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Blood rheology in vegetarians

BY E. ERNST, L. PIETSCH, A. MATRAI AND J. EISENBERG

Hemorheology Research Laboratory, Clinic for Physical Medicine, University of Munich, D-8000 München 2, Ziemssenstrasse 1, Federal Republic of Germany

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1. Blood rheology has been quantified by measuring blood and plasma viscosity, packed cell volume (PCV), erythrocyte filterability and erythrocyte aggregation in forty-eight voluntary vegetarians and compared with matched controls.

2. Results show that in vegetarians, values for PCV were lower than those in controls, leading to reduced native blood viscosity. In addition PCV-standardized blood viscosity was also decreased. This was brought about mostly by lower plasma viscosity. Erythrocyte rheology seemed to be unaltered. Stricter avoidance of animal products was associated with even lower values for these indices.

3. These observations are in agreement with the fact that other low-cardiovascular-risk groups show better than average blood fluidity. They are consistent with the hypothesis that in vitro measurements of blood rheology may provide signs of early atherosclerotic changes in vivo.

Blood is a complex fluid comprising cells and plasma. As such it exhibits complex rheological behaviour (Chien, 1975). Its viscosity is not a constant like that of simple Newtonian fluids, but it is a function of shear forces acting upon blood. This phenomenon, often referred to as 'structural viscosity', is essentially caused by the presence and relative amount of erythrocytes (packed cell volume; PCV), the viscosity of plasma (greatly influenced by macroproteins such as fibrinogen) and the micro-rheological behaviour of blood cells (cell aggregation and deformability).

While such considerations could be largely academic, they gain importance on realization that blood rheology is shown to be abnormal in the presence of virtually all accepted cardiovascular risk factors, e.g. hypertension (Letcher & Chien, 1981), hyperlipoproteinaemia (Lowe, 1982), smoking (Norton & Rand, 1981), diabetes (Barnes *et al.* 1977), obesity (Weihmayr *et al.* 1984), lack of physical exercise (Ernst, 1985*b*) and psychoemotional stress (Ernst *et al.* 1984). Similarly it has been shown that in groups with reduced cardiovascular risk, one or more haemorheological factors are 'better than normal', e.g. in young females (Kannel *et al.* 1976), slightly anaemic persons (White, 1958) and sportsmen (Ernst, 1985*b*).

It has been repeatedly reported that vegetarians are associated with a relative reduction of cardiovascular risk factors compared with groups of omnivorous individuals (Keyes *et al.* 1965; West & Hayes, 1968; Sacks *et al.* 1974, 1981; Burslem *et al.* 1978; Carroll, 1978; Stamler, 1980; Knuiman & West, 1982; Rottka & Thefeld, 1984). Also it is known that PCV is lower in vegetarians (Dong & Scott, 1982). Other factors, important for the rheological properties of blood, however, have not been investigated. The present paper aims to provide further information in this area.

MATERIAL AND METHODS

Forty-eight vegetarians (twenty-four women and twenty-four men) with an average age of 29 (18–54) years and a history of 3·5 (0·3–17) years of vegetarianism were examined. Vegetarian sub-groups were also studied. One sub-group consisted of five individuals

renouncing all animal products (vegan-group), another of twenty-eight persons who did consume eggs, milk and milk products (ovo-lacto-vegetarians) and another of fifteen volunteers who ate some meat (on rare occasions) less than once a week (semi-vegetarians). The control group was composed of twelve women and twenty-nine men (average age 31 (20–54) years) following a normal Western European omnivorous diet. All volunteers (vegetarians and controls) were healthy according to medical history and routine laboratory check-up. None of them was taking any medication (including contraceptive hormones) 3 weeks before testing. To minimize the possibility of hormonal influences, women were always tested on day 10 of their menstrual cycle.

Blood sampling was performed as follows. The volunteer had been lying on a bed for at least 10 min. Subsequently a 19 G needle was inserted into an antecubital vein and 20 ml blood were drawn into a pre-heparinized syringe without venous occlusion and with minimal suction. This technique was shown to avoid possible sampling artifacts due to posture and occlusion time (Matrai & Ernst, 1985).

The indices tested were: blood viscosity at two defined shear stresses within the physiological range, using a rotational instrument at both native and standardized (0·45) PCV at 37° (Davenport & Roath, 1982); plasma viscosity in a capillary viscometer (Harkness, 1963); erythrocyte filterability (as a measure of deformability) by Nucleopore (5 μm pores) filtration (Dodds *et al.* 1979); erythrocyte aggregation using an automated transparent cone-and-plate viscometer (Schmid-Schönbein *et al.* 1982); and yield stress by stress-controlled viscometry (Davenport & Roath, 1982). All rheological tests were performed in duplicate. In the vegetarian group a number of additional indices were examined: fibrinogen (Clauss, 1957), triglycerides, cholesterol, blood count, total serum protein, plasma iron, ferritin and thrombocyte count were all determined by standard methods (Winthrobe, 1965). Blood pressure and heart rate were taken after the volunteers had been lying on a bed for 10 min.

Statistical analysis was performed by Student's t test when data were distributed normally, otherwise by the Mann–Whitney test (Weber, 1980). The null hypothesis was rejected when $P < 0{\cdot}05$.

RESULTS

Table 1 summarizes the comparisons between the vegetarian and the control groups. The former were associated with significantly lower systolic and diastolic blood pressure, PCV, blood viscosity native and at standardized PCV (the latter only at low shear stress) and plasma viscosity. Indices describing erythrocyte rheology (aggregation and filterability) and yield stress did not differ significantly. Table 2 shows the additional tests performed in the vegetarian group only. Although mean values are all within the normal range, it is evident that platelet count, plasma Fe, ferritin, triglycerides and cholesterol were at the lower limit of normal.

Results were also analysed to detect possible differences within the vegetarian group according to the strictness of the diet. Only ovo-lacto-and semi-vegetarians were compared in this manner since the vegan group was too small (n 5) for statistical analysis. Table 3 shows that in the ovo-lacto-vegetarians, systolic blood pressure, cholesterol, PCV, standardized high shear blood viscosity and plasma viscosity were significantly lower, compared with semi-vegetarians.

Table 1. *Comparison of experimental blood indices in vegetarian* (n *48*) *and control* (n *41*) *subjects*

(Mean values and standard deviations)

Index	Vegetarians		Controls	
	Mean	SD	Mean	SD
BP (mmHg)				
Systolic	110**	9·2	126	12·0
Diastolic	73**	7·3	80	9·1
Packed cell volume				
♀	0·410**	0·024	0·424	0·032
♂	0·463**	0·025	0·476	0·026
Bη1 (mPa/s)	6·2**	1·3	7·7	2·5
Bη2 (mPa/s)	4·1**	0·6	4·5	0·7
st Bη1 (mPa/s)	6·4**	1·1	7·2	1·7
st Bη2 (mPa/s)	4·2	0·5	4·3	0·4
Pη (mPa/s)	1·16*	0·04	1·18	0·05
RCF	0·70	0·10	0·68	0·15
RCA	12·4	4·0	11·8	3·0
YS (N/m^2)	0·2	0·1	0·1	0·1

BP, blood pressure; Bη, blood viscosity at shear stresses of (1) 1·7 and (2) 16·8 N/m^2; st, standardized packed cell volume of 0·45; Pη, plasma viscosity; RCF, erythrocyte filterability; RCA, erythrocyte aggregation; YS, yield stress.

* $P < 0{\cdot}05$, ** $P < 0{\cdot}01$.

Table 2. *Results of tests performed on vegetarian subjects only*

Index	Mean	Range	SD	Normal range
Erythrocyte ($\times 10^6$/mm^3)				
♀	4·4	4·0–5·0	0·3	4·2–5·4
♂	4·9	4·4–5·5	0·3	4·6–6·2
Haemoglobin (g/l)				
♀	129	106–147	10	120–160
♂	149	131–162	9	140–180
MCV (μm^3)	87·5	72–95	4·7	80–97
Leucocyte count ($\times 10^3$/mm^3)	5·3	3·4–7·9	1·3	3·5–11·0
Platelet count ($\times 10^3$/mm^3)	185·8	98–286	41·8	150–390
Fibrinogen (mg/l)	2319	1300–3700	491	1500–3000
Plasma iron (μg/l)	893	130–1660	367	800–1800
Ferritin (μg/l)	537	50–2400	502	300–3000
Total serum protein (g/l)	69	61–75	3	65–85
Triglycerides (mg/l)	889	310–2090	391	500–2000
Cholesterol (mg/l)	1838	1260–2530	339	1500–2600

MCV, mean corpuscular volume.

Table 3. *Statistically significant differences between vegetarian sub-groups: ovo-lacto* (n *28*) v. *semi-vegetarians* (n *15*)
(Mean values and standard deviations)

Indices	Ovo-lacto-vegetarians		Semi-vegetarians	
	Mean	SD	Mean	SD
BP, systolic (mmHg)	109**	7·7	115	9·8
Packed cell volume				
♀	0·399*	0·017	0·436	0·023
♂	0·458*	0·026	0·476	0·019
st Bη2 (mPa/s)	4·15**	0·07	4·19	0·15
Pη (mPa/s)	1·15**	0·04	1·18	0·04
Cholesterol (mg/l)	1620**	410	2050	290

BP, blood pressure: st Bη2, blood viscosity at a shear stress of 16·8 N/m^2 at a standardized packed cell volume of 0·45; Pη, plasma viscosity.
* $P < 0{\cdot}05$, ** $P < 0{\cdot}01$.

DISCUSSION

Our findings suggest that blood rheology in vegetarians differed from that of omnivorous controls. This difference exceeded the one caused by lower PCV values (Dong & Scott, 1982). Blood viscosity standardized for a PCV of 0·45 and plasma viscosity also differed significantly. As such the haemorheological difference was most likely to be caused by several factors: low PCV, marginally increased erythrocyte filterability (not significant) and possibly modified plasma protein pattern leading to reduced plasma viscosity. Macroproteins, especially fibrinogen, determine the viscosity of plasma and induce erythrocyte aggregation (Chien, 1975). Fibrinogen has been shown to be unchanged by vegetarianism (Haines *et al.* 1980) or a high-carbohydrate 'prudent' diet (Elkeles *et al.* 1980). The present results confirm that fibrinogen levels were normal in vegetarians (Table 2), hence other macroproteins with strong effects on blood rheology such as IGM or α-2-macroglobulin could be involved. An additional effect on plasma viscosity could be exerted by plasma lipids.

The results confirm findings by Sacks *et al.* (1974) of lower blood pressure in vegetarians. The analysis of vegetarian sub-groups showed that strict avoidance of animal products was indeed associated with lower blood pressure and lower cholesterol levels as well as with higher blood fluidity. This seems to implicate a dose-effect relation, suggesting that these blood changes are in fact caused by vegetarianism.

Controls and vegetarians did not differ in terms of smoking habits, age, sex distribution, average physical activity (evaluated by questionnaire) or psychoemotional stress level (evaluated by self-rating scale); factors that have been shown to influence blood rheology (Ernst, 1985*a*). However, the two groups differed marginally but significantly in terms of average weight (Broca-index 0·9 (SD 0·09) vegetarians, 1·0 (SD 0·14) controls). Although it has recently been demonstrated that haemorheological abnormalities occur in cases of extreme obesity, possibly in connexion with elevated fibrinogen levels (Weihmayr *et al.* 1984), there seems to be no link between body-weight and blood rheology when the excess weight is less severe (Volger, 1980). Hence it is unlikely that the slight difference in average weight contributes markedly to the present results. There can be no doubt, however, that vegetarianism is not confined to eating habits. Most certainly, voluntary vegetarians differ

from controls in their attitudes towards many aspects of life and health. The vegetarians investigated in the present study represented a highly selected population. To what extent this fact influenced the findings cannot be answered at present.

Table 2 shows that values of a number of indices were found to be in the lower normal range in vegetarians. In the case of platelet count, fibrinogen and lipids, low values might contribute to or be the expression of the enhanced overall health of vegetarians (Burkitt *et al.* 1974; Turner, 1979; Burr & Sweetnam, 1982). Contrary to widespread medical opinion, this might also apply to haemoglobin and related variables (Kannel *et al.* 1972; Sorlie *et al.* 1981; Carter *et al.* 1983).

What is the biological relevance of 'better than normal' blood fluidity in vegetarians? Possibly it reflects the lower cardiovascular risk of vegetarians. Recently it has been shown that vegetarianism (Arntzenius *et al.* 1985) or the increase of vegetable products into an omnivorous diet (Kushi *et al.* 1985) does in fact lead to a decrease in cardiovascular risk. As mentioned previously, there is an intriguing association between cardiovascular risk and blood rheology (White, 1958; Kannel *et al.* 1976; Barnes *et al.* 1977; Letcher & Chien, 1981; Norton & Rand, 1981; Lowe, 1982; Ernst *et al.* 1984; Weihmayr *et al.* 1984; Ernst, 1985*a*,*b*). According to our hypothesis (Ernst *et al.* 1986) similar phenomena on cell surfaces affect both the blood cells and the endothelium, leading to changes in blood fluidity as well as early atherosclerotic changes. Hence haemorheological tests may provide a picture of early atherosclerotic changes taking place within the affected blood vessels. Such information is particularly valuable as it can be obtained in a non-invasive way and is not available by any other known diagnostic tool. From this point of view the 'better than normal' blood rheology in vegetarians should be a consequence and not a cause of their relatively low risk. With the present popularity of vegetarianism in Western countries this complex problem is worth further investigation.

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