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RELATIONSHIPS BETWEEN FITNESS AND BLOOD VISCOSITY IN UNTRAINED NORMAL SHORT CHILDREN.

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ABSTRACT

18 healthy untrained children (13 boys, 5 girls) performed a 15 min submaximal incremental exercise on cycloergometer rising heart rate (HR) up to a final step (5min) at 90% of theoretical maximal heart rate. Whole blood viscosity (at high shear rate), plasma viscosity and hematocrit increased after exercise ($p<0.01$). The index of fitness $\dot{W}$ 170 was negatively correlated with blood viscosity at rest ($r = 0.752$, $p < 0.001$). Plasma viscosity and hematocrit were also correlated with $\dot{W}170$ while relative blood viscosity at corrected hematocrit 45% did not show such a correlation. Therefore (a) exercising children undergo the same hemorheologic modification as adults;(b) $\dot{W}170$,a very classical index of fitness, is strongly related to blood fluidity; (c) the viscosity of blood at very high shear rate (i.e.reflecting the newtonian behavior of blood) is correlated with fitness; (c) the factors of blood viscosity involved in this relationship appear to be plasma viscosity and hematocrit rather than red cell flexibility.

INTRODUCTION

Recently, two important circulatory parameters have been shown to be related to fitness: arterial elasticity (1) and blood fluidity (1-5). Since modifications of blood rheology experimentally influence blood supply to various tissues (6), it is attractive to hypothesize that the relationships between blood viscosity and the function of exercising muscles are of physiological relevance (2).

Key words : blood viscosity, hematocrit, fitness, exercise, hemorheology, children.

A longitudinal study showing that improvement of fitness during a training programme is associated with a parallel decrease in blood viscosity supports to some extent this concept(7). However, this aspect of exercise physiology remains incompletely clarified. For example, very little has been reported, to our knowledge, concerning the relationships between blood fluidity and exercise in children . In a previous paper, we demonstrated that a submaximal bout of exercise significantly increases both plasma viscosity and hematocrit in children, in a very similar fashion as formerly reported in adults (8). The relationship between blood rheology and fitness, which has been described in adults, remains to be studied in children. Among the measurements of fitness, $\dot{W}170$ (9), which is widely used for a direct assessment of children's ability to exercise (10) has not been used, to our knowledge, in hemorheological studies. Other indexes which do not give exactly the same information have been used (5). Therefore, in this paper, we aimed at studying the relationships between resting blood viscosity and this index of fitness in healthy untrained children.

MATERIALS AND METHODS

The subjects used in this study were 18 children (13 boys, 5girls) undergoing an exercise-test for the exploration of growth disorders.

Children who exhibited endocrinologic abnormalities during this exploration were excluded from the study. Thus, the subjects included in this protocol can be considered as "normal short" ones. None took part in any organized physical training program. Group characteristics are presented in table 1. Each subject underwent a complete medical history, physical examination and laboratory tests.

The apparatus used for the tests comprised a bicycle ergometer (Bodyguard). An ECG apparatus was used to register heart rate (Cardio-Aid) with the impulses coming from three electrodes taped to the subject's chest. On the experimental day, each subject ate a standardized breakfast more than two hours before the exercise protocol. Indwelling catheters were placed in the antecubital vein 45 min prior the onset of exercise. Blood was sampled at -15, 0, 15 and 25 minutes with respect to the beginning of exercise (0 minute). At time 0 they started cycling. The work load increased up to a final step at 90% of theoretical maximal heart rate, which was maintained 5 minutes . Exercise stopped at time 15, just after the blood samples were drawn. Explicit standardized instructions were given before each test. Pedal speed was kept constant at 60 rpm by the subjects with an rpm-meter.

$\dot{W}170$ was also calculated, this being the work in watts that the subjects can perform at heart rate of 170 $b.min^{-1}$ (9,10).We expressed it in watts per kg of body weight(1).

TABLE 1

Group characteristics of the 18 normal short children of the study. Value : mean ± SEM.

	Age (yr)	Height (m)	Weight (kg)	Pubertal stage	Height standard deviation score
Boys	13.7 ± 0.5	1.43 ± 0.02	37.06 ± 1.32	1.7 ± 0.12	- 2.05 ± 0.52
Girls	11.2 ± 0.6	1.36 ± 0.04	31.3 ± 3.3	1.40 ± 0.22	- 1.40 ± 0.18

Blood samples (7 ml)were obtained by a large bore needle (Luer adaptor Venoject, set into the catheter) to avoid shear damage to erythrocytes. A vacuum tube was used for blood withdrawal, with tripotassium EDTA as the anticoagulant. No tourniquet was used for sample drawing in order to minimize venous stasis. Viscometric measurements were performed at high shear rate (2000 s^{-1})with a falling ball viscometer (MT90, Medica-test, 37 rue de l'Ermitage F-86280 Saint Benoit). The coefficient of variation of this method ranges between 0.6 and 0.8 % (10 repetitive measurement of the same sample). We measured with this device apparent viscosity of whole blood at native hematocrit, plasma viscosity, and blood viscosity at corrected hematocrit (45%). Two indices of erythrocyte flexibility were calculated from viscometric measurements : 'Tk' according to Dintenfass (25) and relative viscosity of whole blood at corrected hematocrit 45%, i.e. corrected blood viscosity at hematocrit 45% divided by plasma viscosity. Corrected blood viscosity at 45% was calculated with Quemada's equation (26).

Hematocrit was measured by microcentrifugation.

Correlations were tested by linear regressions analysis and stepwise multiple regression analysis. Whether one correlation was actually explained by other correlations among the studied parameters was tested by partial regression analysis(11). Comparisons were made using the nonparametric tests of Mann-Whitney and Wilcoxon. A difference of $p < 0.05$ was accepted as significant. Results are presented as mean ± the SE of the mean.

RESULTS

As shown on table 2, in response to the submaximal bout of exercise, all subjects demonstrated an increase in blood viscosity, hematocrit and plasma viscosity which was significant ($p<0.01$). Blood viscosity increased in 17 subjects, hematocrit in 15 and plasma viscosity in 16 .

$\dot{W}170$ ranged between 0.85 and 2.88 watt/kg. It was lower in girls (1.51 ± 0.153) than in boys (2.06 ± 0.12) with a significance level of $p < 0.05$. The correlations of $\dot{W}170$ with the other parameters

TABLE 2

Hemorheological parameters during the exercise-test in the 18 children

Time	- 15	0	15	25
Hematocrit (%)	39.89 ± 1.36	40.78 ± 1.10	41.16 *** ± 1.02	39.56 ±0.89
Whole blood viscosity at $\gamma = 2000\ s^{-1}$ (m Pa . s)	2.07 ± 0.06	2.10 ± 0.06	2.27 *** ± 0.08	2.086 ± 0.06
Plasma viscosity (m Pa . s)	1.15 ± 0.02	1.16 ± 0.02	1.20 *** ± 0.02	1.17 * ± 0.02
Corrected blood viscosity at 45 % hematocrit (m Pa . s)	2.23 ± 0.05	2.30 ± 0.03	2.42 *** ± 0.05	2.28 ± 0.05
Relative blood viscosity at 45 % hematocrit	1.99 ± 0.06	1.96 ± 0.02	1.97 ± 0.05	1.95 ± 0.04

Comparison with baseline value (Wilcoxon test) : * $p = 0.05$ *** $p < 0.01$

TABLE 3

Correlation among fitness index W 170 and hemorheological parameters measured during the exercice test in 18 children.

		$\dot{W}$ 170	Packed cell volume			Plasma viscosity			Apparent blood viscosity			η_{45}	η_{45} r
			at rest	Δ15	Δ25	at rest	Δ15	Δ25	at rest	Δ15	Δ25		
	$\dot{W}$ 170	1											
PCV	at rest	- 0.643***	1										
PCV	Δ15	0.227	- 0.223	1									
PCV	Δ25	0.352	- 0.406	0.630***	1								
plasma viscosity	at rest	- 0.543***	0.06	- 0.03	- 0.02	1							
plasma viscosity	Δ15	0.134	- 0.176	0.402	0.660***	- 0.02	1						
plasma viscosity	Δ25	- 0.286	- 0.264	0.202	0.307	0.728****	0.441	1					
apparent blood viscosity	at rest	- 0.752****	0.857***	- 0.09	- 0.290	0.449	- 0.08	0.172	1				
apparent blood viscosity	Δ15	- 0.452	0.463	- 0.216	0.108	0.323	0.387	0.302	0.565**	1			
apparent blood viscosity	Δ25	- 0.264	0.090	- 0.380	0.0003	0.125	0.220	0.166	0.050	0.510*	1		
	η_{45}	- 0.466	0.092	0.233	0.265	0.734****	0.307	0.825****	0.566**	0.456	0.061	1	
	$\eta_{45\,r}$	0.012	0.052	0.390	0.426	- 0.204	0.496*	0.278	0.246	0.247	- 0.085	0.514*	1

η_{45} = blood viscosity at corrected hematocrit 45% - $\eta_{45\,r} = \eta_{45}$ divided by plasma viscosity

Δ15 = difference between TO and T15 - Δ25 = difference between TO and T25

PCV = packed cell volume

*: $p < 0.05$ **: $p < 0.02$ ***: $p < 0.01$ ****: $p < 0.001$

measured during the test are shown on table 3.Only three parameters are correlated with it : resting apparent blood viscosity ηb (r = -0.752 p < 0.001), resting hematocrit h (r = -0.643 p < 0.01) and plasma-viscosity ηpl (r = -0.543 p < 0.02). A stepwise regression analysis gives the following equation :

$$\dot{W}170 = 7.02 - 0.036\ \eta b - 3.53\ \eta pl - 0.065\ h$$

This equation statistically "explains" 66.66% of the variance of the parameter "$\dot{W}170$" with a r value of 0.816 (p<0.001). The order of choice of the determinants is : 1)blood viscosity ; 2) plasma viscosity; 3) hematocrit. Actually, hematocrit, though it exhibits a higher r coefficient of correlation with $\dot{W}170$ than plasma viscosity, is of less importance in the equation since it is also correlated with blood viscosity (r=0.857 p<0.001). A partial regression analysis shows that the correlation between hematocrit and $\dot{W}170$ is suppressed (r=0.0043 n.s.) if the variable "blood viscosity" is kept constant, whereas the correlation between $\dot{W}170$ and blood viscosity remains significant (r=0.509 p<O.O5) when the influence of the variable "hematocrit" is suppressed. This means that most of the variance of $\dot{W}170$ "explained" by hematocrit is included in the variance "explained"by blood viscosity. The equation for hemorheological determinants of fitness when hematocrit is eliminated becomes :

$$\dot{W}170 = 0.053 - 1.26\ \eta b - 1.82\ \eta pl$$

This equation "explains" 61.83% of the variance of $\dot{W}170$ (r=0.786 p<0.001).

The same correlation matrix than in table 3 has been calculated separately for boys and girls. The factors correlated with $\dot{W}170$ are shown on table 4. In both sexes, resting blood viscosity is correlated with $\dot{W}170$. However, the two other determinants give different results according to the sex. In boys, resting plasma viscosity is correlated with $\dot{W}170$ whereas resting hematocrit is not. In girls, hematocrit is correlated with W170, but plasma viscosity is not correlated with this parameter. The correlations of $\dot{W}170$ with its three determinants (on the whole group and separately for each sex) are shown on fig. 1 and 3.

We calculated 'Tk' coefficient of Dintenfass together with relative blood viscosity at corrected hematocrit. These two indices were strongly correlated to each other in the whole group (r=0.995 p<0.001), in girls (r=0.996 p<0.01) and in boys (r=0.995 p<0.001). In contrast, they were not significantly modified during exercise and were not correlated with $\dot{W}170$.

TABLE 4

Correlation coefficients among $\dot{W}$ 170 and hemorheogical parameters in children broken down in two subgroups according to sex.

	resting blood viscosity	resting plasma viscosity	resting hematocrit	relative corrected viscosity (ht = 45 %)
Whole group of children (n = 18)	- 0.752 ****	- 0.543 **	- 0.643 ***	- 0.03
Boys (n = 13)	- 0.622 *	- 0.574 *	- 0.404	- 0.09
Girls (n = 5)	- 0.990 ***	0.002	- 0.995 ****	- 0.284

* p < 0.05 ** p < 0.02 *** p < 0.01 **** p < 0.001

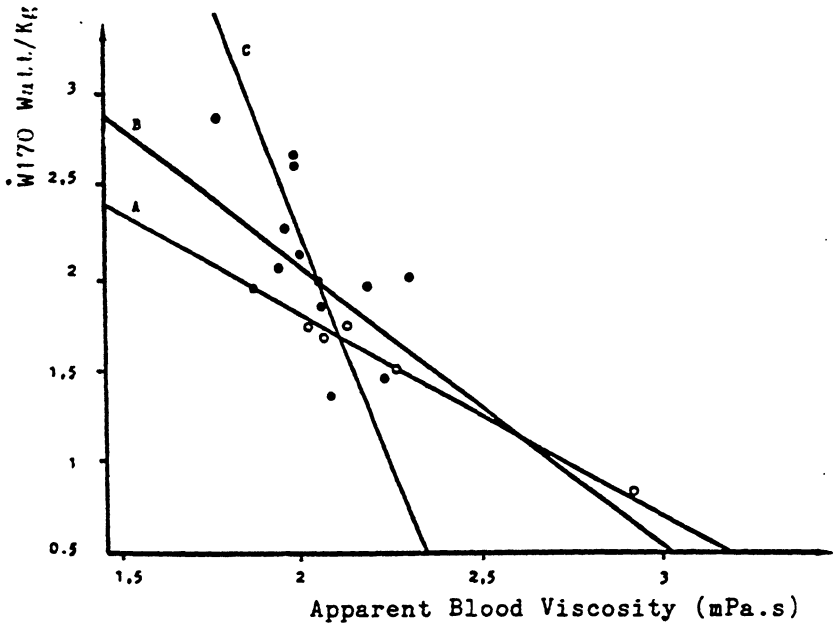

FIG.1 - Correlation between apparent blood viscosity at very high shear rate and $\dot{W}$ 170 (index of fitness). A = whole group (r = - 0.752) ; B = girls (r = - 0.990) ; C = boys (r = - 0.622). (•) boys (o) girls.

DISCUSSION

Physiological investigations in children are limited by ethical problems, since it does not seem acceptable to perform experiments without medical reasons in such subjects. Accordingly, the endocrinological exploration of growth disorders, which in some protocols includes an exercise test, provides a unique opportunity to study the modification of blood parameters during a standardized muscular activity. When the children with endocrine abnormalities (as assessed by this exploration) are excluded from the study, a population of "normal short" children is selected and the parameters measured during the exercise-test can be used for physiological studies (12).

In this sample of children, we confirm our previous finding (8) that both plasma viscosity and hematocrit are increased in children during exercise. This fact has already been demonstrated by many investigators in adults (2,4,12-20). The rise in blood viscosity during exercise has been reported to result from increases in both plasma viscosity and hematocrit (2,4,12-20) whereas red cell deformability remains unchanged. In our preceding work (8) we also found in children that erythrocyte filterability, when measured on resuspended red cells at 8% hematocrit, remains unchanged during exercise. Therefore, the two mechanisms explaining an increase is blood viscosity during exercise are believed to be the changes in hematocrit and plasma viscosity. Table 2 shows that relative blood viscosity for a corrected hematocrit of 45% is unchanged during the test. Similar results are found with 'Tk' coefficient of Dintenfass.

Since both parameters are very highly correlated, we do not give the results obtained with the latter.

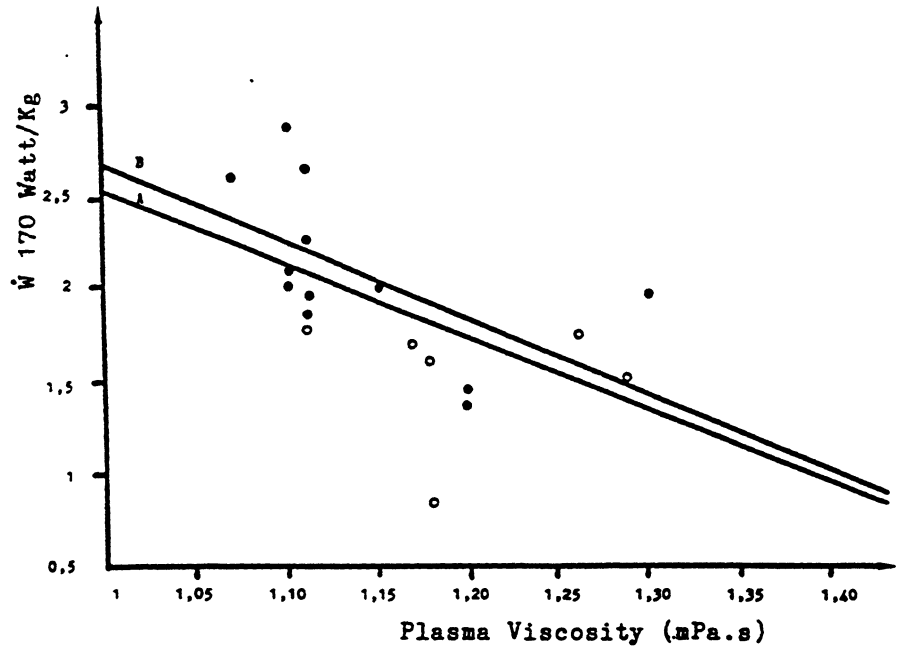

FIG. 2 - Correlation between $\dot{W}$ 170 and plasma viscosity.

A = whole group (r = 0.543) ; B : boys (r = 0.574).

Not significant in girls. (•) boys (o) girls.

which are quite the same. Therefore, when blood viscosity is corrected for hematocrit and plasma viscosity, it does no longer show modifications during exercise. This is in agreement with the reports concerning adult subjects, which show that erythrocyte rigidity remains unchanged during either sumaximal or maximal exercise tests. However, it can be seen on table 3 that the increase in blood viscosity fails to be correlated with the variations in plasma viscosity and hematocrit and is only correlated with resting blood viscosity ($r = 0.565$ $p<0.02$). Since some modifications of leukocyte functions during exercise have been reported (21,22), it can be hypothesized that they could play an additional role in blood rheological changes induced by muscular activity. This point remains to be clarified.

The main subject of this paper, nevertheless, is the correlation between blood fluidity and fitness. The assessment of fitness by $\dot{W}$170 is easy to perform and is generally considered as accurate (1,9,10).

However, most of the previous studies concerning the relationship between fitness and blood rheology did not employ this well-standardized index, and gave assessments of fitness based on other measurements (e.g. the time of exhaustion, 3) which do not exactly provide the same informa-

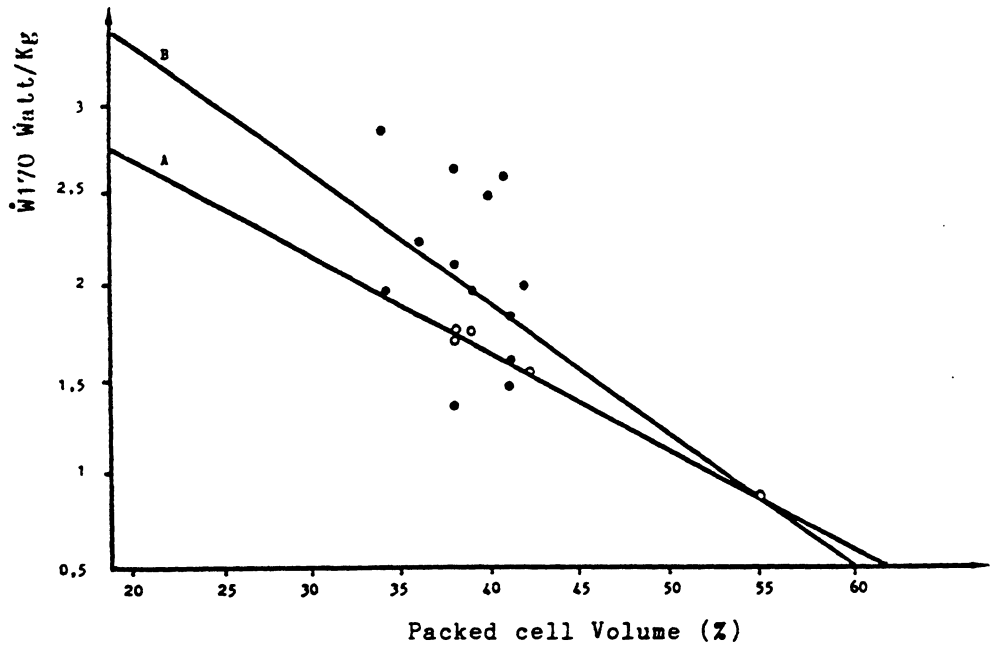

FIG. 3 - Correlation between resting hematocrit and $\dot{W}$ 170.

A = whole group (r = 0.643) ; B : girls (r = - 0.990).

Not significant in boys. (•) boys (o) girls.

tion. The choice of viscometry at very high shear rate (22,23) requires some comments. We chose the MT90 viscometer in order to avoid the influence of red cell aggregation on whole blood viscosity and of flow instability on plasma viscosity (24,25). The influence of aggregation was minimized by the high shear rate. The flow instability which occurs in rotational viscometers is not likely to occur in a falling ball device. Moreover the coefficient of variation for plasma viscosity is very low. Therefore, we believe that our measurements reflect the newtonian behavior of blood, and give a precise evaluation of plasma viscosity.

It should be noticed that the values of whole blood viscosity measured at such shear rates are lower than the values usually measured between 100 and 200 s^{-1}. This point has been already discussed by the first users of this falling ball viscometer (22,23) and some theoretical explanations have been given (23). However, since shear rates ranging between 500 and 5000 s^{-1} have been supposed to exist in arteries, we think that this unusual measurement gives results which are physiologically relevant. Blood supply to exercising muscle could be supposed to occur at such shear rates.

Table 2 shows that three hemorheological determinants of fitness are found with this technique : apparent blood viscosity, plasma viscosity and hematocrit. However, the latter parameter is

eliminated by the partial regression analysis, since most of the variance it "explains"is also "explained" by whole blood viscosity. An equation "explaining"60% of the variance of fitness index by blood viscosity and plasma viscosity can be calculated.

Some differences, as shown on table 3, are found between girls and boys. In both sexes, a highly significant negative correlation between fitness index $\dot{W}170$ and resting blood viscosity is found, but the factor of blood viscosity which correlates with $\dot{W}170$ is plasma viscosity in boys and hematocrit in girls. However, the number of girls is reduced, and these results should be interpreted whit caution, since no theoretical explanation for such a finding can be given.

We calculated 'Tk' coefficient of Dintenfass together with relative blood viscosity at corrected hematocrit. Both indices are believed to be independent from hematocrit and plasma viscosity, so that they measure erythrocyte rigidity in macrorheological conditions.

These two indices were strongly correlated to each other, so that we give only the results obtained with the latter. These indices were not correlated with $\dot{W}170$. Therefore, two determinants of blood viscosity at high shear rate (hematocrit and plasma viscosity) are related to fitness, but when blood viscosity is corrected for the influence of these two factors, it is no longer correlated with fitness. Red cell flexibility, which is the main determinant of such corrected values of viscosity, seems therefore to be unrelated to $\dot{W}170$ in this sample of subjects. However, Yokose (27) recently reported a lower red cell rigidity (as assessed by filtration) in trained sportsmen. In our study, the range of values of red cell rigidity indices is narrow, and our results do not rule out a possible influence of erythrocyte rheology on fitness : for example, rigidification of red cells in pathologic states may be associated with higher viscosity and therefore reduced blood supply to exercising muscles. In contrast, special training (and nutritional) conditions in athletes may improve blood fluidity and be associated with higher fitness. This point remains to be clarified.

In conclusion, this study confirms our previous report that blood rheology is impaired during exercise in children, as already described in adults, and gives also evidence for a highly significant relationship between fitness and blood fluidity. Therefore, in children as well as in adults, there is increasing evidence that blood fluidity is a determinant of an individual's ability to perform an exercise. It can be suggested that blood viscosity is a critical factor in the regulation of oxygen and nutrient supply to the exercising muscle. However, a direct experimental demonstration of this latter assumption remains to be given. Since the previous reports on this subject studied either adult beings, other indexes of fitness, or blood rheology at lower shear rates, we believe that this study raises some original points. In summary, we show : (a) that exercising children undergo the same modification as adults ; (b) that $\dot{W}170$, a very classical index of fitness, is strongly related to blood fluidity; (c) that the viscosity of blood at very high shear rate (i.e.reflecting the newtonian behavior of blood) is correlated with this fitness index.

REFERENCES

1. EUGENE M, VANDEWALLE H, BERTHOLON JF, TEILLAC A. Arterial elasticity and physical working capacity in young men. J Appl Physiol 61, 1720-1723, 1986.

2. LETCHER RL, PICKERING TG, CHIEN S, LARAGH JH. Effects of exercise on plasma viscosity in athletes and sedentary normal subjects. Clin Cardiol 4, 172-179, 1981.

3. ERNST E, MATRAI A, ASCHENBRENNER E, WILL V, SCHMIDLECHNER Ch.Relationship between fitness and blood fluidity. Clin Hemorheol 5, 507-510, 1985.

4. ERNST E, KOENIG W, MATRAI A, KEIL U. Plasma viscosity in a population sample. Biorheology 23,264, 1986.

5. MATRAI A, STOEHR S, ERNST E. Effect of hemorheological factors on exercise hemodynamics and performance. Biorheology 23, 263, 1986.

6. SIMCHON S, KUNG-MIN J, CHIEN S. Influence of reduced red cell deformability on regional blood flow. Am J Physiol 253 (Heart Circ Physiol 22), H898-H903, 1987.

7. ERNST E, MATRAI A. Regular physical exercise increases blood fluidity. Rev Port Hemorreol 1, 33-40, 1987.

8. BRUN JF, LAGOUEYTE C, RAUTURIER M, FEDOU C, ORSETTI A. Hématocrite, viscosité plasmatique et activité musculaire chez l'enfant. Science et Sports 1988, 3 (accepted, in press).

9. WAHLUND H, Determination of physical working capacity. Acta Med Scand 215, 1-78, 1948.

10. MOCELLIN R, LINDEMANN H, RUTENFRANZ J, SBRESNY W. Determination of W170 and maximal oxygen uptake in children by different methodes. Acta Paediat Scand Suppl 217, 13-17, 1971.

11. SCHWARTZ D. Méthodes statistiques à l'usage des médecins et des biologistes. Flammarion (Paris) 1981.

12. BRUN JF, CRIQUI C, FEDOU C, ORSETTI A. La réponse de GH à l'effort s'associe chez l'enfant à une élévation de la glycémie. Science & Sports 1,347-349, 1986.

13. DESCALZI M, CINELLI P, DELEONARDIS V, BECUCCI A, MARIANI R, FATTIROLLI F, CIAPINI A. Response of some haemocoagulatory and haemorheological variables to maximal exercise in sedentary and active subjects. J Int Med Res 15, 361-367, 1987.

14. GUEGUEN - DUCHESNE M, DURAND F, ROCHECONGARD P, LEGOFF MC, LETREUT A, POMMEREUIL M, GENETET B. Could maximal exercise be a hemorheological risk factor? Clin Hemorheol 7, 418, 1987.

15. GUEGUEN-DUCHESNE M, DURAND F, ROCHECONGARD P, LEGOFF MC, LETREUT A, POMMEREUIL M, GENETET B. Effets d'un effort physique intensif sur les paramètres hémorhéologiques chez les sportifs de haut niveau. Biorheology 23, 144, 1986.

16. NEIROTTI M, FERRARIO E, MOLASCHI M, MACCHIONE C, PERNIGOTTI L, VISENTIN PA. Changes in some haemorheological parameter values after controlled physical exercise in aged. Clin. Hemorheol 5, 653, 1985.

17. PEREGO MA, SERGIO G, ARTALE F, GIUNTI P, DANESE C. Effects of physical training on regional blood filterability and platelet B thromboglobulin in patients with peripheral arteriopathy. Clin. Hemorheol 5, 653, 1985.

18. PRETOLANI E, ZOLI I, BATTISTINI G, IOSA G, TONTI D, SALVI P. Hemorheological changes during maximal stress in athletes. Clin. Hemorheol 5, 654, 1985.

19. VANDEWALLE H; LACOMBE C, LELIEVRE JC, POIROT C. Viscosité sanguine lors d'un exercice sous-maximal avec apport hydrique. Biorheology 23, 143, 1986.

20. GALEA G, DAVIDSON RJ. Hemorheology of marathon running. Int J Sports Med 6.136-138, 1985.

21. DEUSTER PA, CURIALE AM, COWAN ML, FINKELMAN FD. Exercise-induced changes in populations of peripheral blood monocuclear cells. Med Sci Sports Exerc 20,276-280. 1988.

22. DOFFIN J, PERRAULT R, GARNAUD G. Blood viscosity measurements in both extensional and shear flow by a falling ball viscometer. Biorheology (suppl. 1), 89-93, 1984.

23. AILLAUD MF, POISSON C, BUONOCORE M, BILLEREY M, LEFEVRE P, JUHAN-VAGUE I. Etude du viscosimetre medical a chute de billes a haut taux de cisaillement : MT 90. Le pharmacien Biologiste 159,291-294, 1985.

24. LIAO FL, DINTENFASS L. Effect of microrheology of blood on the apparent flow instability in a rotational viscometer. Biorheology 20, 327-342, 1983.

25. DINTENFASS L. Red cell rigidity, "Tk", and filtration. Clin Hemorheol 5, 241-244, 1985.

26. QUEMADA D. Rheology of concentrated disperse systems. II. A model for non-newtonian shear viscosity in steady flows. Rheal Acta 17, 632-642, 1978.

27. YOKOSE T, KUTIBA K, AKIYAMA M, MAEDA T, IKEMOTO S, ISOGAI Y.
Effets of exercise on hemorheology in athletes and sedentary normal subjects. Clin Hemorheol 7, 429, 1987.