Assessment of Fundamental Elements of Health Using Impedance Plethysmography

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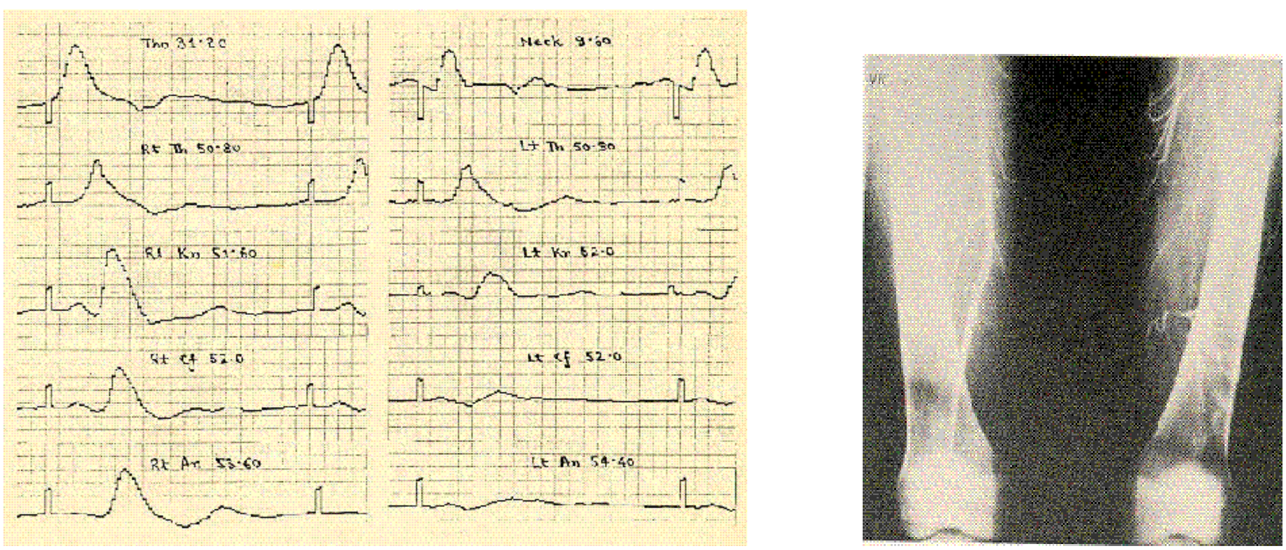
Abstract

Electronics Division, BARC has been working in the field of Impedance Plethysmography since 1978 and has developed several versions of the same during the past 31 years. It has been successfully used in the past for the diagnosis of peripheral vascular occlusive diseases, assessment of cardiac function and variability analysis. Significant difference in variability spectrum in health and disease, as observed in BARC's preliminary study at J.J. Hospital, has led us to study the fundamental elements of health using variability analysis of impedance Plethysmographic signals. Few trials on control subjects at BARC and comprehensive trials by CDAC, Pune have shown 78% agreement between heart rate variability and subjective assessment of Prakruti of the individual. The peripheral pulses have shown different morphology from individual to individual and also within the same individual at different time instants. A retrospective analysis of these signals has suggested manifestation of Vata, Pitta and Kapha (the fundamental elements of health) in different phases of the cardiac cycle, which are described in this paper.

Keywords – Impedance Plethysmography, Peripheral Pulse, Pulse Morphology, Prakruti, Fundamental Elements of Health- Vata, Pitta, Kapha

Introduction

Bhabha Atomic Research Centre developed the 1st model of Impedance Plethysmograph (IPG) in 1978 and installed at Department of Surgery, Seth G.S. Medical College & KEM Hospital and Department of Medicine, Grant Medical College & J.J. Hospital, Mumbai for the assessment of central and peripheral blood flow in human body. Extensive clinical trials on 100 normal subjects and 10,000 patients with peripheral vascular occlusive diseases at KEM Hospital during 1978 to 1990 and comparison of IPG observations with Angiography observations in more than 500 subjects revealed the sensitivity and specificity of the indigenously developed technique to be 96% and 98% for the diagnosis of peripheral arterial occlusive disease [1] and more than 80% for the diagnosis of deep vein thrombosis [2]. Typical IPG data in a patient is shown in Fig 1 and Table I.



(a) **(b)**

Fig. 1*: (a) ICVG waveforms in a patient (RKP-30-M) with femoral artery occlusion in the left leg. The amplitude of the waveform on right side gives normal appearance. Left thigh shows a marginal decrease in the amplitude of the waveform, which becomes moderately lower at knee level and markedly lower at calf and ankle levels. These observations are in agreement with the Aortogram shown in (b).*

Table I

Location	Right Side		Left Side	
	BFI	*DPAT(ms)*	*BFI*	*DPAT(ms)*
Thigh	1.48	70	1.13	70
Knee	2.12	50	0.85	80
Calf	1.64	-	0.29	-
Ankle	1.68	40	0.23	80

As given in above table, all the Blood Flow Index (BFI) values in the right leg give normal impression. Though Differential Pulse Arrival Time (DPAT) at thigh is very marginally decreased and that at knee is very marginally increased, in view of normal BFI values, right leg is considered normal and minor changes in DPAT are attributed to measurement error. In the left leg there is marginal decrease in BFI at thigh level and moderate decrease at knee level with increase in DPAT at knee level, thus indicating an occlusion at iliac or femoral level. Below the knee there is marked decrease in the value of BFI and increase in DPAT at ankle level indicating a further block at calf level with few collaterals, which is validated by Aortogram.

The IPG technique has undergone several renovations during the past 31 years such as development of microprocessor based impedance plethysmograph system, introduction of simple and reliable calibration for dZ/dt waveform [3]. Correction of formula for estimating peripheral blood flow [4], introduction of normalized dZ/dt waveform for easy assessment of peripheral blood flow [5] and development of PC based Impedance Cardiovasograph system [6]. The technology of latest version has been transferred to the industry for commercialization.

The clinical applications of Impedance plethysmography do not end with measurement of central and peripheral blood flow but more important applications are in advance stages of development at several institutes [7,8]. For instance, the fluctuations in heart rate, peripheral blood flow or stroke volume are being explored to study the effect of different diseases on the autonomic nervous system (ANS). In this application, continuous IPG signal is recorded from a body segment for a period of five minutes. BFI values are then obtained from this signal as a function of time and interpolated to get equi-spaced values. Fourier transform of this time series then gives the rhythm of fluctuations. Figure 2 shows typical heart rate fluctuations in time and frequency domain obtained from a normal subject. The peak at 0.012 Hz. represents activity of thermo-regulation/ baro-receptor reflex/ sympathetic nervous system and those at 0.105 Hz. and 0.236 Hz. represent activity of parasympathetic nervous system and respiration respectively.

The Variability Analyzer system developed at BARC gives variability in heart rate, stroke volume and peripheral blood flow from a single data acquisition from the subject, which is not feasible with any other commercial instruments. Preliminary study carried out on 300 subjects has shown that ANS activity gets selectively modified in the presence of major diseases [9].

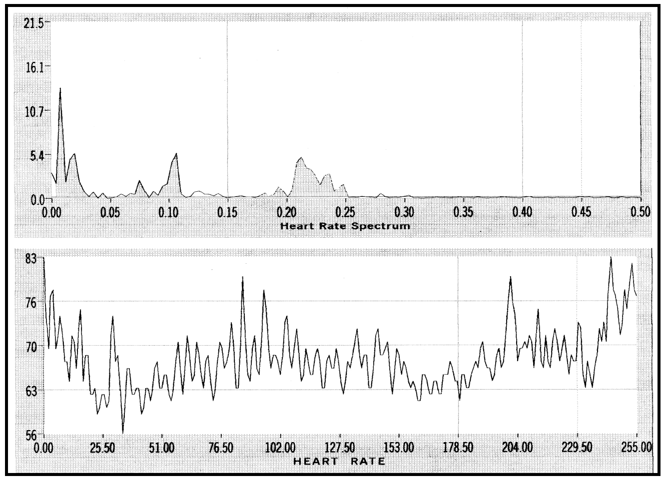


***Fig. 2**: Typical heart rate fluctuations in time (lower) and frequency domain (upper) in a normal subject. Three peaks, centered around 0.012, 0.105 and 0.236 Hz, are prominent. These are termed as Low Frequency (LF), Mid Frequency (MF) and High Frequency (HF) peaks respectively.*

Assessment of Prakruti

According to Sankhya Ideology followed by the ancient medical science Ayurveda, all living or non-living things are made from combination of five basic principles- Pruthvi, Jala, Tej, Vayu & Aakash.(i.e. Earth, Water, Fire, Ether & Space). There are certain elements in the body, which are released in the body cavities at certain intervals, but are not thrown out of the body. They take part in body functions and are re-absorbed in the body. These are called Doshas. They also play a major role in building up the body. They are three, namely-Vata, Pitta & Kapha. These are the fundamental elements of health in a living body. Like all, these are also made up of five basic principles and contain combinations of various characteristics of these five principles. [10]

Harmony or a balance between the three elements signifies the health and is called the Prakruti of the person. This is termed like wise as Vataj, Pittaj, Kaphaj, Vata-Pittaj, Pitta-Kaphaj, Kapha-Vataj and Sannipataj depending upon the dominance of these elements. Any imbalance in either of them leads to Vikruti or disease condition.[10]

It is observed that apart from the underlying disease, the Prakruti of an individual changes with age. For instance Kapha is more dominant in the childhood, Pitta is more dominant in the middle age and Vata is dominant in old age. (In present times Pitta dominance is seen in twenties and thirties and Vata dominance is seen beyond thirties.) Also rhythmic variations are found in these Doshas in an individual during a day as shown in Table II.

Most significant observation on thousands of subjects is that HF peak in HRV spectrum goes on reducing as the age advances and may touch the base line in cases of severe illness. This observation suggests that strength of the HF peak may have inverse relation with the Vata element in the body. Similarly MF & LF may have inverse relations with Kapha & Pitta levels in the body. In view of this, we have recorded variability spectrum in 20 normal subjects at BARC and also assessed their Prakruti through clinical examination by Ayurvedic physicians.

It was observed that Vataj, Kaphaj and Pittaj Prakruti recorded diminished HF, MF and LF peak respectively. The detailed studies carried out by CDAC, Pune (sponsored by DIT, Government of India) in large number of control subjects and patients (typically around 300) have shown 78% correlation between the Prakruti determination by variability analysis and that assessed by a group of Ayurvedic physicians.

While these observations are encouraging, the technique has to be further explored to achieve the target of disease characterization.

Table II

Fundamental Elements	*Dominance*		*Function*	*Ailments Type*
	During Day	*By Age*		
Kapha	Early Morning	Childhood	Bonding of Elements	Chronic in nature, Arterial blocks, Obstructive diseases, Arthritis, Malfunctioning of Reproductive System
Pitta	Mid Day	Middle Age	Processing of Nutrients and Signals	Digestive System, Endocrinal System, Hormonal imbalance, Personality related
Vata	Evening	Old Age	Transportation of Nutrients and Signals	Conduction defects, Brittleness, Fullness in Kapha conjunction and excessive emptiness in Pitta conjunction

Peripheral Pulse Analyzer

We have developed a Peripheral Pulse Analyzer based on the principle of IPG. In this system IPG waveform is simultaneously recorded from three different locations on the wrist corresponding to Vata, Pitta and Kapha locations of Ayurvedic System of Medicine and termed as dZ3, dZ2 and dZ1 respectively. With the subject in supine position, the carrier electrodes are applied around the upper arm and the palm; the sensing electrodes S1 to S4 are applied 2cm apart from each other with S4 on the distal segment around the wrist Thus impedance signals dZ1, dZ2 and dZ3 recorded from S1-S2, S2-S3 and S3-S4 correspond to Kapha, Pitta and Vata locations respectively.

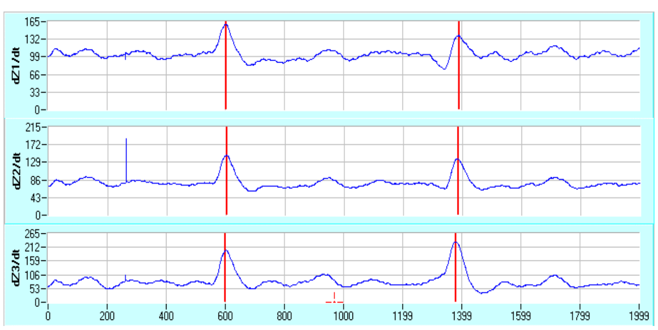


Fig. 3: *dZ1, dZ2 and dZ3 waveforms recorded simultaneously from Kapha, Pitta and Vata locations respectively. In the first cycle, peaks in dZ1 and dZ3 are coincident and precede that of dZ2 where as in the second cycle peak in dZ3 precedes that of dZ2 and peak in dZ2 precedes that of dZ1.*

Preliminary trials carried out with this system on a group of control subjects before and after lunch have indicated that the amplitude of any signal, say dZ3, appears proportional to Vata element and likewise for dZ1 and dZ2. Most significant observation from this data is that sometimes peak in dZ3 appears before that of dZ2, which is not consistent with the human anatomy and physiology as shown in Figure 3.

Pulse Morphology

During the above studies, it was observed that shape or pattern (morphology) of the peripheral pulse changes significantly in an individual as a function of time. Also there is marked variation in the pulse pattern from subject to subject. Detailed examination of the pulse patterns recorded for 300 seconds in more than 1000 subjects have shown that there are 8 basic patterns (P1 to P8 in Fig. 4), which keep on reoccurring with variable rhythms.

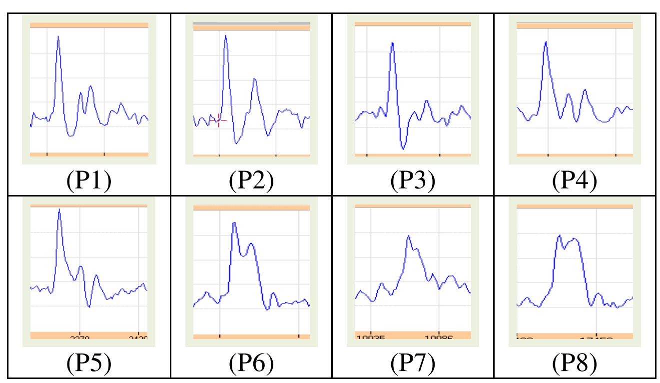


Fig. 4: *Dominant morphological patterns in peripheral IPG signal*

In data of 300 seconds in an individual, few patterns are observed to be dominant and occur for more than 250 seconds; with other patterns interposing occasionally during the remaining 50 seconds. It has also been observed that patterns 1,2 and 4 are recorded in control subjects without having any signs or symptoms of a disease, where as patterns 7 and 8 are dominant in severely sick patients. On the basis of these observations, it can be deduced that most dominant pattern in an individual represents his health status and the occasional appearance of the non-dominant pattern possibly specifies the tendency of the individual for acquiring the respective disease. It is therefore necessary to relate these patterns with various ailments.

For better understanding of these morphologies, it is better to have a closure look at the physiological correlates. In human physiology a cardiac cycle can be divided into three time segments known as pre-systole, systole and diastole. Pre-systole prepares the heart for the pumping action, systole is the pumping action and diastole is the filling of the heart. Thus pre-systole keeps the blood ready for delivery, systole pumps and delivers the blood to the body and diastole is the returning of the blood to the heart after gaseous exchange in the body. An IPG cycle, which essentially follows a cardiac cycle, also can be divided into these three segments. As shown in Table II, Kapha represents the building of body or bonding mechanism of nutrients; Pitta represents the conversion process of the nutrients for easy assimilation in the body & processing of various signals and Vata represents the transportation of nutrients as well as all the signals to various organs of the body. Keeping in view that the nutrients assimilate in the body through the blood, the pre-systolic and early systolic segment can be attributed to the action of Kapha; the mid and late systole can be attributed to the action of the Pitta, as the capillary exchange gets initiated during this period and the diastole can be attributed to the action of Vata as the transportation of waste products along with blood takes place during this period. In view of above hypothesis it should be possible to detect the ailments of these fundamental elements during respective segments.

Discussion

Impedance Plethysmography has been in use in Clinical Medicine for the past 70 years for the assessment of central and peripheral blood circulation. Peripheral pulse palpated at the wrist level has been given considerable importance by the Ayurvedic Physicians in ancient medical system of India for the purpose of disease characterization. We have tried to record the peripheral pulses, following their method in human subjects. We have observed an inverse relation between the Prakruti of a subject and the amplitudes of LF, MF and HF peaks in the variability spectrum. Since an increase in one of the fundamental elements increases the trigger level of corresponding ANS activity, therefore a decrease in this activity of ANS is expected. Peripheral Pulse Analyzer has shown an increase in Pitta after heavy lunch, which is in accordance with the principles of Ayurveda. Anomalous early arrival of peak in dZ3 before that of dZ2 in few cases also is in accordance with the principles of Ayurveda, as in cases of Arthritis, Spondylosis and Parkinson's disease, the Vata element is palpated before the Pitta element.[11]

Based on our observations on peripheral pulse morphology, we have proposed a hypothesis for representation of fundamental elements of health during three phases of an IPG cycle. Kapha, Pitta and Vata are represented by pre and early systolic phase, mid systolic phase and diastolic phase respectively. This needs revalidation by multi-centric trials on large number of subjects in order to convert this technique into a diagnostic tool.

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