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原　　著

The Diagnosis of Arteriosclerosis by Adpressoplethysmogram (Adp-PTG)

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"A person grows old with artery" and it is often said, "The aging of a person is an aging of his artery". According to the results of human dissection, arteriosclerosis is occurred from the younger ages. It is seen in about 70 % of 20 years old both of men and women and in about 80 % of 30 s. In Fig. 1, it is shown the change of the aortic pulse wave velocity (PWV) in 273 healthy cases of all ages by Yoshimura[1]. In his recording, all of these cases were healthy, normotensive and non-diabetic and there were no abnormalities in the examinations of blood pressure, electrocardiogram, optic fundus and urine analysis.

From the analysis of PWV measurements, arteriosclerosis is not seen in less than 7 m/sec of PWV, mild or moderate arteriosclerosis is seen in 8 m/sec of PWV group and severe arteriosclerosis is found in 9-10 m/sec of PWV group. This data is pathologically confirmed. In Fig. 1, we can see that some person of 20 years old has a PWV of 50 years and some person of 50 years has a young artery of PWV at 20 years. Of course, the PWV is gradually increased with the age from 6 m/sec at 20 s to 9 m/sec at 60 s. However, there is a great variation of the degree of arteriosclerosis even in healthy and symptom-less people.

Fig. 2 also by Yoshimura shows the three curves of mean values of PWV of 49 cases of cerebral arteriosclerosis, 71 cases of coronary arteriosclerosis and healthy control group. The both PWV values of pathologic groups were significantly higher than that of control group. Because of the aortic sclerosis is preceding occurred than the appearance of cerebral arteriosclerosis and coronary arteriosclerosis, we are able to use the PWV measurement of aorta to the prediction of arteriosclerosis of brain and coronary arteries which directly affects the length of life.

However, in here we should pay enough attention to that the age of blood vessels is not always same as a true age of the person. Until now, physicians have aimed to diagnose and treat the arteriosclerosis as earlier as possible. It is correct in a sense. However, nowadays the people of long life are acceleratingly increasing, it is important to find the older people having a young vascular age and to give them both of self-confidences and dreams of daily life. For those people, the adpressoplethysmogram (Adp-PTG) analysis is a very simple and excellent method, and useful for mass screening of arteriosclerosis requiring a short examination time. The Adp - PTG is obtained by the recording of plethysmogram (PTG) adding a diastolic pressure

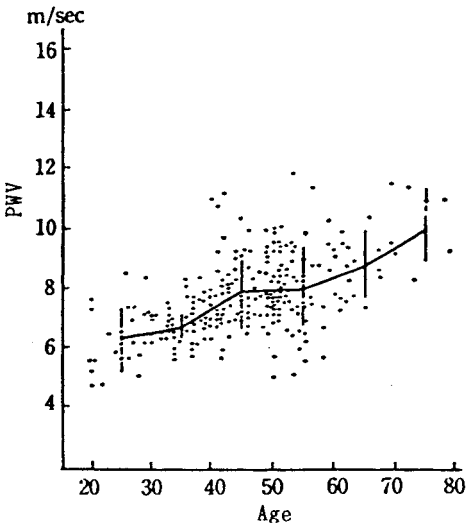


Fig. 1 Aortic pulse wave velocity (PWV) of each age in 273 healthy cases (S. Yoshimura, 1972)

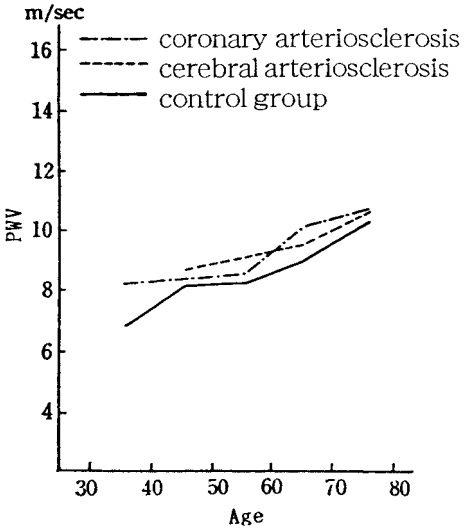


Fig. 2 Aortic pulse wave velocity (PWV) of each age in 49 cases of cerebral arteriosclerosis, 71 cases of coronary arteriosclerosis and healthy cases (S. Yoshimura, 1972)

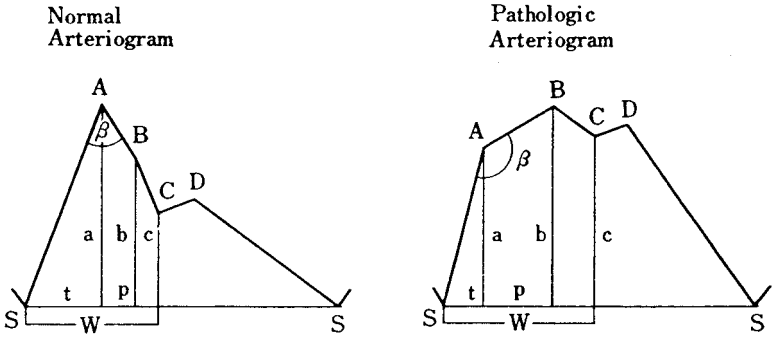


Fig. 3 Diagram which illustrates the geometrical analysis (Chlebus H. 1962)
Up stroke time (sec)……SA time (normal wave), SB time (pathologic wave)
AB time (sec)……duration of systolic plateau……p
Ejection time (sec)……W
The angle of ascending slope SA with Plateau AB……β (degree)
The ratio of height a and b: EI (elasticity index) (%)……distance a/distance b
The ratio of height c and a: DI (dicrotic index) (%)……
distance c/distance a (normal wave), distance c/distance b (abnormal wave)

with the blood pressure cuff on the upper arm.

The Principle of Adpresso-Plethysmogram (Adp-PTG)

When we diagnose the arteriosclerosis of patients, we may start to recognize one normal and six abnormal plethysmograghic wave patterns and as for these wave patterns, we have already explained in the paper of "A Simple Diagnostic Manual of Autonomic Dystonia". Here we will show the theory of Adp-PTG by the schema in Fig. 3[2].

Abnormal wave patterns such as sclerotic, anacrotic, contracted and trapezoid wave were

observed in the cases of hypertension and / or arteriosclerosis respectively. Compared with the normal wave, the up-stroke time (UT), which is a time from the starting point (S) of pulse wave to the peak of wave, is prolonged in these abnormal wave patterns.

When we record the PTG in patient shows abnormal wave adding his diastolic pressure with the blood pressure cuff on the upper arm, the height of wave is gradually decreased and UT is shortened simultaneously and the wave pattern changes to similar pattern as normal. These changes are due to the dilatation of blood vessels and this phenomenon is called "the temporal rejuvenation of blood vessels". The degree of UT shortening is up to the level of arteriosclerosis and UT shortening is greater in mild arteriosclerosis. In highly advanced arteriosclerosis, this shortening of UT is not remarkable. Therefore, we can know the degree of arteriosclerosis by the measurement of UT adding the pressure load to arm. Yosimura[3] has given us a more detailed theory of Adp-PTG.

Formerly it was explained that the pressure induced vasodilatation caused by some substances in the vessel portion might provoke this phenomenon, and such substances were lately showed to be endothelium-derived relaxing factor; EDRF by Furchgott[4] and Palmer[5]. The several changes of Adp-PTG were proved to be an indirect action of nitric oxide (NO) and its affinities.

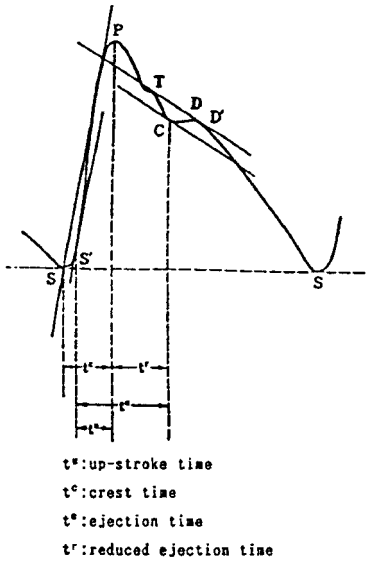


Fig. 4 Normal wave of fingertip plethysmogram (PTG)

Up-stroke time (UT) and Crest time (CT)

Because we are using not UT but CT for the diagnosis of arteriosclerosis in Adp-PTG, the distinction between UT and CT is very important. Now let's try to read the pressure change of normal wave in Fig. 4, the starting point of pulse wave S is a point of diastolic pressure, at this point aortic valve is opened and blood comes into aorta from the left ventricle. After that, the blood pressure is elevated up to the systolic pressure peak of P. However the true starting point of pulse wave is read as the point of S', it is not as S. This is due to the distorted process in the transmission of pressure pulse wave.

It is a very troublesome work that we have to construct manually the point of S' on the pulse wave, but the point of S is easily seen and CT time from S to P is simply measured in many cases. In Adp-PTG, the level of shortening of CT determines the degree of arteriosclerosis. Also SS' time is almost equal to the transformation period of the left ventricular isovolumetric contraction phase, it is considered about 0.02 sec. Since the mean value of UT in normal wave is defined as 0.13 ± 0.01 sec, the normal value of CT is decided 0.15 ± 0.01 sec in our analysis.

Both of UT and CT are influenced by heart rate, are shortened in tachycardia and prolonged in bradycardia, it is necessary to correct by heart rate. Ordinarily we use "Bazett formula", that is a formula; measured value/$\sqrt{RR}$, (RR is an interval of R peak in ECG), and this is described as CTc (corrected CT). In Adp-PTG we judge "normal" that CTc value calculated adding a diastolic pressu

Table 1 The Bazett formula, that is measured value/$\sqrt{RR}$ (RR is an interval of R peak in ECG), we substitute pulse interval SS for RR interval in the cases of simple PTG recording without ECG. Each $\sqrt{RR}$ value is corresponding to each heart rate(HR)

HR	$\sqrt{RR}$	HR	$\sqrt{RR}$	HR	$\sqrt{RR}$	HR	$\sqrt{RR}$	HR	$\sqrt{RR}$
		60	1.000						
		61	0.991	71	0.919	81	0.860	91	0.811
		62	0.983	72	0.912	82	0.885	92	0.807
		63	0.971	73	0.906	83	0.850	93	0.803
		64	0.968	74	0.900	84	0.845	94	0.798
		65	0.690	75	0.894	85	0.840	95	0.794
55	1.040	66	0.953	76	0.888	86	0.835		
56	1.030	67	0.946	77	0.882	87	0.830		
57	1.020	68	0.939	78	0.877	88	0.825		
58	1.010	69	0.932	79	0.871	89	0.821		
59	1.000	70	0.925	80	0.866	90	0.816		

Table 2 The classification of the degree of arteriosclerosis by CTc value on Adp-PTG and the wave pattern

Grade	CTc or wave pattern	Remarks
nomal	＜0.115 sec	
mild	0.116-0.150 sec	functional change or aortic lesion only
moderate	0.151-0.200 sec	arteriolosclerosis; need therapy
severe	＞0.201	dangerous type
most severe	trapezoid wave	most dangerous pattern

re is shortened less than 0.115 sec.

We substitute pulse interval SS for RR interval in the cases of simple PTG recording without ECG. Actually as in Fig. 4 we draw a horizontal line on SS, and draw a parallel line on the top of pulse wave and its contact point is named P. This SP interval is CT. The each $\sqrt{RR}$ value is shown to each heart rate in Table 1. Next, CTc is calculated by Bazett formula. We apply this CTc value in Table 2 (by Yoshimura, Mikami and Kagiya; 2000), and diagnose the degree of arteriosclerosis. Table 2 points the classification of the degree of arteriosclerosis by CTc values and wave pattern.

We classified arteriosclerosis into five groups by CTc on Adp-PTG and the wave pattern. The five groups are respectively, normal (blue signal), mild (blue signal), moderate (yellow signal), severe (red signal) and most severe (double red). Clinically in normal and mild groups, there are no vascular problems. In moderate group, arteriosclerosis is occurred moderately and determined to start the treatment considering of the data of other examinations. In this group, their recovery from arteriosclerosis may be possible and step up to mild group responding to several treatments. In severe group, the rapid treatment is necessary for the improvement of arteriosclerosis even if the result of other examinations is negative, but the recovery to moderate group is sometimes difficult offering resistances to the treatment. We classified the trapezoid wave into the most severe group in which arteriosclerosis is very strong and a cardiovascular accident is inevitable.

It is often said that the value corrected by Bazzet formula is inaccurate in both cases of tachycardia over 90 and bradycardia under 60. In Table 1, we show the each $\sqrt{RR}$ value from 55 to 95 heart rate, readings over 90 and under 60 are accessories.

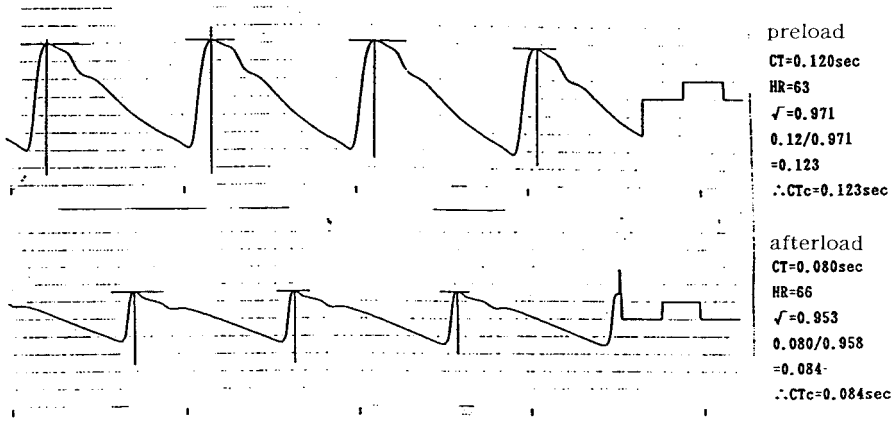


Fig. 5 PTG of 43 years old male before (preload) and after pressure load (Adp-PTG; afterload) He was judged as "normal"

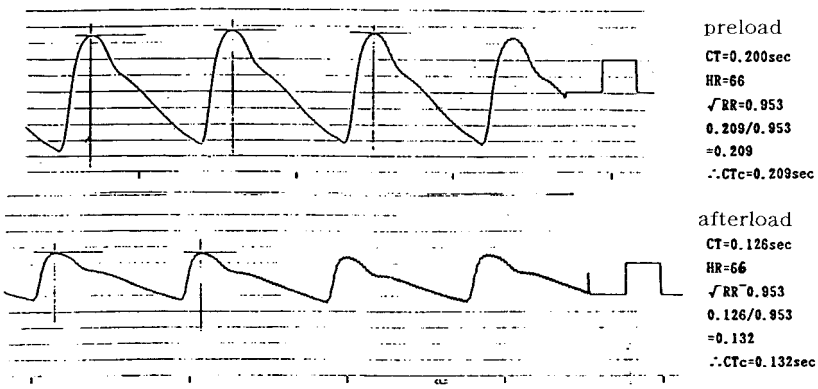


Fig. 6 PTG (preload) and Adp-PTG (afterload) of 38 years old female She was judged as "mild"

Recording and Measurement of PTG and Diagnosis of Arteriosclerosis

We record PTG and Adp-PTG in a quiet room with 23 ± 2 ℃ temperature, all examinees take a several minutes rest at comfortable supine position or sitting on chair, then the recording on the right or left second fingertip is done after the base line of the pulse wave becomes stable. You can use either finger and record at a supine or sitting position, but you have to use the same finger and position at the reexamination of the same person. Running speed of the recording paper is 25 mm/sec or 50 mm/sec. We named the technique of adding a diastolic pressure on the upper arm of examinees as "afterload".

1. At first the ordinary PTG without pressure load (preload) is recorded and when the normal wave is seen in this PTG, following recording is unnecessary because there is no arteriosclerosis in normal catacrotic wave. In Fig. 5, 43 years old man shows 0.084 sec CTc in Adp-PTG. In this case Adp-PTG recording will be finished.

2. Fig. 6 displays the recording of 38 years old female. Her PTG is sclerotic wave and the afterload pattern is normal wave, measured CT is 0.126 sec, heart rate (HR) is 66. According to the Table 1, $\sqrt{RR}$ of HR 66 is 0.935 and CTc is calculated as 0.126/0.935 = 0.132 sec. In Fig. 4 she is classified into the mild group. However, in

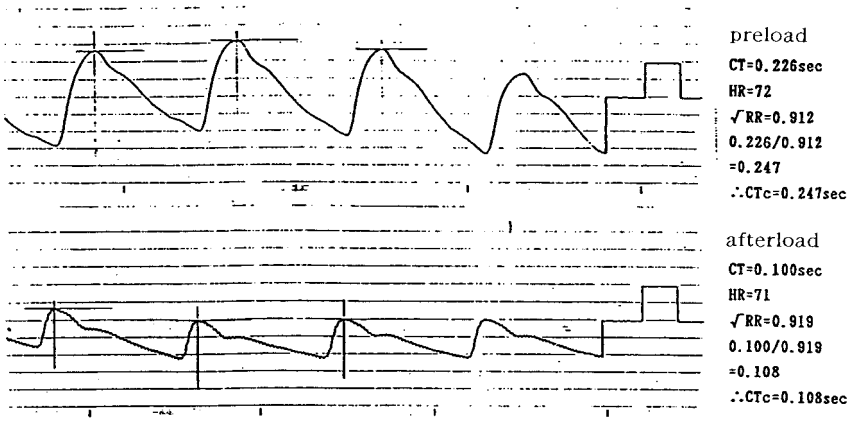


Fig. 7 PTG (preload) and Adp-PTG (afterload) of 57 years old female
She was judged as "mild"

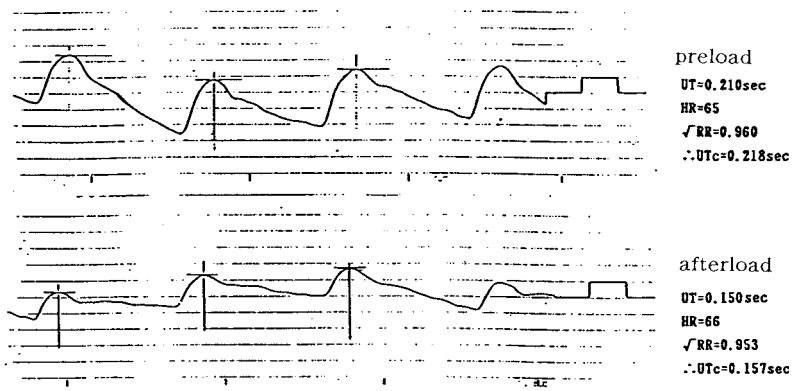


Fig. 8 PTG (preload) and Adp-PTG (afterload) of 56 years old female
She was judged as "moderate"

here there are some remarks. Fig. 7 shows the recording of 57 years old woman. Her preload pulse wave is sclerotic wave and changed to normal wave after pressure load. From the preload wave form and the change of afterload wave form, her wave is judged as mild group but CTc of the afterload wave is 0.108 sec which is judged as normal group, namely this CTc value is obscure whether in normal or mild group. In fact, in several cases of sclerotic wave, the CTc value of afterload often is within the range of normal group. The replacement of wave pattern from abnormal to normal is considered due to the simple functional vasoconstriction or arteriosclerosis is limited in only aorta. The recording machine diagnoses that value as normal group, but we correctly diagnose that as "mild" by the pulse waveform. Anyway, both of normal and mild groups have no clinical problems nor require some treatments.

3. In Fig. 8 it is shown the recording of 56 years old woman, preload wave is sclerotic and CTc is 0.210 sec. The afterload wave is also sclerotic and CT is 0.150 sec, HR is 66 and CTc is 0.150/0.953 = 0.157. In Table 2, this CTc value is classified into moderate group. In moderate group, arteriosclerosis is seen to some extent and this group is pointed "yellow signal". Many patients

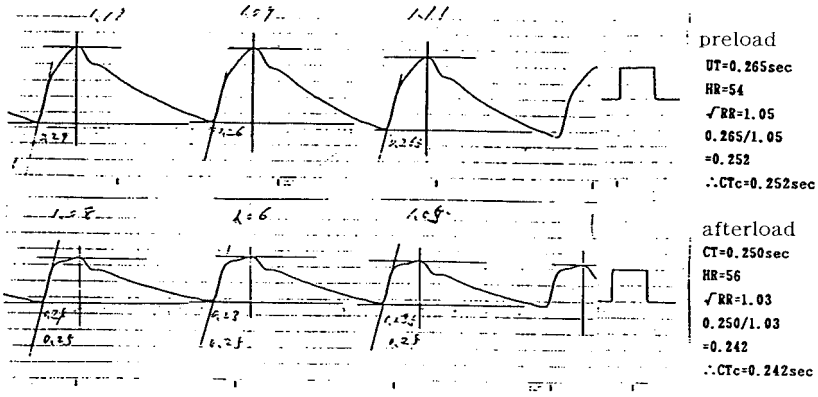


Fig. 9 PTG (preload) and Adp-PTG (afterload) of 51 years old female She was judged as "severe"

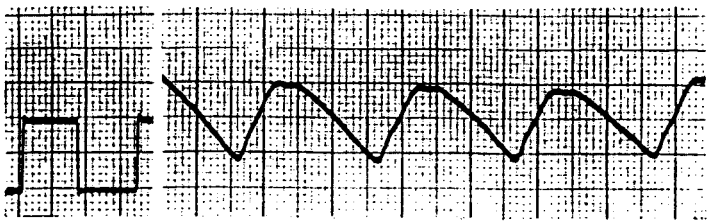


Fig. 10 Trapezoid wave, in this wave pattern arteriosclerosis is greatly advanced and blood vessels vary like a solid pipe.

in moderate group are responsive to treatment and sometimes they will move to mild group.

4. Fig. 9 shows a recording of 51 years old female, the preload wave is sclerotic and the afterload pattern is anacrotic wave. The value of CTc in afterload is 0.242 sec and this case is diagnosed as severe. In this group, arteriosclerosis is highly strong and pointed "red signal". In severe group we start several treatments immediately even if the result of other examinations is normal, but many cases of this wave form are resistant to treatment and seldom return to more improved wave form.

5. The trapezoid wave is demonstrated in Fig. 10. In this wave pattern, arteriosclerosis is greatly advanced and blood vessels vary like a solid pipe. Systolic and diastolic peaks are merged together and a top of wave becomes flat.

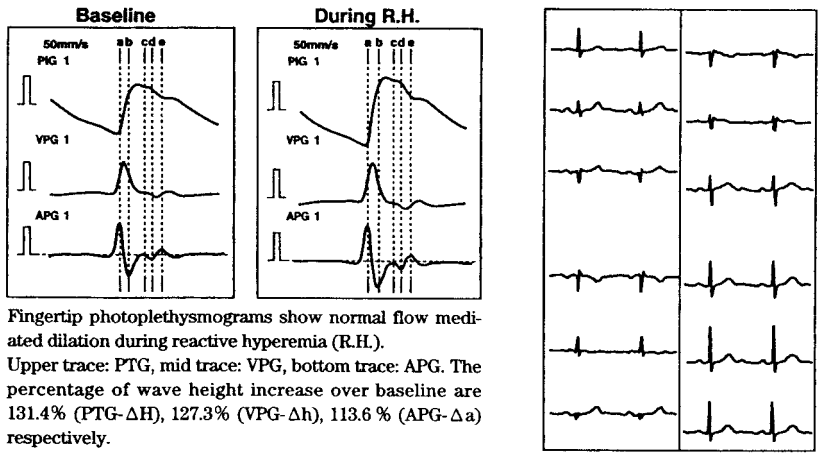
The blood flow is almost not pulsatile and becomes a lengthy flow like a constant tide around the top of the pulse wave. This pattern is the most severe and pointed "double red". It's very danger if the patient is not under some treatment. However, we encounter such cases very seldom on the arteriosclerosis mass screening.

6. In Table 3 we showed the result of arteriosclerosis screening by Adp-PTG in 104 cases at some company. Six cases of 12 in 30-39 years old had abnormal wave patterns. With aging normal and mild types were decreased and moderate and severe types were increased. It is very interesting about a half of 21 cases at 60-69 years old were in the mild group. These older people may be in low risk of cardiovascular accidents such as myocardial infarction or apoplexy. We have to tell them that

Table 3 The result of arteriosclerosis screening by Adp-PTG in 104 cases at some company

	Age 30-39	40-49	50-59	60-69	total
Grade Normal	6 (50)	2 (7)	3 (7)		11 (11)
Grade mild	5 (43)	12 (43)	22 (52)	11 (52)	50 (48)
Grade Moderate	1 (8)	11 (39)	9 (21)	5 (24)	26 (25)
Grade Severe		3 (11)	9 (21)	5 (24)	17 (16)
total	12 (12)	28 (27)	43 (41)	21 (20)	104 (100)

( ) : %



Fingertip photoplethysmograms show normal flow mediated dilation during reactive hyperemia (R.H.).
Upper trace: PTG, mid trace: VPG, bottom trace: APG. The percentage of wave height increase over baseline are 131.4% (PTG-ΔH), 127.3% (VPG-Δh), 113.6 % (APG-Δa) respectively.

Fig. 11 The example of ECG and fingertip photoplethysmogram in 70 years old female normal subject at baseline and after 1 min during reactive hyperemia (T.Ozawa, 2001)

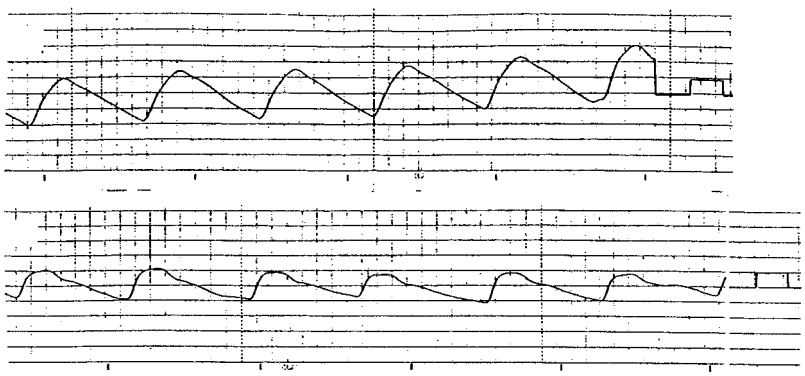


Fig. 12 PTG (preload) and Adp-PTG (afterload) of 75 years old female
She was judged as "severe".
PTG (upper): HR; 78, CTc; 0.273 sec
Adp-PTG (lower): HR; 75, CTc; 0.217 sec

their vessels are relatively young and give them a beam of hope and confidence in future for enjoying a daily active healthy life.

7. Ozawa reported a recording of 70 years old female [6]. In Fig. 11, it is shown the result of his experimental PTG analysis of reactive hyperemia which is a PTG recording after several minutes pressure overload on arm. Photoplethysmogram (PTG), velocity PTG (VPG) and acceleration PTG (APG) on fingertip were recorded together. Fig. 11 demonstrated "base line" is the preload PTG and

the upper wave is PTG, middle is VPG and the bottom trace is APG. Both of her PTG and VPG are normal wave and APG is same as the wave seen at 20-30 years old. Because normal wave is defined the basic wave pattern in 17-30 aged healthy young people, her vascular age is at most 30 years old. Sometimes there are such healthy people have a younger vascular age.

8. The PTG and Adp-PTG examinations were done in 75 years old female on July 11, 2001, her record is in Fig. 12. Blood pressure is 130/72, preload PTG is sclerotic wave like a triangle wave, and CTc is calculated as 0.273 sec. After pressure load wave pattern changes anacrotic and CTc is 0.217 sec. She is judged as severe. We start the treatment as soon as possible, but she is very active in ordinary daily life. On December 15, 2001, she was found falling down in coma at her room by next-door neighbors. She died 7 hours later although she was rushed to a nearby emergency hospital. The cause of her death is cerebral hemorrhage. It is very risky for old people having a severe type of Adp-PTG to stay alone at their home.

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