methods. Fresh whole human blood preserved in an acid citrate–dextrose solution was used in all experiments. A decrease in particle (blood cells, plasma proteins, etc.) concentration was produced by adding a 0.85% solution of sodium chloride solution to the blood. Ideally, autologuos plasma would have been used as the diluent to exclude the possible effect of altering the plasma protein concentration. Unfortunately, sufficient quantities were not available. Hemoconcentration was produced by decanting plasma after centrifugation of the whole blood. The hematocrits of the blood samples were determined in duplicate using an Adams Redacrit microhematocrit centrifuge. A Harvard infusion/withdrawal pump (model 600-900) was used to deliver blood at constant flow rates (1.05, 0.433, and 0.028 ml/sec) through a Doppler ultrasonic flow transducer (DUF). The extracorporeal DUF was placed around a segment of thin wall (0.6 mm) Silastic tubing having an internal diameter of 1.95 mm. This assembly was encased in Styrofoam container filled with an ultrasonic coupling jelly (Aquasonic; Parker Laboratories, Irvington, NJ) with extreme care being taken to remove any air bubbles. A directional Doppler (Model 806, Parks Electronics Laboratory, Beaverton, OR) ultrasonic flowmeter (F_c = 9.3 MHz) was used in all experiments. The Doppler shift in frequency was read on a Heath digital frequency counter (Model 1B101).

Freshly mixed whole blood was pumped through the DUF at three different speeds, and multiple readings of the F_d were recorded at each speed and for each hematocrit value.

Presentation of data. All statistical analyses and graphic presentations of data were performed on an IBM 370 computer. On Fs. 1–3, the data point numbers refer to the number of observations which coincide with a given set of coordinates. When the number of points for a given locus exceeded 9, an al-

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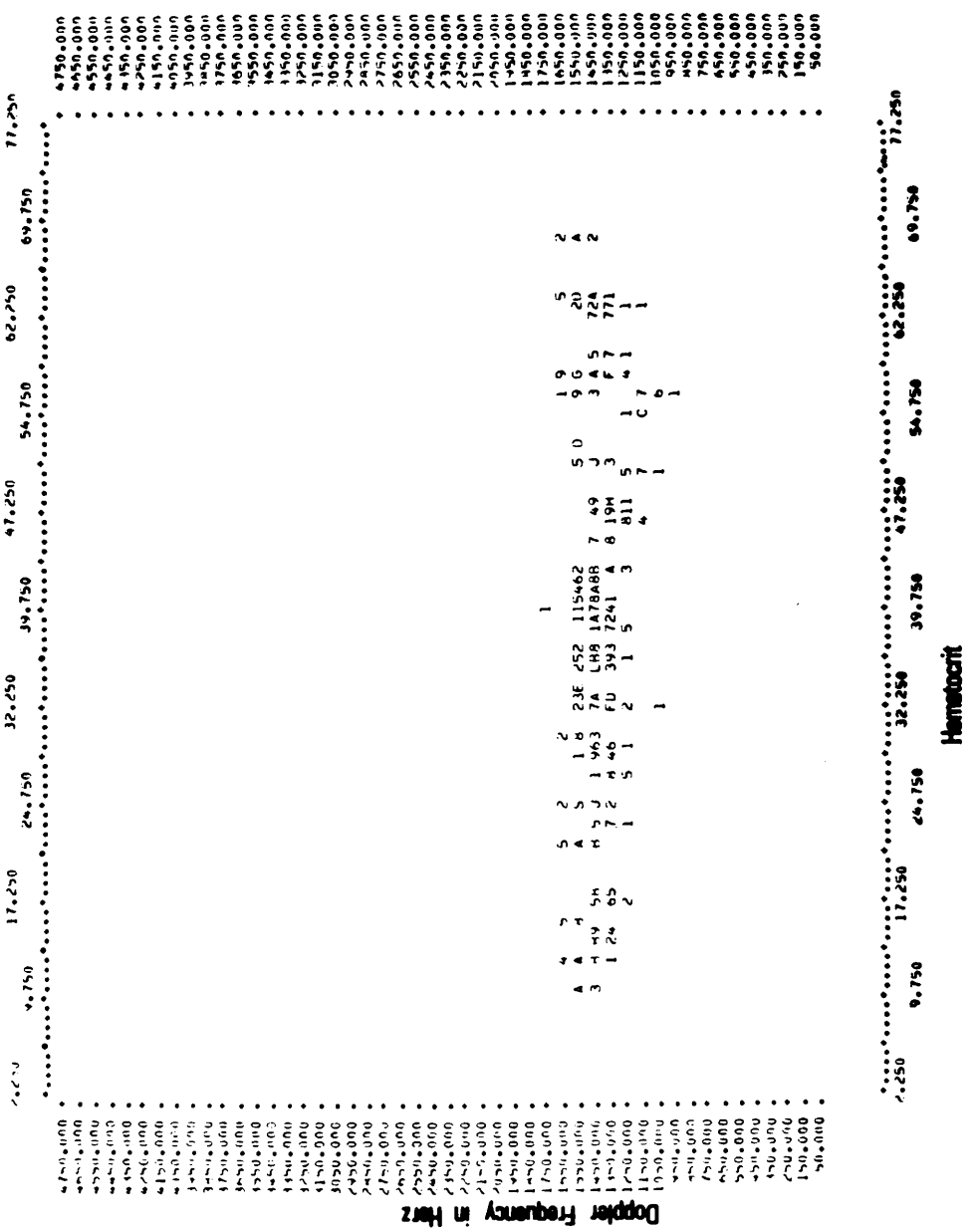

FIG. 1. Relationship between hematocrit (cell vol %) and Doppler frequency (Hz) at a flow rate of 1.05 ml/sec. The regression equation is: $Y = 3594.7 + 1.9599\ (X)$, with a standard deviation of the sample from the regression of 155.7.

phabetic progression was used ($A = 10$, $B = 11, \ldots Z = 35$).

Results. Figures 1–3 show the relationships between hematocrit and Doppler frequency at the different rates of blood flow. Table I presents various statistical computations of these data.

A comparison of Figs. 1–3 confirms the fact that, for any level of hematocrit, the F_d increases as the blood flow velocity increases. At all three rates of blood flow, there is a very slight linear relationship between hematocrit and F_d ($p < .05$). This slight linear drift (ΔF_d) does, however, account for only a

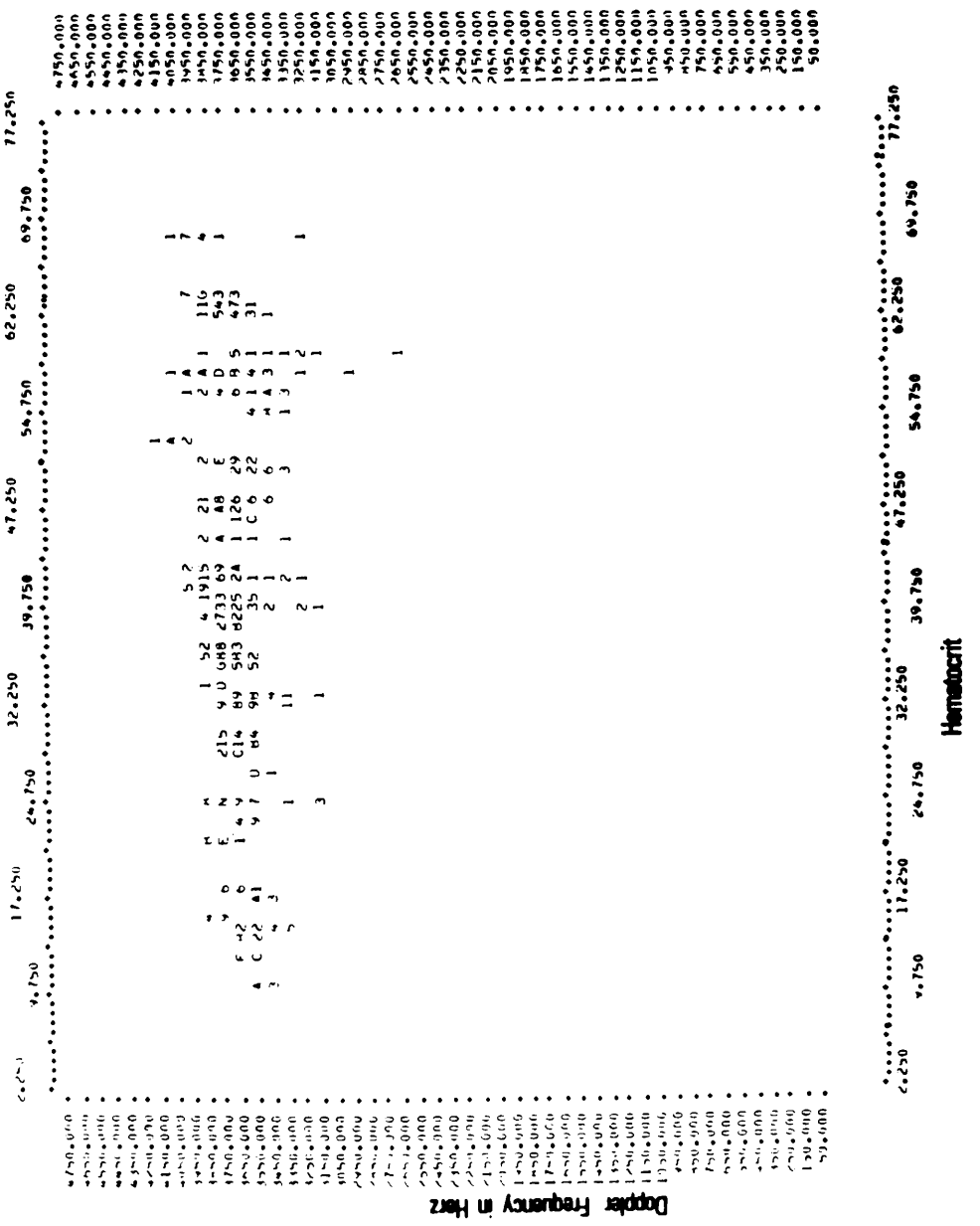

FIG. 2. Relationship hematocrit (cell vol. %) and Doppler frequency (Hz) at a flow rate of 0.433 ml/sec. The regression equation is: $Y = 1478.9 - 1.1953\ (X)$, with a standard deviation of the sample from the regression of 114.90.

very small percentage of the variance (see Table I).[2]

Discussion. These data further confirm the well-known facts that the shift in frequency of reflected ultrasound can be used as a measure of the velocity of the reflecting surface (4, 5) and that these measurements are somewhat higher than the true velocity of blood flow (6). This latter observation is

[2] $2\ \% \ \Delta F_d = \dfrac{\text{slope} \times \text{HCT range}}{\overline{F}_d}$.

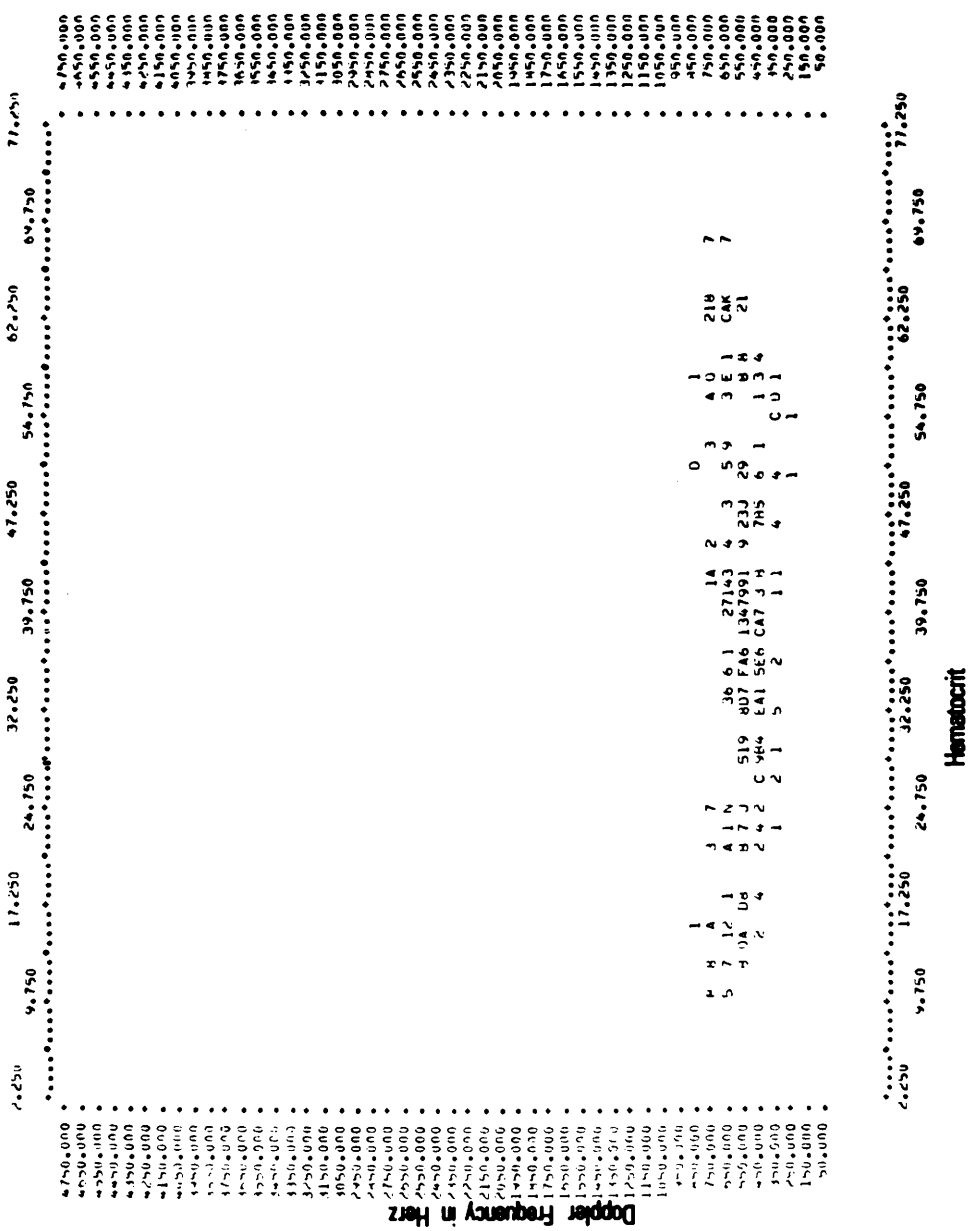

FIG. 3. Relationship between hematocrit (cell vol %) and Doppler frequency (Hz) at a flow rate of 0.208 ml/sec. The regression equation is: $Y = 535.58 + 0.84308\ (X)$, with a standard deviation of the sample from the regression of 114.06.

perhaps due to the fact that, in the case of blood flowing in a vessel (or tube), the velocity does not have a single value (5). Similarly, this study has confirmed the results of Chalupnik and Green (7), that the Doppler technique is a feasible means of measuring flow velocity when a sufficiently high concentration of scatters are available. Over the wide range of hematocrit studied (10–68 cell vol%) there is not an appreciable change in F_d as a function of hematocrit (Figs. 1–3). It has been reported by Green (8) that when the scatter concentration is low, the signal-to-noise ratio of the Doppler signal may be too

TABLE I. Statistical Computations.

Flow rate (ml/sec)	1.05	0.433	0.208
Sample size	787	787	786
Mean Doppler freq. (Hz ± SE)	3671 ± 5.6	1432 ± 4.14	568 ± 4.09
R value	0.1903	−0.1582	0.1131
Variance[a]	0.0362	0.0250	0.0128
Mean HCT ± SE	39 ± 0.5	39 ± 0.05	39 ± 0.05

[a] R^2 = proportion of variance due to linear regression.

low to permit measurement of its frequency on a zero crossing counter. This observation does not appear to apply over the wide range of cell concentration studied here. These data appear to be in disagreement with the finding of Koczy *et al.* (3) that the F_d fluctuates as a function of the particle concentration. However, this apparent discrepancy could be attributed to differences in turbulence between these two experiments. It is quite conceivable that different conditions of flow, and hence turbulence, exist between the towing tank employed in Koczy's study (3) and the positive displacement pump used in this investigation.

Conclusion. Over a wide range of erythrocyte concentration (10–68 vol%) there is not an appreciable change in the Doppler frequency shift when blood flow conditions and temperature remain constant.

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