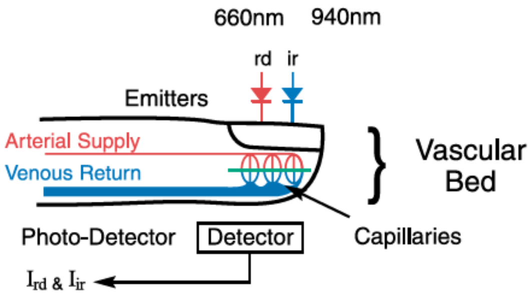
White Paper ES Teck PEMS 03/20/2009
Writer: Albert MAAREK
Reviewer: Richard Clement

Oximeter:

Pulse Oximeter Definition

What is it? (2) (3) (4)
A pulse oximeter consists of a computerized monitor and a probe that can be attached to the patient's finger, toe, nose, or earlobe. The monitoring unit displays digital percentage read out of a calculated estimate of the patient's hemoglobin (Hgb) that is saturated with oxygen (SpO2.) A visual waveform indicator is displayed and an audible signal is emitted with each pulse beat, where the tone decreases with a corresponding decrease in saturation. Also displayed is a calculated heart rate. Alarms are available to alert the user to either a high or low saturation level or fast or slow pulse rate.
What does it do? (5) (6) (7)
The device measures two types of hemoglobin: oxygenated and deoxygenated. Since two different substances are being measured, two frequencies of light are necessary. This is called spectrophotometry. The red frequency measures desaturated hemoglobin and the infrared measures oxygenated hemoglobin. If the oximeter measures the greatest absorbance in the red band, it will indicate low saturation. If the greatest absorbance is in the infrared band, it will indicate a high saturation.
How does it do it? (6) (7) (8)
The pulse oximeter utilizes the two wavelengths of light to calculate the saturation of Oxyhemoglobin. As a light is shone through the finger, it is picked up by a receiver. Some of the light is absorbed by the tissues, including arterial blood. As the artery fills with blood, the absorption increases; and as the artery empties, the absorption decreases. Since the pulsating blood is the only substance that is changing, the stable substances (skin and tissue) are eliminated from the calculation.



Basis For Measurement:

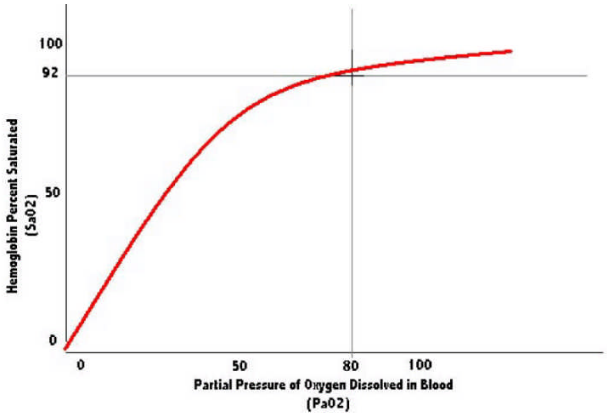
$$\frac{I_{rd}}{I_{ir}} = \frac{S_{rd} + N_{rd}}{S_{ir} + N_{ir}} = \text{Ratio } (r) \rightarrow \% \; SpO_2$$

SpO2 % Normal range [6] [7] [9]
95% for adult
>= 96% for children

Oxyhemoglobin Dissociation curve [11] [12] [13] [14]

Oxygen can be measured in two forms:
Partial atmospheric pressure of oxygen (PaO2)
Oxygen saturation (SaO2)
Calculated estimate of oxygen saturation (SpO2): an indirect SaO2
There is a relationship between the amount of oxygen dissolved in the blood and the amount attached to the hemoglobin. This is called the normal oxyhemoglobin dissociation curve.

Normal Oxyhemoglobin Dissociation Curve



The chart above illustrates that when the PaO2 is 80, the hemoglobin is 92% saturated with oxygen. As the pressure of oxygen increases, the hemoglobin saturation increases. A pressure of 105 or above will completely saturate the hemoglobin. More oxygen can still be diffused into the blood but the hemoglobin is at its maximum capacity. By using the pulse oximeter we can indirectly assess the PaO2 by measuring the SpO2. For example:

97% saturation = 97 PaO2 (normal)
90% saturation = 60 PaO2 (danger)
80% saturation = 45 PaO2 (severe hypoxia)

Oxygen - hemoglobin Affinity Changes.
The functions of hemoglobin are oxygen pickup and delivery. The hemoglobin has an affinity (the strength of bond between oxygen and hemoglobin) that can be increased or decreased due to various situations. If hemoglobin has an increased affinity, it is highly saturated; but oxygen is less available for release to the tissues due to the strong bond. The reverse is also true.

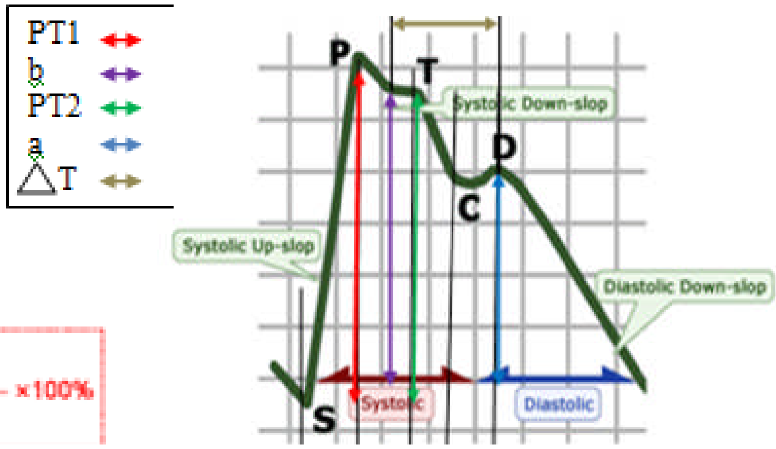
Photoelectrical Plethysmograph

The photoelectrical Plethysmography technique is the mathematical Analysis of the wave form provided by the oximeter.

Original wave: PTG [15]

Description of the wave

S (Starting point)
P (Percussion wave)
T (Tidal wave)
C (Incisura)
D (Dicrotic wave)



AI = augmentation index = PT2/PT1

Reflection Index (RI)

$$RI_{DVP} = \frac{a}{b} \times 100\%$$

Stiffness Index (SI)

$$SI_{DVP} = \frac{\text{Subject height}}{\Delta T_{DVP}} \text{ in m/s}$$

RI Norms* (patients without coronary disease CAD): 37.82% ± 7.3%
RI in patients with significant coronary disease (CAD) *: 73.098% ± 10.093% ($P < 0.001$)
These observations suggest that RI may useful in predicting CAD and not the severity*.
SI Norms* (patients without coronary disease CAD): 8.28 ± 1.06 m/sec
SI in patients with significant coronary disease (CAD) *: 9.52 ± 1.05 m/s
($P = 0.0055$)

S-P time: Etc (Estimated Cardiac Ejection time): Normal range 260~380 ms

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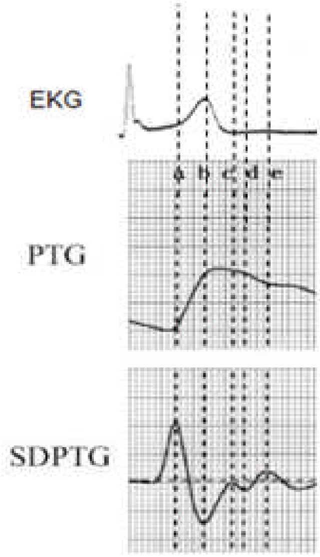
SDPTG = second derivative wave of fingertip photo plethysmography [16] [17] [18] [19] [20]

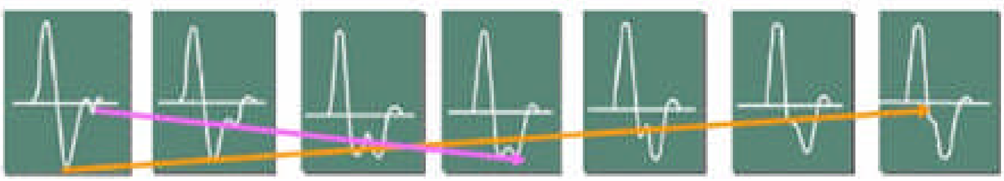
Relationship between the EKG /PTG and SDPTG



The SDPTG results of a Process of mathematical acceleration of the original wave PTG
Description of the SDPTG wave
5 points: a, b, c, d, and e.

Aging Index [17]

b-c-d-e/a was defined as the SDPTG aging index



Year old	20-30	30-40	40-50	50-60	60-70	70-80	>80

The b/a ratio increased with age, and c/a, d/a, and e/a ratios decreased with age

Analysis of the SDPTG

The subjects who had any history of arteriosclerotic disease showed a higher SDPTG aging index (17) (18)

The negative d/a ratio increased with increases in the AIs of PTG and ascending aortic pressure wave (19) (20) , which indicates that the negative d/a ratio should be a useful index for the evaluation of Vasoactive agents, as well as an index of left ventricular after load. The SDPTG aging index may be useful for evaluation of vascular aging and screening of arteriosclerotic patients (17)

Mathematical Index calculation

PH (Pulse Height) and **EEI** (Ejection Elastic Index) are related to the ratio b/a
DDI (Dicrotic Dilation Index) is related to the ratio – d/a
DEI (Dicrotic Elastic Index) is related to the ratio e/a

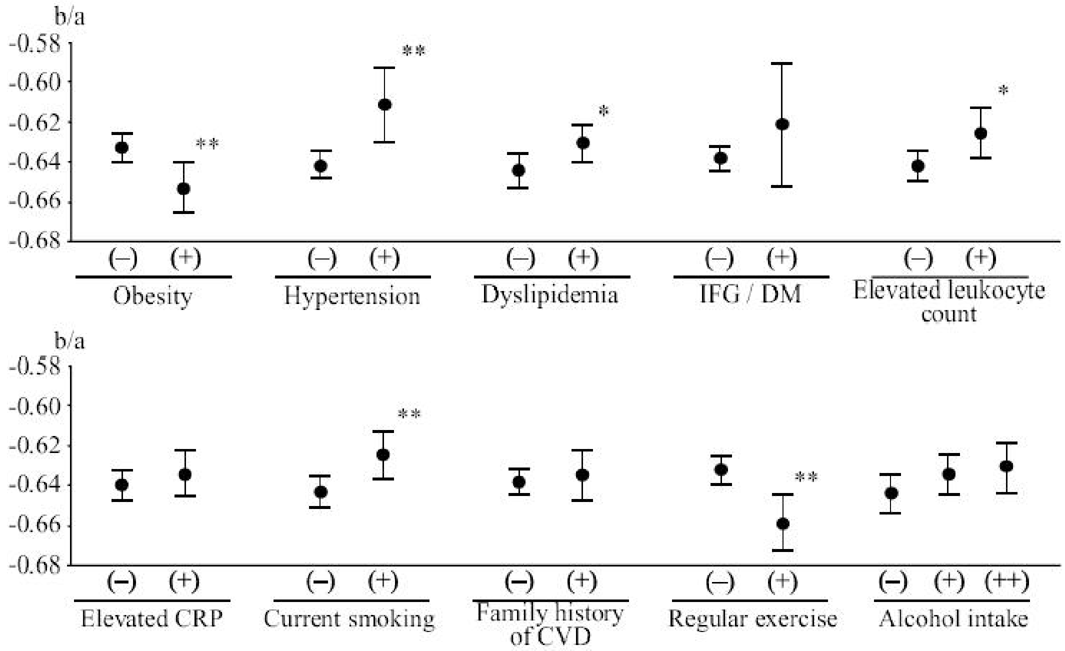
Indicator of the Index:

AI (Augmentation Index): Indicator of the elasticity of the carotid artery
EEI: (Ejection Elastic Index) Relation with LV ejection and elasticity of large artery
Decreased value = possible left ventricular ejection insufficiency / arteriosclerosis
Increased value = possible increased left ventricular ejection power.
DDI (Dicrotic Dilation Index): Relation with contraction, tension and stiffness of small artery
Decreased value = possible hypertension and arteriosclerosis / arterial stiffness
Increased value = possible arteriole dilation; decreased vascular resistance

DEI (Dicrotic Elastic Index): Relation with blood flow to peripheral artery
Decreased value = possible decreased vessel elasticity / arteriosclerosis
Increased value = possible arteriole dilation or venous disorders

PR (Pulse rate): Vascular circulation according to the heart rate.
Etc: Estimated Cardiac Ejection time related with the LV function
PH: Pulse Height: Related with Peripheral blood volume

PTG Aging Index: Mathematical calculation of the aging index from the SDPTG
b/a: Ratio between the 2 points .Negative point. The absolute value Increased with age. Marker of the Heart Left ventricle function
-d/a: Ratio between the 2 points .Negative point. The absolute value decreased with age. Marker of Hypertension

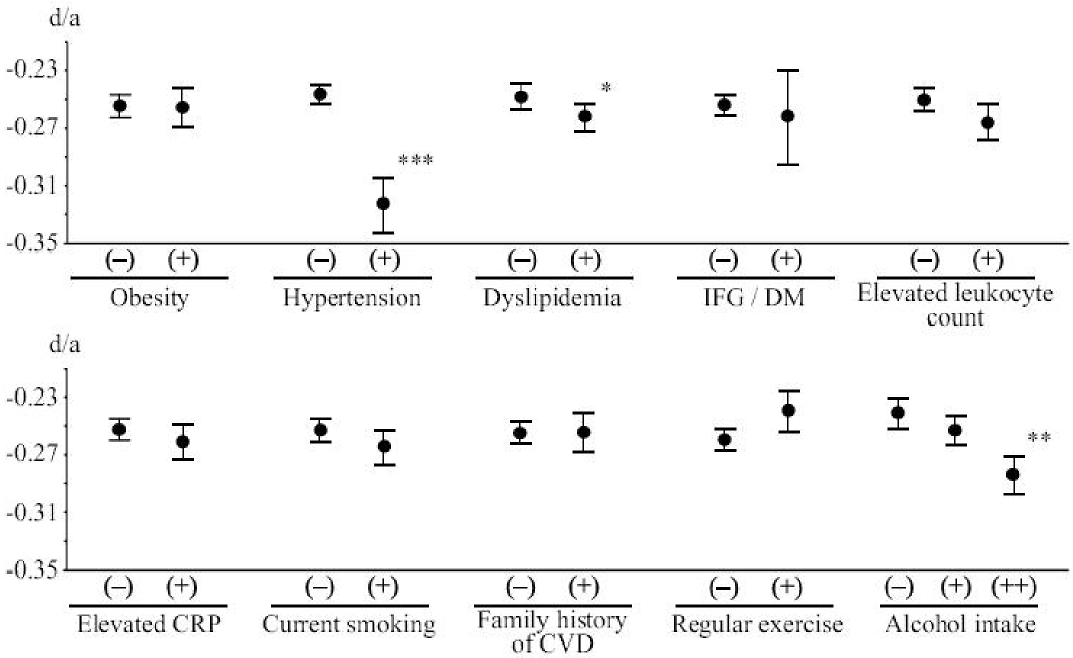


Comparison of the mean b/a between the groups with and without each cardiovascular risk factor. The mean values were adjusted for age, height, and heart rate. Error bars indicate 95% confidence intervals. CRP, C-reactive protein; CVD, cardiovascular disease; DM, diabetes mellitus; IFG, impaired fasting glucose. *p<0.05, **p<0.01. Alcohol intake: (−), 0 to 1 day per week; (+), 2 to 5 days per week; (++), 6 to 7 days per week. [18]

[18] **Correlation Coefficients of the SDPTG Indices with the Clinical Parameters**

	b/a		*d/a*	
	r	*p* value	*r*	*p* value
Age	0.40	<0.001	-0.41	<0.001
Height	−0.23	<0.001	0.17	<0.001
Body mass index	−0.02	0.470	−0.08	0.019
Systolic BP	0.10	0.003	−0.27	<0.001
Diastolic BP	0.09	0.004	−0.29	<0.001
Heart rate	−0.17	<0.001	0.09	0.007
Total cholesterol	0.09	0.005	−0.10	0.002
Triglycerides	0.02	0.583	−0.05	0.159
HDL cholesterol	−0.03	0.425	−0.02	0.475
LDL cholesterol	0.10	0.003	−0.07	0.035
Fasting plasma glucose	0.09	0.007	−0.10	0.002
Leukocyte count	0.09	0.006	−0.08	0.011
log CRP	0.02	0.448	−0.07	0.039

BP, blood pressure; CRP, C-reactive protein; HDL, high-density lipoprotein; LDL, low-density lipoprotein; SDPTG, second derivative of a finger photoplethysmogram.

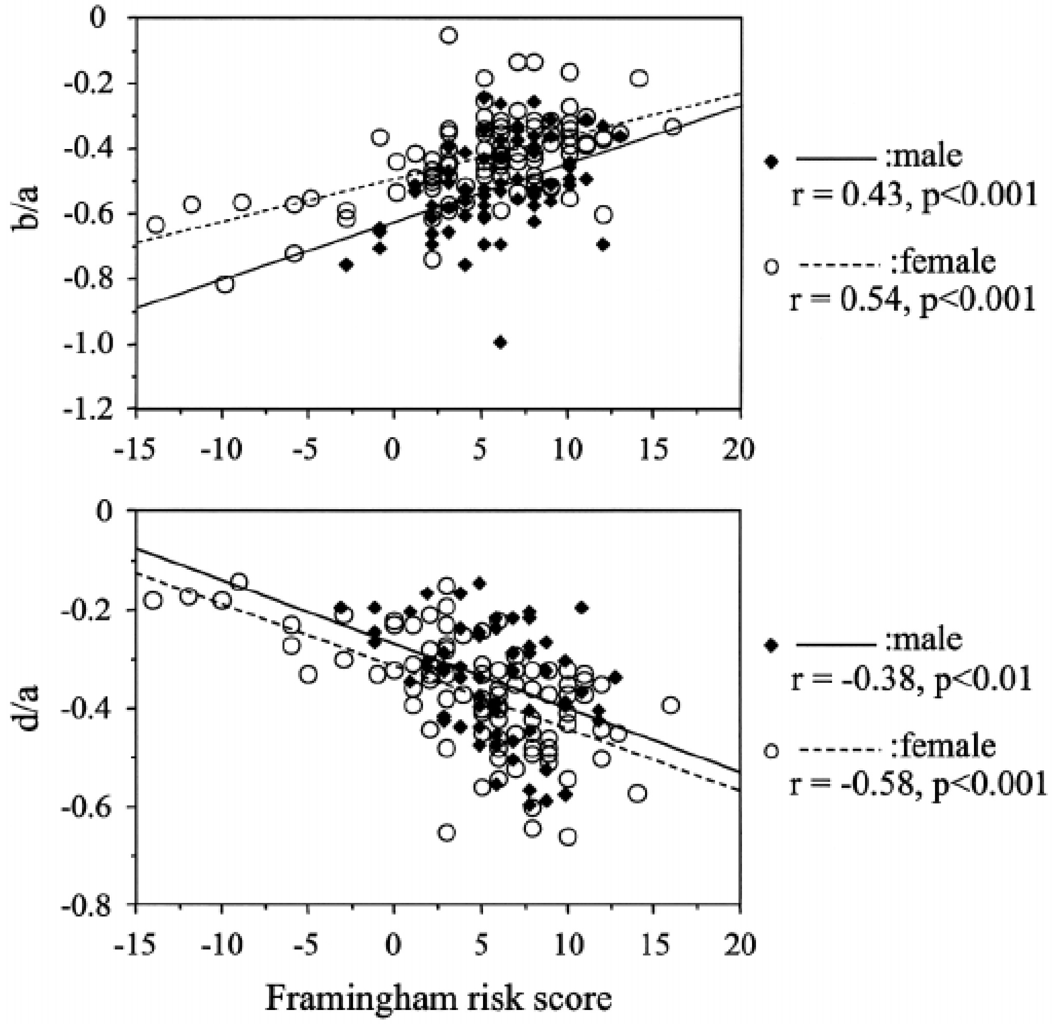


Comparison of the mean d/a between the groups with and without each cardiovascular risk factor. The mean values were adjusted for age, height, and heart rate. Error bars indicate 95% confidence intervals. CRP, C-reactive protein; CVD, cardiovascular disease; DM, diabetes mellitus; IFG, impaired fasting glucose. *p<0.05, **p<0.01 vs. (+) and p<0.001 vs. (−), ***p<0.001. Alcohol intake: (−), 0 to 1 day per week; (+), 2 to 5 days per week; (++), 6 to 7 days per week. [18]

[18] **Odds Ratio of Each Cardiovascular Risk Factor for an Increased *b/a***

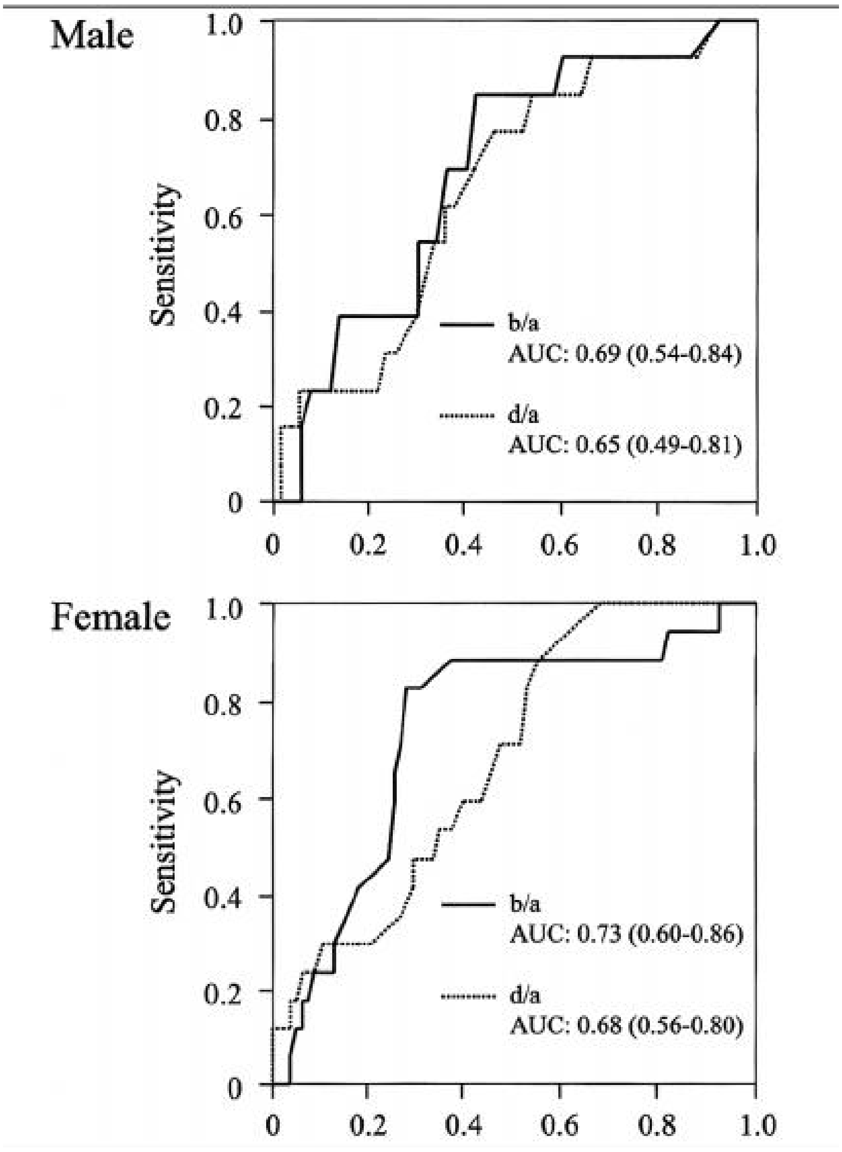
Variables	Univariate		Multivariate	
	Odds ratio (95% CI)	*p* value	Odds ratio (95% CI)	*p* value
Age (per 1-year increase)	1.13 (1.10–1.16)	<0.001	1.12 (1.09–1.15)	<0.001
Height (per 0.01-m increase)	0.93 (0.90–0.95)	<0.001	0.94 (0.91–0.97)	<0.001
Heart rate (per 1-bpm increase)	0.97 (0.96–0.99)	0.003	0.96 (0.94–0.98)	<0.001
Obesity	0.84 (0.59–1.20)	0.337	—	
Hypertension	1.81 (1.19–2.76)	0.006	1.65 (1.03–2.65)	0.038
Dyslipidemia	1.70 (1.27–2.28)	<0.001	1.51 (1.09–2.09)	0.014
IFG/DM	3.24 (1.71–6.13)	<0.001	2.43 (1.16–5.07)	0.018
Elevated CRP	0.97 (0.70–1.35)	0.852	—	
Elevated leukocyte count	1.34 (0.97–1.85)	0.079	0.92 (0.63–1.34)	0.650
Current smoking	1.47 (1.08–2.01)	0.016	1.27 (0.89–1.83)	0.189
Family history of CVD	1.23 (0.88–1.72)	0.234	—	
Lack of regular exercise	1.54 (1.05–2.28)	0.028	2.00 (1.29–3.08)	0.002
Alcohol intake*				
2 to 5 days per week	1.17 (0.83–1.64)	0.365	—	
6 to 7 days per week	1.27 (0.87–1.85)	0.221	—	

Variables with a *p* value of less than 0.10 in the univariate analysis were entered into the subsequent multivariate analysis. *Zero to 1 day per week as a reference. CI, confidence interval; CRP, C-reactive protein; CVD, cardiovascular disease; DM, diabetes mellitus; IFG, impaired fasting glucose.



Correlations between second derivative of the finger Photoplethysmogram indices and the Framingham risk score in each gender. The b/a was positively correlated (Top), whereas the d/a inversely correlated (Bottom) with the Framingham risk score in both genders. [19]

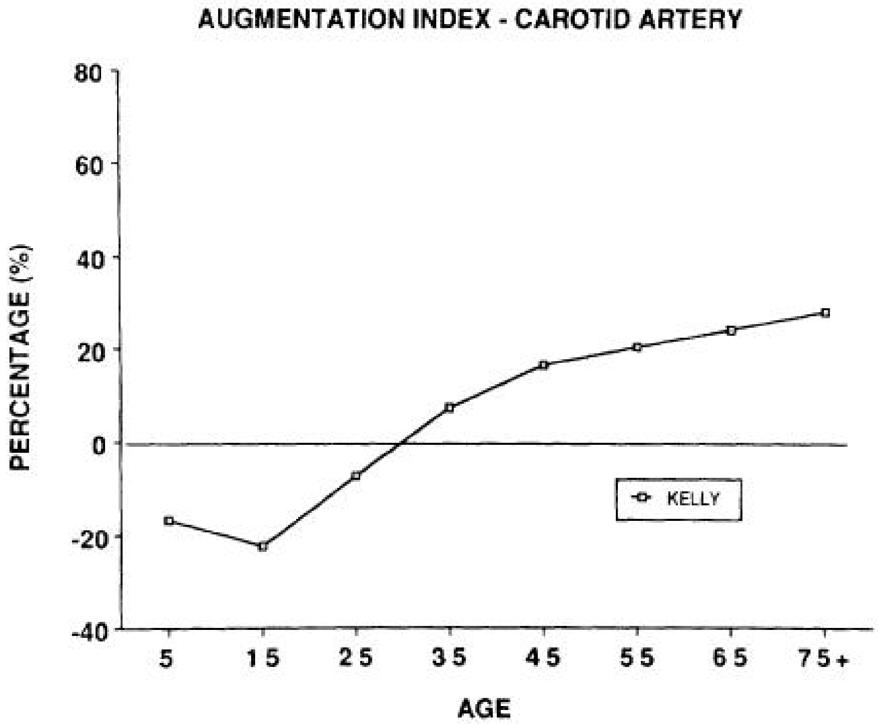
Receiver operating characteristic (ROC) curves of the second derivative of the finger photoplethysmogram indices for the discrimination of high-risk subjects for coronary heart disease in males (Top) and in females (Bottom). The 95% confidence interval of the area under the ROC curve (AUC) are shown in the parentheses. The b/a in both genders and the d/a in females revealed significant discriminatory performance. [19]



(19) **Ability of the SDPTG Indices to Discriminate High-Risk Subjects for CHD**

	Cut-off value	*Sensitivity*	*Specificity*	*Accuracy*
Male				
b/a	–0.53	0.85	0.58	0.64
Female				
b/a	–0.40	0.83	0.72	0.74
d/a	–0.39	0.59	0.60	0.60

CHD, coronary heart disease. Other abbreviation see in Table 1.



(16) *Graph of augmentation index for carotid artery as function of age.*

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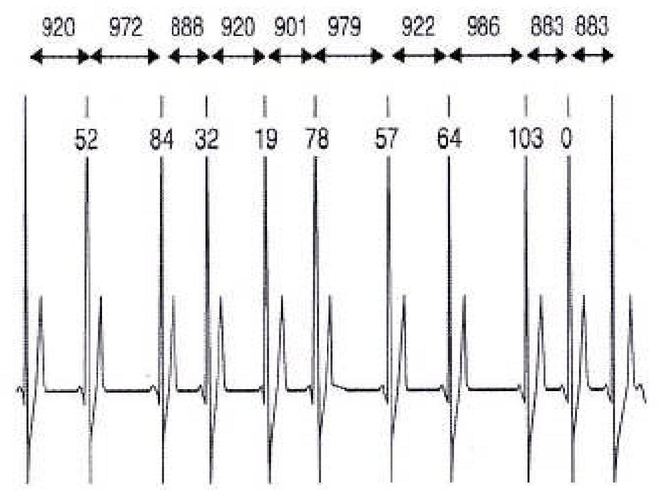
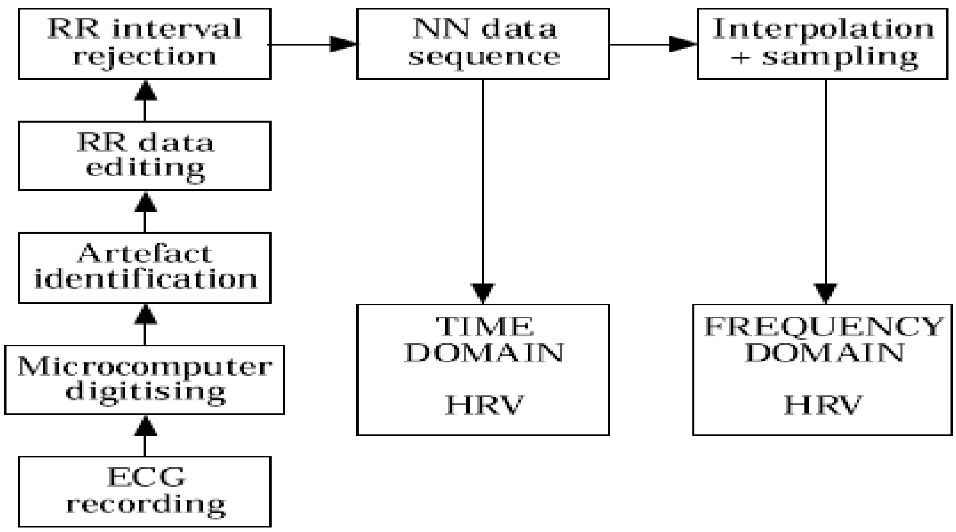
Heart Rate Variability (HRV) [1]
The HRV is a mathematical analysis of the Heart rate time. HRV evaluates the variation of the heart rate, both in the time domain (statistical methods) and in the frequency domain (spectral analysis). Each QRS complex is detected and the so-called normal-to-normal (NN) or Rate-to-Rate (RR) intervals between adjacent QRS complexes are resulting from sinus node depolarization



Example of an ECG output over 11 beats. R-R interval times and difference between adjacent R-R intervals are displayed.

Process of analysis



Means of the HRV Results

Time domain results		
Items	**Units**	**Description**
Heart Rate (HR)	bpm	Mean heart rate per minute
Mean values of RR intervals	ms	Mean of RR intervals
Maximum values (Mx)	ms	longest NN interval
Minimum values (Mn)	ms	shortest NN interval
MxDMn HIB	ms	The difference between the longest and shortest NN interval
MxDMn (HIB)	ms	Irregular heart beat (IHB) indicator. Displays when the device detects large variation in RR Interval during measurement.
SDNN	ms	Standard deviation of all NN intervals.
RMSSD	ms	The square root of the mean of the sum of the squares of differences between adjacent NN intervals.
NN50 count		Count Number of pairs of adjacent NN intervals differing by more than 50 ms in the entire recording. Three variants are possible counting all such NN intervals pairs or only pairs in which the first o the second interval is longer.
pNN50 %	%	NN50 count divided by the total number of all NN intervals.

frequency domain results			
Items	**Units**	**Description**	**Frequency range**
5 min total power	ms2	The variance of NN intervals over the recording segment	$\leq$ 0·4 Hz
VLF	ms2	Power in very low frequency range	$\leq$ 0·04 Hz
LF	ms2	Power in low frequency	range 0·04–0·15 Hz
HF	ms2	Power in high frequency range	0·15–0·4 Hz
LF/HF	%	Ratio LF [ms2]/HF [ms2]	

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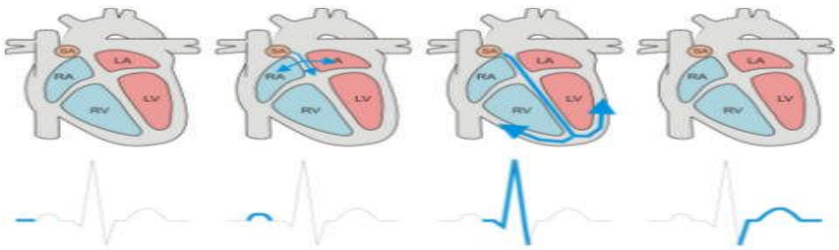
Heart Rate and sinus node depolarization: **Drawing**

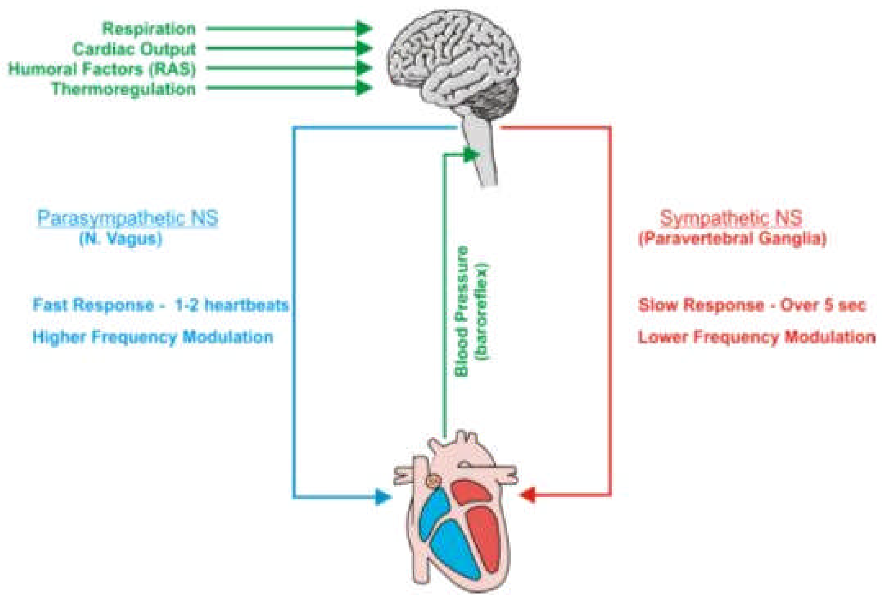


Indicators HRV [1]
Heart rate: Fast pulse may signal the presence of an infection or dehydration
Normal Range
For resting heart rate:

- newborn infants; 100 to 160 beats per minute
- children 1 to 10 years; 70 to 120 beats per minute
- children over 10 and adults (including seniors); 60 to 100 beats per minute
- well-trained athletes; 40 to 60 beats per minute

RMSSD: Indicator of Parasympathetic (vagal) activity
HF: Indicator of Parasympathetic (vagal) activity
LF: Indicator of Sympathetic system or both sympathetic and vagal activity.
LF/HF: ratio considered by some investigators to mirror sympathetic/vagal balance or to reflect sympathetic modulations.

HRV and autonomic nervous system links



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