# Effect of a fatty meal on whole blood and plasma viscosity[1,2]

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CHARM, S., W. McCOMIS, C. TEJADA, AND G. KURLAND. *Effect of a fatty meal on whole blood and plasma viscosity.* J. Appl. Physiol. 18(6): 1217–1220. 1963.—The viscosity of whole blood of 40 medical students measured with a Brookfield cone and plate viscometer showed no change before and after a fatty meal although the serum lipids increased. In separate experiments, no change was noted in plasma viscosity as determined by the capillary tube technique although plasma lipids increased. From theoretical considerations, it was suggested that methods of determining viscosity within a 2% error would be necessary in order to detect changes in plasma and whole blood viscosity after a fatty meal. However, even with the GDM low-shear rate coaxial viscometer, which has an accuracy reputed to be 2%, no change was observed in the whole blood or plasma viscosity. The results with the GDM viscometer compared favorably with the results from the Brookfield cone and plate viscometer. In 2 out of 52 cases a definite decrease in whole blood viscosity was found 3 hr after a fatty meal. The plasma viscosities, however, did not change. It is postulated that in rare cases a decrease in the yield stress of the cell aggregates due to the increased lipids results in a decreased blood viscosity. The mechanics by which this occurred is under study.

dietary fat viscosity of blood

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THE EFFECT OF A FATTY MEAL on blood viscosity has been the subject of several investigations. Swank (4) after feeding dogs a fatty meal noted variable effects on blood viscosity, i.e., sometimes the resistance to flow increased and sometimes it decreased. Shearn and Gousios (3) measured the viscosity of native blood of 13 patients and found no change although the total serum lipids increased by as much as 980 mg/100 ml following intravenous infusion of a fat emulsion. In both of these studies a tube-flow method was employed to measure blood viscosity. Shearn's measurements were carried out on blood without anticoagulant.

A Brookfield cone and plate viscometer has been shown to be useful in recent blood viscosity studies (1, 6). We have employed this instrument to study the effect of a fatty meal on viscosity characteristics of blood.

## PROCEDURES

Forty male medical students at the Roosevelt Hospital in Guatemala, ages 20–35, served as subjects. Ten-milliliter samples of venous blood were drawn from the fasting students in the morning; they then consumed a fatty meal which included 50 g of butter. Three and a half hours later, 10 ml of venous blood were drawn for viscometry, hematocrit, and serum lipid analysis. Dried ammonium and potassium oxalate was the anticoagulant.

The whole blood viscosity was measured in a Brookfield cone and plate viscometer with a water-jacketed plate (6) maintained at 37 C. One milliliter of blood was pipetted onto the plate and the shear stress, $\tau$, at a shear rate $\gamma$ of 230 $sec^{-1}$ was determined. The ratio, $\tau/\gamma$, is the apparent viscosity of blood.

In subsequent studies, data obtained with the cone and plate viscometer at 1–230 $sec^{-1}$ were compared with those obtained in a low-shear rate coaxial GDM viscometer at 0.1–20.5 $sec^{-1}$ (2).

In the shear stress range in which the viscosity of the whole blood was measured in the Brookfield cone and plate viscometer the error in measurement is about 5%. A much greater error in the measurement of plasma viscosity would result if it were measured in this viscometer because of its lower shear stress. For this reason, a capillary tube was used to determine the viscosity of

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plasma which is essentially a Newtonian fluid and obeys Poiseuille's equation (*equation 1*).

The hematocrit was measured by a micromethod. The change in serum lipids was reflected in the per cent transmission at 620 $\mu$ wavelength in a Beckman spectrophotometer.

The effect of a fatty meal on plasma viscosity was also studied in specimens from seven students at Massachusetts Institute of Technology who drank 250 ml of 30% cream after fasting at least 12 hr. The viscosity of plasma before and 3 hr after the fatty meal was determined from the flow rate and pressure loss in a glass capillary tube 0.0298 cm in diameter (1). The flow system is described in detail elsewhere (1). Plasma viscosity was calculated using Poiseuille's equation. The plasma triglycerides were determined using the method of Van Handel and Zilversmit (5).

TABLE 1. *Apparent viscosity at 230 sec$^{-1}$ and serum lipids before and 3.5 hr after feeding a fatty meal*

| No. | Apparent Viscosity, c.p. | | Serum Lipids, Optical Density at 620 $\mu$ | |
|---|---|---|---|---|
| | Before | After | Before | After |
| 1 | 4.88 | 4.40 | | |
| 2 | 4.10 | 4.00 | | |
| 3 | 5.54 | 5.50 | | |
| 4 | 4.40 | 4.55 | | |
| 5 | 4.50 | 4.40 | | |
| 6 | 4.50 | 4.20 | | |
| 7 | 3.77 | 3.83 | | |
| 8 | 4.45 | 4.37 | | |
| 9 | 5.25 | 5.15 | 284 | 727 |
| 10 | 4.64 | 4.54 | 77 | 610 |
| 11 | 4.68 | 4.64 | 53 | 335 |
| 12 | 4.55 | 4.73 | 48 | 320 |
| 13 | 4.40 | 4.44 | 44 | 180 |
| 14 | 4.94 | 4.86 | 55 | 122 |
| 15 | 4.88 | 4.92 | 73 | 145 |
| 16 | 4.94 | 4.68 | 54 | 180 |
| 17 | 5.35 | 5.26 | 61 | 125 |
| 18 | 4.98 | 4.82 | 56 | 126 |
| 19 | 4.54 | 4.50 | 39 | 73 |
| 20 | 4.40 | 4.46 | 57 | 432 |
| 21 | 4.50 | 4.55 | 61 | 210 |
| 22 | 5.12 | 5.02 | 88 | 334 |
| 23 | 4.22 | 4.31 | 48 | 253 |
| 24 | 5.20 | 4.88 | 133 | 188 |
| 25 | 4.50 | 4.69 | 123 | 457 |
| 26 | 4.55 | 5.07 | 51 | 189 |
| 27 | 5.20 | 5.20 | 117 | 539 |
| 28 | 5.16 | 4.98 | 198 | 210 |
| 29 | 5.50 | 5.40 | 310 | 388 |
| 30 | 4.74 | 4.98 | 70 | 213 |
| 31 | 4.84 | 4.84 | 118 | 246 |
| 32 | 4.94 | 4.50 | 105 | 194 |
| 33 | 4.69 | 4.73 | 40 | 337 |
| 34 | 5.17 | 5.33 | 54 | 440 |
| 35 | 4.39 | 4.90 | 65 | 202 |
| 36 | 6.51 | 6.51 | 73 | 610 |
| 37 | 4.26 | 4.17 | 168 | 180 |
| 38 | 4.84 | 4.84 | 56 | 700 |
| 39 | 5.26 | 5.26 | | |
| 40 | 4.79 | 4.30 | 46 | 820 |
| 41 | 5.16 | 5.03 | 55 | 155 |
| 42 | 5.20 | 5.16 | 96 | 144 |
| 43 | 4.80 | 4.74 | 62 | 355 |

## RESULTS

The apparent viscosity of whole blood measured at a shear rate of 230 sec$^{-1}$ did not change 3.5 hr after eating a fatty meal despite an increase in the serum lipids (Table 1).

The plasma viscosity was also unchanged although plasma triglycerides increased (Table 2).

In one case aliquots of the same specimen were studied both in the Brookfield cone and plate viscometer and in the GDM low-shear rate coaxial viscometer at shear rates as low as 0.113 sec$^{-1}$ (Table 3). The shear stress–shear rate characteristics were similar; in neither was there significant change after the fat meal.

TABLE 2. *Plasma viscosity measured by capillary tube flow before and after a fatty meal*

| Before Fatty Meal | | | | After Fatty Meal | | | |
|---|---|---|---|---|---|---|---|
| Sample | Viscosity | c.p. | Triglycerides, mg/100 ml | Sample | Viscosity | c.p. | Triglycerides, mg/100 ml |
| 1a | 1.59 | 1.59 | 75 | 1b | 1.61 | 1.63 | 90 |
| 2a | 1.39 | 1.32 | 100 | 2b | 1.44 | 1.45 | 250 |
| 3a | 1.51 | 1.48 | 140 | 3b | 1.63 | 1.65 | 185 |
| 4a | 1.55 | 1.58 | 80 | 4b | 1.61 | 1.65 | 120 |
| 5a | 1.51 | 1.52 | 85 | 5b | 1.48 | 1.55 | 140 |
| 6a | 1.45 | 1.48 | 140 | 6b | 1.52 | 1.51 | 251 |
| 7a | 1.70 | 1.67 | 143 | 7b | 1.70 | 1.67 | 226 |

TABLE 3. *Shear stress–shear rate characteristics of whole blood and plasma before and 3 hr after a fatty meal as measured by GDM coaxial and Brookfield cone and plate viscometers*

| Viscometer | Sample | Shear Stress, dynes/cm$^2$ | | Shear Rate, sec$^{-1}$ |
|---|---|---|---|---|
| | | 0 hr | 3 hr | |
| Brookfield | Whole blood | 10.78 | 10.86 | 230 |
| | | 5.86 | 5.90 | 115 |
| | | 2.82 | 2.86 | 46 |
| | | 1.63 | 1.67 | 23 |
| | | 1.01 | 1.01 | 11.5 |
| | | 0.682 | 0.638 | 5.8 |
| | | 0.352 | 0.330 | 2.3 |
| | | 0.176 | 0.176 | 1.15 |
| GDM | Whole blood | 1.355 | 1.342 | 20.52 |
| | | 0.845 | 0.816 | 10.26 |
| | | 0.468 | 0.462 | 4.11 |
| | | 0.324 | 0.307 | 2.05 |
| | | 0.233 | 0.223 | 1.026 |
| | | 0.166 | 0.159 | 0.411 |
| | | 0.146 | 0.144 | 0.205 |
| | | 0.113 | 0.111 | 0.1026 |
| GDM | Plasma | 0.253 | 0.260 | 20.52 |
| | | 0.124 | 0.128 | 10.26 |
| | | 0.049 | 0.051 | 4.11 |

plasma which is essentially a Newtonian fluid and obeys Poiseuille's equation (*equation 1*).

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| 3a | 1.51 | 1.48 | 140 | 3b | 1.63 | 1.65 | 185 |
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| | | 0.468 | 0.462 | 4.11 |
| | | 0.324 | 0.307 | 2.05 |
| | | 0.233 | 0.223 | 1.026 |
| | | 0.166 | 0.159 | 0.411 |
| | | 0.146 | 0.144 | 0.205 |
| | | 0.113 | 0.111 | 0.1026 |
| GDM | Plasma | 0.253 | 0.260 | 20.52 |
| | | 0.124 | 0.128 | 10.26 |
| | | 0.049 | 0.051 | 4.11 |

TABLE 4. *Shear stress–shear rate characteristics of subject S blood and plasma before feeding and 3 hr after fatty meal measured with GDM viscometer*

| Sample | Shear Stress, dynes/cm² | | Shear Rate, $sec^{-1}$ |
|---|---|---|---|
| | 0 hr | 3 hr | |
| Whole blood | 1.348 | 1.284 | 20.52 |
| | 0.828 | 0.777 | 10.26 |
| | 0.440 | 0.407 | 4.11 |
| | 0.284 | 0.260 | 2.05 |
| | 0.190 | 0.174 | 1.026 |
| | 0.125 | 0.1064 | 0.411 |
| | 0.0987 | 0.0910 | 0.205 |
| | 0.0780 | 0.0642 | 0.1026 |
| Plasma | 0.253 | 0.258 | 20.52 |
| | 0.127 | 0.127 | 10.26 |
| | 0.051 | 0.051 | 4.11 |
| | 0.026 | 0.025 | 2.05 |

TABLE 5. *Shear stress–shear rate characteristics of subject W blood before feeding and 3 hr after a fatty meal measured with Brookfield cone and plate viscometer*

| Date | Shear Stress, dynes/cm² | | Shear Rate, $sec^{-1}$ |
|---|---|---|---|
| | 0 hr | 3 hr | |
| 3/ 2/62 | 18.1 | 16.3 | 450 |
| | 9.6 | 8.6 | 230 |
| | 4.3 | 3.9 | 92 |
| | 2.4 | 2.2 | 46 |
| | 1.4 | 1.2 | 23 |
| 3/14/62 | 17.3 | 17.3 | 460 |
| | 9.1 | 9.2 | 230 |
| | 4.1 | 4.3 | 92 |
| | 2.4 | 2.5 | 46 |
| | 1.4 | 1.4 | 23 |

In 2 of 52 cases the whole blood viscosity decreased 3 hr after a fatty meal although the plasma viscosity remained unchanged (Tables 4 and 5). Plasma turbidity was markedly increased in both; in one, the plasma triglycerides were quantitated and increased from 166 to 422 mg/100 ml. The decrease of blood viscosity occasionally noted after a fatty meal could not be reproduced in repeated experiments on the same individual (Table 5).

## DISCUSSION

The data indicate no significant difference in blood viscosity before and after a fatty meal.

These results (Table 1) confirm observations made with the capillary tube method (3). It was anticipated that the increased fat bodies in the plasma would result in an increase in plasma viscosity which, in turn, would increase whole blood viscosity. However, no change in plasma viscosity was found after the fatty meal (Table 1). Several explanations are available.

A small change in plasma viscosity may have occurred which could not be detected by this method. The error associated with the tube-flow method of determining plasma viscosity may be found by the following analysis. The viscosity is calculated from Poiseuille's equation,

$$\mu_p = \frac{\pi}{8}\frac{R_w^4}{L}\frac{P}{Q} \qquad (1)$$

where

$\mu_p$ = plasma viscosity
$R_w$ = radius of the capillary tube
$L$ = length of capillary tube
$P$ = pressure drop through capillary tube
$Q$ = volumetric flow rate

The two measured variables in a given tube are $P$ and $Q$.

The first derivative of *equation 1* indicates how a change or an error in measuring $P$, $dP$, and a change or an error in measuring $Q$, $dQ$, results in a change or an error in $\mu_p$, $d\mu_p$.

The first derivative of *equation 1* is

$$d\mu_p = \frac{\pi}{8}\frac{R_w^4}{L}\left(\frac{dP}{Q} + \frac{P\,dQ}{Q^2}\right) \qquad (2)$$

In a case where the viscosity is found to be 1.5 centipoises (c.p.), the flow conditions are as follows:

$Q = 2.42 \times 10^{-2}$ ml/sec
$dQ = 0.075$ ml/sec
$P = 14.36 \times 10^4$ dynes/cm²
$dP = 1.33 \times 10^3$ dynes/cm²
$R_w = 0.0149$ cm
$L = 7.22$ cm

Substituting these values in *equation 2* it is found that $d\mu_p = \pm 0.0498$ c.p.

Therefore the viscosity in this case is $1.50 \pm 0.0498$ c.p. Thus, in order to recognize a real difference in plasma viscosity by this method, there must be a measured difference greater than 0.0498 c.p. in plasma viscosity.

In order to estimate the increase in plasma fat bodies required for a 0.0498 c.p. difference in viscosity, it may be assumed that Einstein's equation for expressing the viscosity of dilute suspensions applies.

$$\mu_s = \mu(1 + 2.5\phi) \qquad (3)$$

where

$\mu_s$ = viscosity of the suspension
$\mu$ = viscosity of the suspending medium
$\phi$ = volume fractions of the suspended bodies

The change in the suspension viscosity as a function of the change in volume fraction of suspended bodies, $d\phi$, is given by the first derivative of *equation 3*.

$$d\mu_s = \mu(2.5)\,d\phi \qquad (4)$$

In this case $\mu$ is the plasma viscosity before addition of fat bodies and is equivalent to $\mu_p$. Also $d\mu_s$ is equivalent to the change in plasma viscosity of $d\mu_p$, after the addition of the fat bodies, and in this case is numerically 0.0498.

Recalling that $\mu_p$ is 1.50 c.p., it is possible to calculate the change in the volume fraction of fat bodies required to cause a change of 0.0498 c.p. in $\mu_s$ by substituting these values in *equation 4*, thus

$$0.0498 = (1.5)(2.5)\, d\phi$$
$$0.0133 = d\phi$$

There must be a 1.3% change in the volume fraction of total fat bodies or assuming that fat has a density of 0.9 there must be a change of 1.48 g/100 ml by weight of fat in the plasma to cause a recognizable change of 0.0498 c.p.

The data indicate that the increase in plasma triglycerides 3 hr after the fatty meal was in the order of 100–200 mg/100 ml. This is about 5% of the change theoretically required to show a change in plasma viscosity by the method employed. Since no change in plasma viscosity was recognized, the failure to observe a change in the whole blood viscosity by this method is not surprising.

The GDM coaxial viscometer is said to be accurate to within a 2% error and permits accurate measurement at shear rates as low as 0.1 $sec^{-1}$. Measurements of blood viscosity before and after a fatty meal carried out with this viscometer also indicated no change in whole blood or plasma viscosity although the plasma lipid increased 3 hr after the fatty meal. An aliquot of the same sample was measured in a Brookfield cone and plate viscometer and the results were similar to those obtained with the GDM viscometer (Table 3).

During the studies on blood viscosity after fatty meals, occasional unexpected results were observed. In these cases, the blood viscosity decreased although plasma lipids were decidedly increased. It was not possible to reproduce these effects in the same subjects at will (Table 5). Experiments on fat feeding in dogs yielded similar anomalous results which were difficult to reproduce. It is significant that in these isolated instances, the drop in viscosity was noted both with the GDM low-shear rate viscometer and in the Brookfield used at higher shear rates. By both methods the shear stress at given shear rates was decidedly lower 3 hr after the fatty meal (Table 4). However, plasma viscosity remained constant when measured in tube flow as well as in the GDM viscometer. Chemical analysis of the plasma lipids showed an increase from 166 mg/100 ml triglycerides on fasting blood to 422 mg/100 ml 3 hr after the fatty meal. Hematocrit levels remained constant at 45 over this period. It is suggested that the decrease in viscosity after a fatty meal in these occasional instances is the result of a decrease in the blood yield stress after a fatty meal. This may be the result of an interaction of the plasma lipid with the cell surface.

It is possible that other mechanisms for altering blood viscosity might operate in the absence of a change in plasma viscosity. For example, alteration of red cell floc or aggregate size might result from qualitative changes in plasma lipoproteins or in red cell surface interactions. These changes might not be recognized at shear rates of 230 $sec^{-1}$ where flocs and aggregates have been reduced to minimal circulating size. The study (Table 3) at shear rates as low as 0.176 and 0.113 $sec^{-1}$ with the Brookfield and GDM viscometers is, therefore, particularly important in showing no change in shear stress-shear rate characteristics. We are unable at this time to evaluate the role of anticoagulants in disguising possible changes in blood viscosity.

The authors thank Professors Merrill and Cokelet of M.I.T. for the use of the GDM low shear rate viscometer and William Margets of M.I.T. for running the GDM viscometer. For the statistical analysis of the blood viscosities of the Guatemalan medical students, the authors thank Miguel Guzman of INCAP, Guatemala.

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