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The Radial Pulse Wave and Blood Viscosity

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***Abstract*—**The aim of this study was to investigate the effect of blood viscosity on the radial pulse wave. For this, we obtained the radial pulse wave of 15 males with abnormal high hematocrit level and 47 males with normal hematocrit level at the age of thirties and forties. Various variables of the radial pulse wave between two groups were analyzed and compared by Student's T test.

There are significant differences in several variables about height, time and area of the pulse wave. The first peak of the radial pulse wave was higher in abnormal high hematocrit group, but the third peak was higher and longer in normal hematocrit group. Our results suggest that the radial pulse wave can be used for diagnosis of high blood viscosity and more clinical application.

***Keywords*—**Radial pulse wave, Blood viscosity, Hematocrit.

I. Introduction

THE pulse wave which is pressure wave formed by heart contraction. Pulse pressure wave can be obtained on many arterial points, such as ascending aorta, carotid artery, radial artery, femoral artery, and its contour is various according to the respective artery legion. Heart function and artery elasticity is major determinants creating pulse wave, so wave contour is affected by age, gender and other physical factors [1].

Recently, this pulse wave distinction helps the diagnosis of arterial stiffness. Pulse wave velocity rise correlated artery stiffness, so the wave velocity measured with electrocardiogram can indicate the artery condition. The Augmentation index which is about the ratio between the pulse pressure and augmentation pressure is widely used to clinically examine the artery stiffness, too [2].

Flow is related a tube length, radius, pressure gradient and fluid viscosity in the fluid dynamics, therefore the blood viscosity can affect the pulse wave contour. The blood viscosity is determined by the hematocrit, plasma protein, lipid levels, etc [3]. The hematocrit is major factor of the viscosity and used as diagnostic criteria for the polycythemia which causes blood circulation problem. In this work, we investigated the effect of the hematocrit as a factor of blood viscosity on radial pulse wave.

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II. Subjects and Methods

A. Subjects

In the choice of the subjects, we attempted to minimize the variations depending on the sex, age, and disease except the hematocrit level. For this purpose, 15 males of abnormal high hematocrit level and 47 males of normal hematocrit level at the age of thirties and forties who had no cardiovascular disease, diabetes, hypertension participated in this study. The details of the physiological data of the subjects are listed in Table I.

TABLE I
SUBJECTS CHARACTERISTICS

	Number	Age	Height	Weight	BMI	Hematocrit
High hematocrit	15	39.9	172.2	74.3	26.1	49.6
Normal hematocrit	47	40.1	173.4	70.6	23.4	43.0

B. Pulse Wave Measurement

The measurement was carried out by 3D pulse analyzer (by Daeyomedi Co.) in the left radial artery. The device used a pressure sensor and obtained the highest pressure wave automatically. It was proved to have a good reliability and reproducibility in the previous study [4]. The subjects determined in criterion of this study through health examination and blood sampling took the pulse analyzer measurement. Each subject had been forbidden from smoking and drinking for 1 hour and 6 hours, respectively, before the experiment.

C. Pulse Wave Variables

The radial pulse wave has three peaks and five extrema in general. We can imagine the wave contour approximately by this points' data. H1 of first peak reflects the blood ejaculation by heart contraction and h3, h5 of second and third peak are related the artery recovery and reflect wave from peripheral vessels and aortic valve. T4, which means the time of h4, is the start point of diastole.

We compared the variables related height, time and area of two groups' pulse waves. In addition, we added the ratio variables of height and time to reflect the wave contour pattern.

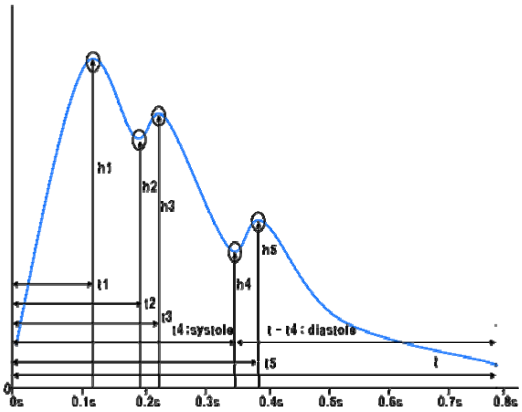

Fig. 1 The Radial Pulse Wave

D. *Statistical Method*

Analyses were performed with SPSS version 14.0 (SPSS Inc., USA). We used Student's t-test to compare the two groups' pulse wave variables. Data are presented as means±SD unless stated otherwise. The acceptable level for statistical significance was set at a p-value of 0.05.

III. Result

A. *The Mean Differences of Height Variables of the Pulse Wave between Two Groups*

There are significant differences in h2, h4, (h5-h4)/h1, (h5-h4)/h4 among all height variables of pulse wave between two groups (Table II). Abnormal high hematocrit group's h2, h4 is higher than those of normal hematocrit group. Contrary, (h5-h4)/h1, (h5-h4)/h4 are higher in normal hematocrit group (Table II).

TABLE II
Height Variables of the Pulse Wave

Variables	Group	N	Means	standard deviation	p-value
h1	High hematocrit	15	175.200	47.577	0.244
	Normal hematocrit	47	154.723	61.600	
h2	High hematocrit	15	108.867	42.571	0.038 *
	Normal hematocrit	47	83.957	38.743	
h3	High hematocrit	6	111.833	43.586	0.071
	Normal hematocrit	18	77.278	37.004	
h4	High hematocrit	15	46.873	16.656	0.019 *
	Normal hematocrit	47	34.389	17.628	
h5	High hematocrit	15	55.899	14.686	0.206
	Normal hematocrit	47	48.600	20.463	
h3-h2	High hematocrit	6	8.500	4.970	0.348
	Normal hematocrit	18	5.556	6.905	
h5-h4	High hematocrit	15	9.026	6.533	0.051
	Normal hematocrit	47	14.211	9.357	
h3/h1	High hematocrit	6	0.675	0.115	0.094
	Normal hematocrit	18	0.585	0.107	
h5/h1	High hematocrit	15	0.324	0.053	0.794
	Normal hematocrit	47	0.318	0.085	
h5/h3	High hematocrit	6	0.516	0.080	0.280
	Normal hematocrit	18	0.595	0.167	
(h3-h2)/h1	High hematocrit	6	0.058	0.037	0.321
	Normal hematocrit	18	0.040	0.040	
(h3-h2)/h2	High hematocrit	6	0.098	0.058	0.659
	Normal hematocrit	18	0.080	0.093	
(h5-h4)/h1	High hematocrit	15	0.054	0.036	0.005 *
	Normal hematocrit	47	0.094	0.050	
(h5-h4)/h4	High hematocrit	15	0.240	0.226	0.029 *
	Normal hematocrit	47	0.573	0.558	

B. *The Mean Differences of Time Variables of the Pulse Wave between Two Groups*

There are significant differences in t5-t4, t5-t4/t among all time variables of pulse wave between two groups. Abnormal high hematocrit group's t5-t4, t5-t4/t is shorter than those of normal hematocrit group (Table III).

TABLE III
Time Variables of the Pulse Wave

Variables	Group	N	Means	standard deviation	p-value
t1	High hematocrit	15	0.114	0.012	0.317
	Normal hematocrit	47	0.111	0.012	
t2	High hematocrit	15	0.186	0.014	0.648
	Normal hematocrit	47	0.188	0.019	
t3	High hematocrit	6	0.218	0.007	0.648
	Normal hematocrit	18	0.215	0.013	
t4	High hematocrit	15	0.325	0.025	0.183
	Normal hematocrit	47	0.315	0.023	
t5	High hematocrit	15	0.372	0.020	0.356
	Normal hematocrit	47	0.378	0.021	
t-t4	High hematocrit	15	0.513	0.095	0.633
	Normal hematocrit	47	0.530	0.131	
t	High hematocrit	15	0.838	0.112	0.839
	Normal hematocrit	47	0.846	0.147	
t3-t2	High hematocrit	6	0.041	0.009	0.309
	Normal hematocrit	18	0.035	0.011	
t3-t	High hematocrit	6	0.252	0.018	0.183
	Normal hematocrit	18	0.234	0.031	
t3-t2/t	High hematocrit	6	0.047	0.010	0.107
	Normal hematocrit	18	0.038	0.011	
t5/t	High hematocrit	15	0.450	0.052	0.720
	Normal hematocrit	47	0.457	0.065	
t5-t4	High hematocrit	15	0.047	0.018	0.002
	Normal hematocrit	47	0.062	0.015	
t5-t4/t	High hematocrit	15	0.058	0.027	0.024
	Normal hematocrit	47	0.077	0.027	
t-t4/t	High hematocrit	15	0.608	0.037	0.364
	Normal hematocrit	47	0.620	0.044	
t4/t	High hematocrit	15	0.392	0.038	0.353

	Normal hematocrit	47	0.380	0.044	
systolic time -diastolic time	High hematocrit	15	0.650	0.105	0.397
	Normal hematocrit	47	0.621	0.118	

C. The Mean Differences of Area Variables of the Pulse wave between Two Groups

There are significant differences in Systolic area among all area variables of pulse wave between two groups. Abnormal high hematocrit group's systolic area is larger than that of normal hematocrit group (Table IV).

TABLE IV
AREA VARIABLES OF THE PULSE WAVE

Variables	Group	Means	standard deviation	p-value
Total area	High hematocrit	10271.733	3158.272	0.092
	Normal hematocrit	8585.957	3370.877	
Systolic area	High hematocrit	8048.864	2589.247	0.056
	Normal hematocrit	6499.117	2704.379	
diastolic area	High hematocrit	2222.869	729.819	0.587
	Normal hematocrit	2086.841	869.905	
Systole/Diastole	High hematocrit	3.723	0.973	0.260
	Normal hematocrit	3.344	1.165	
Systole-Diastole	High hematocrit	5825.995	2121.083	0.032
	Normal hematocrit	4412.276	2185.860	

IV. DISCUSSION AND CONCLUSION

The first peak of the pulse wave was higher in abnormal high hematocrit, but the third peak was higher and longer in normal hematocrit group (Fig. 2). The first peak is formed by heart contraction, otherwise the third peak contains the reflect wave of peripheral vessels. These results indicate that strong heart pressure is diminished rapidly proceeding along the artery in high hematocrit blood. The rapid attenuation of pressure in peripheral vessels can lead to the weak reflect wave. In the Poisuille's Equation (1) [5] or Womersley's theory (2) [6] about fluid dynamics, pressure gradient is correlated with fluid flow, viscosity and length of tube. Therefore, the rapid pressure descent brings about the attenuation of pressure wave transition in high viscous blood. Our study suggests that the radial pulse wave can be useful for diagnosis of high blood viscosity. We hope that our attempt may motivate further research towards various clinical applications of the pulse wave.

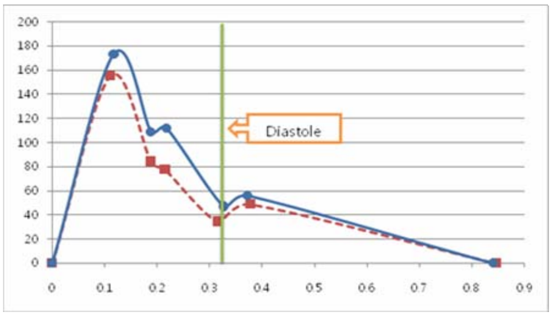

Fig. 2 The Radial Pulse Wave of Two Groups

$$P_1 - P_2 = \frac{\text{Flow} \times \text{viscosity} \times \text{length} \times 8}{\pi \times (\text{radius})^4} \quad (1)$$

$$Q = P_m \frac{\pi r^4}{\mu} \frac{M'_{10}}{\alpha^2} \sin(\omega t - \varepsilon'_{10}) \quad (2)$$

P	=pressure gradient
P_m	=amplitude of pressure gradient sinusoid
Q	=instantaneous volume flow
Q_m	=amplitude of flow wave form
r	=radius of tube
d	=diameter
μ	=viscosity of fluid
μ'	=apparent viscosity
f	=frequency (cps)
ω	=angular frequence (radians/sec)
ε'_{10}	=phase angle in Womersley's theory
M'_{10}	=modulus in Womersley's theory
α	=dimensionless frequency parameter
ρ	=density of fluid
υ	=average velocity
Re	=Reynolds number

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