A Review On Ayurvedic Approach In Sphygmology: Characteristics, Traditional Parameters And Existing Sensors In Sphygmology

Ammu Anna Mathew, Dr. S. Vivekanandan

Abstract: Ayurveda is a word derived from the Sanskrit language with meaning Ayur as life and Veda as knowledge or science, hence Ayurveda is known as Knowledge of Life. Sphygmology is the science of pulse diagnosis which deals with the principles and practices in Nadi Pariksha. According to Ayurveda, Nadi Pariksha is an extensive method used to find the root cause of illness in a human being. This method forewarns about possible health risks. This paper surveys on the characteristics of pulses, traditional parameters and sensors used in this field for disease identification using pulse diagnosis. The character of the pulse in good health and the changes which will occur in illness are of great attention in determining the cause of diseases. Nadi Pariksha helps in identifying more than 80 varieties of diseases from the three pulses on the radial artery thereby analyzing the diseases at its initial stage in a non-invasive way and curing them at an early stage.

Index Terms: Darshana, Kapha, Nadi Pariksha, Pitta, Prakruti, Prashna, Sparshana, Sphygmology, Tridosha, Vata, Vikruti

1 INTRODUCTION

Ayurveda is the art of everyday living in synchronization with the commandments of nature. Ayurveda is the oldest healing science which is believed to have a history of more than 5000 years in India and was conveyed to us through sutras or small phrases. Ayurveda is an applied, clinical, medical discipline. The maintenance of perfect wellbeing of a healthy person through avoidance is the main aim and objective of Ayurveda. It also aims to cure the disease progression in an unhealthy person through proper diet, way of life, purification therapy and transformation [1]. According to Ayurvedic tradition, the entire physical world is described in terms of five elements: space or ether, air, fire, water, and earth [2]. These five elements are not treated as some purely physical substances but are considered as energetic patterns with each having a particular feature.

- Earth is considered to have features like cold, heavy, solid, stable and dry. This element is denoted by dirt.
- Water is considered to have qualities like cold, mobile, heavy, soft and liquid such as Ocean.
- Hot, subtle, mobile, dry and sharp are the qualities of Fire. Sun is its purest manifestation in nature, which provides warmthness to the earth and sky.
- Space / Ether, like that of the sky, is vast, cold, light and clear. The form and existence of all other things are aided by this element.
- Dryness, cold, rough and full of motion is the features of air. The characteristic of this quality is whipping by an aggressive wind.

These five elements exist in all things at all times; including in the body and each has its own precise role to play [2]. As shown in figure 1, the three primary principles known as tridosha is the manifestation of the five basic elements in the human body. The bodily air principle called vata is the combination of Ether and Air. The fire principle called pitta is the combination of Fire and Water elements. The Earth and Water elements exhibit as the water principle known as Kapha. In normal conditions, the individual constitution is determined by these three doshas and it governs the functions of the body. The imbalance between these three doshas will lead to the disease process. The general characteristics of the doshic pulse are compared with the movements of different animals, called gati. The mobility of the vata pulse is called sarpa gati or cobra pulse (curvilinear motion), that of pitta is called manduka gati or frog pulse (jumping nature), while the motion of kapha pulse is called hamsa gati or swan pulse (lesser curvature) as shown in fig. 2.

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Fig. 1 Tridosha
Nadi Pariksha is a primitive Ayurvedic practice of identification through the pulse. Both physical and mental illnesses and imbalances can be accurately diagnosed using this technique. This indicative tool forewarns us of possible health risks. It is consigned that the knowledge of pulse science was coined a few years back in various medical treatments of the world, like in Greek medicine, Chinese medicine, Turkish, Arab remedies, Homeopathy, Allopathic etc. and it expanded as a necessary tool for an accurate diagnosis. From the past eras, Nadi has been acknowledged as the essential signal of one's life, and the pathology as well as the physiology of the body is being recognized by the Vaidya through proper Nadi Pariksha. Even in today’s chaotic routine, under emergency clinical situations, modern physicians seek help by the Pariksha of Nadi, as it is believed to show the present working efficacy of heart, and the rate of pulse, its rhythm, volume of flow and character of the pulse which indicates clearly the condition of the patient in various aspects. These pulses can be analyzed through Nadi Pariksha. It is done by placing the index, middle, and ring fingers at the wrist of the subjects over the radial artery as shown in fig. 3. It discloses the characteristics of doshic imbalance, the nature of diseases and expected prognosis. The vibratory frequency of human pulse at different pressure levels at the radial artery is identified using Nadi Pariksha.

Parameters to be considered while taking pulses are the frequency, amplitude and quality of the pulse. Usually for the female left-hand pulse and for the male right-hand pulse is considered for accurate results [1-3]. Some restrictions and conditions are followed while examining the pulse reading. The pulse waves of people who had just bath, just taken food, who are having thirst and hunger, just undergone oil massage or fat intake (snehana), and who is asleep cannot be recognized by specialists properly. While analyzing the pulse reading, some additional physical conditions along with general conditions are noted. The response of the patient hunger, behaviors of the patient facial expression, the response toward the climatic situations, strength, nature of sleep, breathing pattern history of diseases is also needed to be confirmed. The experts can come to the conclusion of the diseases based on these factors [4].

2 CHARACTERISTICS OF PULSE AND PULSE FORMATION

2.1 Characteristics of Pulse

The characteristic of Nadi of a healthy person mainly means identification of the normal features of the pulse of that person. These variations can be identified only by experience on a large number of possibly healthy persons, thereby appreciating the path precise variations in the pulse. The face of a healthy person looks cheerful, and the pulse movement is similar to the movement of a swan or an elephant [5]. Table 1 below gives a summary of the three basic and vital pulses: Vata, Pitta and Kapha, which can be used to analyze a variety of diseases and its symptoms in a human being.

2.1.1 Vata

The characteristics of vata pulse are Fast, Irregular, Narrow, Feeble, Cool. The pulse rate will be in the range of 80-100 beats per minute. The Vata pulse is obtained by the proper placement of the index finger. When the vata pulse predominates, there will be a strong throb feeling under the index finger and the pulse movement will be felt like that of a snake, quick and slippery [5].

2.1.2 Pitta

The characteristics of pitta pulse include jumping, warm, charged, prominent, moderate and standard. Rate of the pulse is 70-80 beats per minute. The pulse of Pitta is obtained by placing the middle finger. When the pitta pulse predominates, there will be a strong feel under the index finger and the pulse movement will be felt like that of a frog, quick and jumpy similar to that.
2.1.3 Kapha
A slow, strong, stable, soft, wide, regular and hot pulse character is obtained in kapha pulse. The rate of pulse is 60-70 beats per minute. The pulse of Kapha is acquired under the ring finger. When the kapha pulse is predominating, a stronger effect is felt under the ring finger. This pulse movement is slow and reminds us of the floating of a swan [5].

2.1.4 Sannipata Pulse
A very fast pulse rate is felt below all the three fingers when all the three Doshas are dominant for a person. The three pulses seem to have a movement like that of quail (Lava) for vata, Francolin partridge (Titaara) for pitta and Batera for kapha pulse [5].

2.1.5 Dual Dosha Pulse
When the pulses of two Doshas are combined, it contains the characteristics of both the Doshas involved. For instance, we can feel the pulse of Vata Pitta below both the index and middle fingers which may be of full volume, but its other characteristics like rate, rhythm, and volume may vary in a short span of time that too may be within quarters of minutes. Similarly, when both Pitta and Kapha pulses are dominant, below both the middle finger and ring finger can get a feel of the same and so on [5].

2.2 Pulse Formation
The mechanism of pulse formation can be related to a tube attached with the piston and tied into an artery. As the blood is incompressible when the piston is pushed forward towards the right into the tube, the vessel distends locally. There is a local increase of pressure due to the immediate incompressible column of blood produced. This has little effect on the advancing piston which is a mass of incompressible blood. The wave of pressure travels along the vessel wall due to the stretching of next artery section and does not involve actual blood transmission. This distension wave is transmitted along the arteries and is felt pulse. In short, pulse is actually a wave formed in the vessel walls by the systole of the ventricle. The pulse does not depend on the passage of blood along the arteries. The elasticity property of arterial walls helps in the generation and transmission of pressure wave of the pulse. The pressure wave travels in meters per second, to be more precise 7 meters per second the movement of the red blood cells or plasma is much slower at 10 to 20 centimeter per second. The factors that affect the speed of the blood include blood pressure gradient, viscosity and area of cross section of the blood vessel. The rate of flow of blood is inversely proportional to the total cross section of the vascular bed. The factors that affect the pulse pressure are stroke volume and compliance. When the stroke volume increases, there is an increase in the amount of blood which is to be accommodated in the arterial tree during each heartbeat. This leads to rise in pressure during systole and pressure fall during diastole. There is a slight decrease in the compliance as the arterial pressure rises from low to high values. A person with high arterial pressure but normal stroke volume output has increased pulse pressure. The pulse formed due to the above mentioned mechanism is detected at three different and precise positions on the wrist at the radial artery using three fingers: index finger, middle finger and ring finger, corresponding to vata, pitta and kapha respectively (Nadi Pariksha). Due to the anatomical variation in these positions on the wrist at the radial artery, the pulse obtained will show three different characteristics, especially in terms of movement, frequency, rate and rhythm. Hence, from a person one can analyze three different pulses leading to a personalized and individual prediction which is detailed and accurate. The root cause of a disease can be detected using this Ayurvedic method. This proposed Ayurvedic pulse diagnosis method can be correlated with Allopathic approach. In the Allopathic approach, these three signals from the wrist at the radial artery are analyzed and averaged as a single pulse signal as the allopathic treatment is concentrated on the symptoms of the disease and not on the root cause of the disease. All the parameters mentioned below for pulse diagnosis are taken care in allopathic approach but in terms of modern parameter. These parameters are averaged and interpreted as a single signal giving more preference to its rate and rhythm rather than focusing on movement of the pulse. In Ayurvedic approach, movement of the pulse is given more importance compared to all other parameters mentioned below.

3 TRADITIONAL PARAMETERS OF PULSE
From ancient days, Nadi Pariksha is considered as an Ayurvedic tool of diagnosis. Nadi Pariksha is the science of life which observes the pulse from a perception of diagnosis of the human body, sub-conscious and the mind [6]. Usually, Nadi Pariksha is done by identifying the pulse at three positions over the radial artery and estimating doshas by feeling the pulse. The nature or properties of the Nadi are important in evaluating doshas. Most of the standard textbooks have highlighted the unique quality of the pulse, the importance of gati, which plays a main part in disease analysis [7]. The determinate qualities of Nadi which is strictly related with the pulse movement parameters of modern pulses like wave velocity, rate variability of pulse and stiffness of artery are gati (movement), vega (speed), shiratva (stability) and kathinya (hardness of the artery) of pulse respectively. According to Ashtanga Hridayam, for disease diagnosis and specifically for considering doshas there are twenty qualities or gunas which plays a vital part. They are gurubhArika (heavy), manthara (slow), haima (cold), medura (unctuous), medura (smooth), ghana (solid), mudula (soft), sushira (stable), atsUKSmA (subtle), visada (non-slimy) and their counterparts aguru (light), javana

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Vata Pulse</th>
<th>Pitta Pulse</th>
<th>Kapha Pulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics</td>
<td>Fast, cold, light, tachycardia, thin, which can disappear on pressure</td>
<td>Premature, hot, strong, high amplitude, dynamic and lifts up the palpating fingers</td>
<td>Deep, wide, slow, thin, cool or hot, regular</td>
</tr>
<tr>
<td>Position on Radial Artery</td>
<td>Index Finger</td>
<td>Middle Finger</td>
<td>Ring Finger</td>
</tr>
<tr>
<td>Movement</td>
<td>Coxa movement</td>
<td>Frog movement</td>
<td>Swimming, Swift movement</td>
</tr>
</tbody>
</table>
(quick, fast), upatapta (hot), vasu (dry), durga (roughness) sara (liquid), kaThora (hard), lola (moving), mahan (big), lindu (slimy) [7]. Gati plays an important role in evaluating the predominant dosha and expert traditional ayurvedic doctors do the assessment of gati from Nadi.

3.1 Gati (Movement of Pulse)

The word gati means movement. Gati is a very distinctive way of diagnosis in Ayurveda used for assessing the dosha predominance where the pulse movements are compared with the movement of animals, reptiles and birds [7]. The varieties and complexities in three basic pulses in pulse reading can be determined by the variations in these pulses or gatis [1]. In addition to the three basic doshic gatis, there are other pulses which help to identify specific diseases as shown in table 2. Based on the Ayurvedic concept, the movement of vata pulse known as sarpa gati, will be curved like the movement of a snake (sarpa) and leech (jaluka). The significance of vata pulse is curved and zigzag nature of the movement. The pitta pulse movement called manduka gati, is hopping and jumping in nature hence was compared with the frog movement. When the movement is slow named as manda gati (also called as hamsha gati) is the importance of kapha pulse and is compared with the swan movement. The importance of gati of the pulse comes into significance when there is a presence of more than one dosha, for instance the nature of gati will be of sarpa and manduka if both vata and pitta doshas are in magnification, similarly it will be of sarpa and hamsha in nature if there is an aggravation of both vata and kapha doshas and it will be of manduka and hamsha in nature if there is an aggravation of both pitta and kapha doshas [7].

3.2 Vega (Rate)

Vega means the rate of the pulse, in other words, the number of beats per minute. Vega can be varied due to exercise, anxiety, excitement or any anatomical, intellectual and medicinal conditions of the person. The rate of the pulse is widely used in medical practice which gives a primary assessment about the condition of the health. It also warns about the need for further examinations for disease diagnosis [1-7]. To get an accurate reading certain precautions are taken. Usually, the pulse reading is noted in early morning in restful condition. Vega is normally high in vata in the range of 80 to 95 beats per minute, moderate in pitta in the range of 70 to 80 beats per minute and low in kapha, in the range 50 to 60 beats per minute. This law is applicable when dosha is governing vega. The rate of the pulse is measured by feeling the pulse for one minute and counting the number of pulsations.

Vega depends on the physical, emotional and pharmaceutical states of the person, for example, the pulse rate is high in certain pathological conditions. Tall people have slower heart rates and shorter people have faster heart rates [1-7]. The rate is inversely proportional to height. Table 3 shows the predominant pulse based on different age categories. When the pulse rate is slow, metabolism will be slow and for faster pulse rate, the metabolism will be fast. Agni governs metabolism. The quality of Agni can be determined from the general examination of pulse that is when agni is strong, there will be fast, light and hot pulse but when agni is slow, the pulse will be slow, heavy and cool.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>VARIOUS MOVEMENTS IN PULSE AND CORRESPONDING CONDITIONS INDICATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gati</td>
<td>Indications</td>
</tr>
<tr>
<td>Sarpa</td>
<td>Regular vata pulse</td>
</tr>
<tr>
<td>Manduka</td>
<td>Standard pitta pulse</td>
</tr>
<tr>
<td>Hamsha</td>
<td>Normal kapha pulse</td>
</tr>
<tr>
<td>Raksha</td>
<td>Joint Inflammation, Gouty Arthritis</td>
</tr>
<tr>
<td>Katijatu</td>
<td>Endoparasites, Ectoparasites, Worms</td>
</tr>
<tr>
<td>Upadikā</td>
<td>End-Stage Disease</td>
</tr>
<tr>
<td>Mayūra</td>
<td>Pulmonary hypertension, Hypercholesterolemia</td>
</tr>
<tr>
<td>Tittī</td>
<td>Stomach ulcer, ententitis</td>
</tr>
<tr>
<td>Vartalāh</td>
<td>Prostate</td>
</tr>
<tr>
<td>Kakā</td>
<td>Aortic insufficiency (AI)</td>
</tr>
<tr>
<td>Pārīvāta</td>
<td>Bronchial asthma</td>
</tr>
<tr>
<td>GhāṭīkAyāstra</td>
<td>Diabetes, Proteinuria</td>
</tr>
<tr>
<td>Uṣṭrāh</td>
<td>Aortic Valve Stenosis, Rheumatic Valve</td>
</tr>
<tr>
<td>Gajāh</td>
<td>Heart Condition</td>
</tr>
<tr>
<td>Vahya</td>
<td>Lymphedema, Lymphatic Filariasis, Lymphosarcoma</td>
</tr>
<tr>
<td>Parvata</td>
<td>Bradycardia, Bundle</td>
</tr>
<tr>
<td>Vyābhicāra</td>
<td>Atrial Fibrillation</td>
</tr>
<tr>
<td>Uḍīgana</td>
<td>Fatal Illness, Kidney</td>
</tr>
<tr>
<td>Sarasūja</td>
<td>Ideal Health, enlightenment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3</th>
<th>MILESTONES OF AGE INFLUENCING THE PULSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infancy and childhood (up to 16 years of age)</td>
<td>Kapha is predominant in the pulse</td>
</tr>
<tr>
<td>Adult (age 17-50)</td>
<td>Pitta is predominant in the pulse</td>
</tr>
<tr>
<td>Adult (age 51-70)</td>
<td>Pitta is predominant in the pulse with gradually increasing vata</td>
</tr>
<tr>
<td>After age 70</td>
<td>Vata is predominant in the pulse</td>
</tr>
</tbody>
</table>
3.3 Tala (Rhythm)
Tala also known as rhythm is defined as the time interval between two consecutive or successive uplifts [1-7]. For balance, healthy and normal tala, the time interval is regular, uninterrupted and rhythmic. When there is an out of balance in vata it will create irregularity in pulse. Vata and pitta can be blocked by Kapha and vata can be blocked by pitta but only vata can push pitta and kapha. Pitta blocking Vata leads to an irregularly irregular tala, a crazy pulse that involves both vata and pitta as both are mobile. Also the pulse becomes fast, feeble and irregular when Vata is blocking Vata. Table 4 shows the comparison of different dosha with tala.

<table>
<thead>
<tr>
<th>Dosha</th>
<th>Tala</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vata</td>
<td>Irregular</td>
</tr>
<tr>
<td>Pitta</td>
<td>Regular</td>
</tr>
<tr>
<td>Kapha</td>
<td>Regular</td>
</tr>
</tbody>
</table>

3.4 Bala (Force)
Bala is the force or pressure of the pulse which can be experienced when three fingers are pressed against the artery. As per Newton’s third law of motion, every action has an equal and opposite reaction; therefore the amount of force pressing on the blood vessel will be exerted back onto the fingers. The force is the difference between the systolic and diastolic pressure, which produces a ratio called pulse pressure (PP). When there is a high pulse pressure, the heart will be working under great stress. In short, bala corresponds to the pulse pressure. Table 5 shows the relation between dosha and bala.

<table>
<thead>
<tr>
<th>Dosha</th>
<th>Bala</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vata</td>
<td>Low</td>
</tr>
<tr>
<td>Pitta</td>
<td>High</td>
</tr>
<tr>
<td>Kapha</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

From individual to individual, the amount of pressure varies depending on the prakruti and volume of blood in the radial artery. When deeper pressure is used to stop the artery the force will be higher.

3.5 Akruti (Volume and Tension)
Akruti indicates volume and tension. Volume is experienced as the uplift to the palpating finger and an estimate of left ventricular output per beat (stroke volume) is given by the duration. Tension is the pressure between two uplifts, diastolic pressure [1-7]. It is not mandatory to depress the radial artery but one can experience the uplift while placing the finger lightly on the artery. The volume of the pulse corresponds to the systolic blood pressure. The systolic blood pressure becomes higher when volume is high and vice versa. Table 6 below shows the relationship between dosha and volume of pulse. By pressing the ring finger to stop the pulsation of the radial artery, tension can be felt and also the tension can be felt under the middle and index fingers as the blood behaves like a rubber tube full of water.

<table>
<thead>
<tr>
<th>Dosha</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vata</td>
<td>Low</td>
</tr>
<tr>
<td>Pitta</td>
<td>High</td>
</tr>
<tr>
<td>Kapha</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

3.6 Tapamana (Temperature) and Kathinya (Consistency of the vessel walls)
Tapamana means Temperature. There is a relationship between gati of the pulse, the wave of the pulse, the temperature of the pulse, agni and metabolic fire of the individual as shown in table 7. The consistency of the vessel wall, analyzed by rolling the artery between the palpating finger and the radial bone, is called kathinya.

<table>
<thead>
<tr>
<th>Dosha</th>
<th>Tapamana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vata</td>
<td>Cold</td>
</tr>
<tr>
<td>Pitta</td>
<td>Hot</td>
</tr>
<tr>
<td>Kapha</td>
<td>Warm to cool</td>
</tr>
</tbody>
</table>

But before this analysis, the radial artery should be emptied by pressure on the brachial artery in the bicipital groove against the humerus. This way of palpation helps to find whether the vessel is thick or thin, elastic or plastic, rigid, hard or rough [1-7]. Table 8 shows the relation between dosha and Kathinya.
4 COMPARISON OF TRADITIONAL PARAMETERS WITH MODERN PARAMETERS

Based on Ayurvedic conventional texts, pulse qualities or properties such as Gati (pulse movement), Vega (Rate or speed of the pulse), Bala (force), Akriti (Volume and Tension), Tapamana (Temperature) and Kathinya (Consistency of the vessel walls) plays an important part in Nadi Pariksha and these properties were investigated above in this review. Among these properties mainly Gati, Vega, Tala and Kathinya of pulse can be matched with the parameters of the modern pulse specifically pulse movement, wave velocity of pulse, variation of pulse rate and stiffness of artery.

4.1 Pulse Movement

For thousands of years, the traditional practice followed by Ayurveda in the assessment of gati of the pulse is very subjective in manner. In the view of research based on evidence, the scientific way of assessing the gati nature is of importance with a perfect considerate of its biological significance. The physiological importance of gati from rate, volume and character of the pulse is discussed by Upadhyaya in his medical and investigational studies on Nadi Pariksha which states that the gati resembles sarpa gati whose character is curvilinear when the pulse rate is fast and small volume, it signifies vata pulse whereas when the rate is slow and volume is high with jumping character, similar to Chapala gati it resembles pitta pulse. Kapha pulse is obtained when there is slow rate with volume in between vata and pitta [8].

4.2 Pulse Wave Velocity

The measurement of the swiftness of the pressure waves that travel along the segments of the artery is called Pulse Wave Velocity (PWV). The distance or the traveling time of the pulse wave between two assessing positions of the pulse is termed as the PWV [9]. Compared to the peripheral network, blood flows faster in aorta with a speed variation from m/s in aorta to mm/s in peripheral network. Pulse wave velocity (PWV) is the velocity of the pulse wave and it ranges from 5 to 15 m/s. Cardiovascular risks are indicated with the help of the Pulse wave velocity (PWV) in the recent past [10]. Based on the longitudinal studies, the aortic PWV is observed as a perfect interpreter of impending cardiovascular events and all-cause mortality.

As per the studies, in modern medicine pulse wave velocity has significant results and the role of wave velocity of the pulse in Tridosha analysis in the context of Ayurveda has to be explored. Based on traditional texts, there is no direct relationship between the pulse wave velocity and vega but can be closely associated to it. By the pulse wave velocity measurement, the variations in doshas can be considered. Table 9 gives the summary about PWV based on Tridosha.

4.3 Pulse Rate Variability

The palpation of pulse gives the pulse rhythm which is by nature more qualitative. The time pulse series enables the pulse rhythm which is to be analyzed quantitatively by acquiring through instruments. The study on pulse rate variability (PRV), which is considered as a surrogate pointer of heart rate variability (HRV) is of great interest in the recent past [11-13]. PRV cannot be compared with any equivalent terms in traditional texts but there is a close association between intermittent Nadi and PRV. This is because intermittent Nadi and its nature can be clearly explained on the basis of some important parameters such as analysis of pulse rate variability and its missing peaks, beat to beat variation in the interval of pulse etc. Based on the pulse wave obtained from Nadi Tarangini, there are significant variations based on different age groups and disorders depending on the beat to beat alterations [14]. Significant differences across age and disorders in the pulse intervals of artery (API) are obtained in the analysis based on the time domain, frequency domain and nonlinear measurements [15]. There is a major role in Nadi Pariksha for the pulse stability or rhythm but detailed description is lacking in the textbooks about its relationship with Tridoshas.

4.4 Arterial Stiffness

The arterial stiffness examined from velocity of pulse wave (PWV) is of great importance in the field of research as it is considered as a cardio-vascular events predictor [16]. Due to age and atherosclerosis, the arteries stiffen. In cardiovascular risk assessment, the role of arterial pulse wave analysis is discussed in detail by Alberto et al. [28]. The longitudinal study done by Boutouyrie provided the first direct evidence on the fact that the aortic stiffness is a self-determining interpreter of primary coronary even in hypertensive patients [29]. An independent study done by Laurent claims that the stiffness of aorta is believed to be in an independent analyst of all-cause and cardiovascular death in hypertensive patients. The pulse wave velocity is
considered as an arterial stiffness surrogate measurement, closely corresponding to the depiction of mrityu nadi. The measurement of stiffness of the aorta is termed as stiffness index (SI). This is measured from the radial artery and is closely corresponding to the volume of the pulse measured using photoplethysmograph (PPG). There is pulse amplification at peripheral artery when the pressure wave is propagating from central to peripheral arteries, due to multiple reflections from various reflection sites and these reflection sites are closer to peripheral arteries while comparing with central arteries. The peripheral arteries do not give precise results in cardiovascular studies due to the above reason so the arterial stiffness measured from peripheral arteries cannot be used as a surrogate for aortic and carotid stiffness [27-29]. As there is a major role for radial artery in Ayurveda, where SI measured from radial artery is reflected as major parameter in Tridosha analysis.

5 SPHYGMOLOGY SENSORS

There are varieties of sensors used for pulse diagnosis. Sensors ranging from normal piezoelectric sensor (Lead Zirconate Titanate) to heart beat sensor (SEN-11574) can be used for this purpose. Proper positioning of sensors on the radial artery along with a perfect signal conditioning unit will give three perfect waveforms: Vata, Pitta and Kapha. A variety of systems have been designed for pulse diagnosis in Ayurvedic as well as Allopathic field. This section covers the existing sensors used for pulse diagnosis.

5.1 Soft Wearable Ionic Polymer Sensors

Based on sensing applications, a new bio-compatible flexible structure sensor made of IPMC (Ionic-Polymer-Metal-Composites) is introduced as shown in fig. 4. With a soft-wearable IPMC-sensing unit they were able to explore the bio-potential measurement domains thereby recording the natural auscultations in wrist artery. The IPMC strip used is made of Nafion. A configured digital stethoscope was used to measure the simultaneous pulse tracks. The natural auscultation due to the pulsating blood flow is recorded with the sensor-strip placed over the wrist artery. These will be demonstrated as periodic impacts on the polymer strips. The electrical potential produced due to the trusted mechanical stimuli is accepted through a pulse rate extraction scheme yielding the number of beats produced per minute [31]. A sub-tensioned surface is posed by the polymer which can be pressed against the posterior aspect of the wrist. The IPMC output voltage is passed through a signal conditioning and beat detection unit. This experiment suggests a novel material for pulse bit sensing and pulse rate monitoring.

5.2 Stretchable Graphene-Coated Fiber Pulse Sensor

The human health status is analyzed by using a newly designed and fabricated facile, scalable and portable radial artery pulse sensor. Here the sensing component is a stretchable graphene-coated fiber which has properties like good linearity and sensitivity towards the tensile strain. Due to the smart structure of sensor it can exactly detect the periodic pulse waves and its changes while doing exercise and disease. These signals are precise and repeatedly available. This single waveform has all the medical analysis characteristics for evaluating the cardiovascular risk factors in patients specifically artery stiffness and disease prevention [32]. The basic material used for fabrication of the graphene-coated fiber is a type of double covered yarn, highly elastic polyurethane (PU) fiber core which is wrapped by two helically-wound polyester (PE) fibers. This has characteristics like good linearity, sensitivity, stability, reproducibility together with the fast response and recovery suitable for a smart radial artery pulse sensor. Here the sensing element is PDCY-RGO as shown in fig. 5 [32].

Fig. 4 The IPMC-pulse extraction setup installed on an individual [31]

5.3 Compound Pressure Sensor Array

In disease diagnosis, it is important to collect the pulse wave from different points on the radial artery under different static pressure. This type of pulse acquisition is not possible by single type sensor and the feasibility of setting three sampling points for detecting the variation in radial artery pulse wave is also less. Thus for this purpose a novel flexible compound pressure sensor array is used. This combination includes both piezoelectric and piezoresistive sensor for measuring the pulse wave and static pressure individually. The inverted waveform occurrence and signal intensity are guaranteed by the bending structure of the sensor. The poroelastic materials help in flexible connection and reduction of interference in sensors as shown in fig. 6 [33]. The physical characteristics of sensor are important for collecting valid data from pulse wave and are satisfied by the dynamic pressure sensor and static

Fig. 5 PDCY-RGO pulse sensor [32]
pressure sensors. The structure includes a bending dynamic sensor, PVDF piezoelectric sensor (produces deformation due an external force) and a contactor. The static pressure sensor detects the bending pressure and the pressure reflected at the wrist. An innovative bendable compound pressure array was designed for achieving in-depth information about the radial artery pulse wave under various static pressures. The full attention of all the points on a patient according to TCM theory depends on the arrangement and size of the proposed sensors [33].

5.4 Pressure Sensors: Piezoelectric and Piezoresistive

Radial artery pulse signals are pressure signals so pressure sensors are used to convert the mechanical pressure to electrical signal by placing the sensors over the radial artery at the wrist. This helps in digitization of pulse signals for Nadi Pariksha. The pressure sensor for this purpose includes both piezoelectric and piezoresistive. The sensor is the main element of a pulse acquisition system which also includes an analog signal conditioner and digitizer units. Electrical signals from the sensor are passed through the analog signal conditioning unit followed by amplifier and filter circuits. Finally the signal is sent to the digital circuit for ADC conversion. The signal is stored and further processed in the PC [34]. The piezoelectric effect in measuring the variations in pressure, force or strain, acceleration is done using the piezoelectric sensor Murata’s 7BB-15-6LO, which produces an electrical signal when a dynamic force is applied (active transducer). Piezoelectric sensors are used to measure the pulse signals as they are in dynamic nature as shown in fig. 7 [34]. A pressure is formed on the silicon substrate is measured through the diaphragm using a piezoresistive pressure sensor MPX5010G6U. When pressure is applied the sensor bends as a result of which deformation occurs in the diaphragm crystal lattice. The resistivity of the material changes due to deformation. The piezoelectric sensor is inferior to piezoresistive pressure sensor in terms of accuracy, positioning MPX5010G6U and sensitivity [34]. Nadi is obtained in the form of time series as shown in fig. 8. The fingertip exerts pressure at the artery which is sensed as nadi pulses. Three pressure transducers on the wrist will sense the very minute pulsations in pressure units. In differential mode, the experienced pressure is converted to electrical signal which is then digitized using the 16-bit multifunction data acquisition card NI USB-6210 [35]. Nadi is obtained in the form of time series as shown in fig. 8. The fingertip exerts pressure at the artery which is sensed as nadi pulses. Three pressure transducers on the wrist will sense the very minute pulsations in pressure units. In differential mode, the experienced pressure is converted to electrical signal which is then digitized using the 16-bit multifunction data acquisition card NI USB-6210 [35]. Three Millivolt Output Medium Pressure Sensors (strain gauge transducer) of size 1cm×1cm having a tiny flexible diaphragm at the center with 0–4 inch H2O pressure is attached on the wrist to sense three location pulses, namely vata, pitta and kapha as shown in fig. 9. The strain is converted to electrical signal with the help of a Wheatstone bridge circuit with three constant resistors and a variable resistor [35]. As shown in figure 10, piezoresistive MPXM2053D sensor from FREESCALE is used to sense the wrist pulse. Signal conditioning unit using instrumentation amplifier is connected to the sensor followed by a real-time monitoring using myRIO DAQ card in LabVIEW myRIO 2014. Frequency domain analysis is done to extract the band energy. The advantage over piezoelectric sensor is that it
does not require shielding. This sensor provides both
dynamic and static responses. This sensor gives
satisfactory results for wrist pulse [36]. Human pulse is
detected using a piezoelectric sensor and the signals are
processed using signal processing circuit which includes
signal amplifier, filters and noise reduction circuit. The
shape of pulse, rate of repetition and amplitude were found
to be different for different doshas [37]. The transducer on
operating will reject the static pulse pressure and detect the
dynamic pulse pressure at the wrist. Pulse acquisition is
done with help of an IC with PIC16F877A chip level
programming and MPLAB IDE software. Heart rate is
displayed using LCD. Signal processing is done with
MATLAB while the SNR signals are exhibited with the mean
factor for vata, pitta and kapha. Increment in pulse and the
normal pulse for each is detected with the help of mean
factor as shown in fig. 11 [37]. Piezoelectric sensor
specifically Grove-Piezo vibration sensor shown in fig. 12 is
considered due to its specialties such as flexibility, vibration,
impact and touch sensitivity, dimension, thickness and so
on. The computational models and biostatic approaches
help in analysis of waveform. These signals will help in
disease analysis. The disease diagnosis is done based on
certain specific factors like viscosity of blood, volume of
blood etc. This sensor proved itself by giving better results
compared to existing ones [38].

5.5 Optical Sensors
Very minute details were captured using Optical sensor
HOA 709 in its reflective mode and thereby acquiring pulse
signals at the pitta point at radial artery. The sensor
recorded the data before and after food and also the
important changes in signal contour. The pulse contour
obtained at wrist using optical sensor is similar to the signal
obtained from the radial artery catheter. Figure 13 shows
the experiment setup. Feature extraction is done on the
information obtained from the pitta location. Several clinical
parameters are also taken care with this experiment [39].

![Fig. 9 Line diagram of pulse diagnosing system Sensor [35]](image)

![Fig. 10 Soldered SMD MPXM2053D sensor [36]](image)

![Fig. 11 Mean factor of pulse [37]](image)

![Fig. 12 Nadi Pariksha System with Grove-Piezo vibration sensor [38]](image)
The blood flow rate is monitored using a photoplethysmographic (PPG) sensor. This sensor is placed at identifiable points on radial artery corresponding to Vata, Pitta and Kapha respectively and its output is analyzed with the help of LabVIEW software. This method is a non-invasive method for detecting pulse with a light source and detector. The change in blood volume is indicated by the PPG signal. These changes are noted mainly at the peripheral parts of the body such as fingertips, earlobe etc. The rate of blood flow is identified using the light intensity variation which is passing through the skin or reflected from it [40]. The PPG signal detection has two modes: transmission mode and reflection mode. The finger is located between LED and photodiode during transmission mode whereas in reflection mode both LED and photodiode are positioned on one side of the fingertip as shown in fig. 14. There is a variation for vata, pitta and kapha in accordance with PPG signal mean values [40].

The three phases Sparshana, Darshana and Prashna phases are used for Ayurvedic disease diagnosis. Three optical sensors at the three locations on the radial artery are used for implementing the first phase of Sparshana. These sensors are interfaced with the Arduino Uno microcontroller via USB connection which requires a 5V supply for operation. The captured analog output of sensor is converted to digital values using ADC in Arduino. Figure 15 shows the experimental setup [41]. A Velcro strap is used to attach three pulse sensors and also minimizes the external interference. This is wrapped around the wrist of the subject to get the pulse readings. A non-invasive system of Nadi Pariksha is designed to assist the medical practitioners in the diagnosing various ailments. The pulse palpation by three fingers at the wrist helps in finding the affected organ. Timely observation and identification of abnormal situation will help in saving a patient’s life. The Sparshana phase is included by incorporating optical sensors and then to identify the Prakruti of the patient Artificial Neural Network algorithm is applied on the output waveform. Finally a decision tree algorithm is applied that resembles the other two phases Darshana and Prashna [41].

5.6 Image Sensors
A CCD based device is used to detect the pulse image for diagnosis according to Traditional Chinese Medicine. Here the three pulses are Cun-Guan-Chi. Synchronous pulse image data of distinctive pulse condition is collected using MM-3 pulse model. The characteristic pulses comprise of the standard pulse, the slippery pulse, the gentle pulse and the spineless pulse. The pulse waves were removed by using the area method based on lens imaging principle. The restricting of 3D pulse condition image is done. Important features were extracted including the
5.7 PVDF based Pulse Sensor
The three pulses from the radial artery are obtained by designing and analyzing a PVDF material based pulse sensor. The sensitivity of the material is also analyzed. Frequency and amplitude analysis is done to determine the shape of the pulse. The design is shown fig. 17 [43]. The factors that determine the length and breadth of the PVDF required for the sensor are as follows:

- The radial artery diameter and its sheath above which varies from 2mm-4mm without sheath and with sheath it varies from 3mm-5mm.
- The length of sensor should be more than or twice the diameter with sheath. Therefore the length is (5x2) mm that is 10mm.
- The length should not be more than the distance between the two tendons: Abductor pollicis longus and Extensoris pollicis longus. This can vary from individual to individual from 10 mm to 20 mm; therefore the length was restricted to 14mm. The breadth of the PVDF depends on the placement of sensor at three points on the wrist.
- The three pulses are obtained at a distance of 7mm center to center thus the breadth is restricted to 5mm. Plexiglas is used for making the handle for holding the PVDF material [43].

The sensors are placed on the wrist at the locations identified by Siddha experts. The system necessary for getting the radial artery pulses is tested initially with signals from the function generator which resembled in shape with any other pulse system such as PPG. PVDF (polyvinylidene fluoride) is a piezoelectric polymer which is highly non-reactive. It is a pure thermoplastic fluoropolymer. The hidden physiological signals are found by experts using palpation techniques hence pulse reading becomes a haptics technique [44].

5.8 USB- based Doppler ultrasonic blood analyzer
The wrist pulse signals are collected by using a USB-based Doppler ultrasonic blood analyzer. The collected signals are transmitted using a USB interface and for further processing and analysis it's stored in PC. The signals are collected in three steps. Initially a rough location is found in the wrist by feeling the pulse fluctuation using three fingertips. As there is only single probe for the Doppler ultrasound device, the pulse fluctuation is detected at one position. Pulse fluctuation at the second position is more compared to others, hence this position is chosen. The second pulse is Guan according to TCM (Pitta in Ayurveda) as shown in fig. 18. The next step is to obtain the most significant signal by varying the probe positions, slightly changing the angle of against the skin. Finally, this wrist pulse is recorded and saved as Doppler spectrograms. To reduce the measurement errors, the above steps are repeated several times.
In computerized pulse diagnosis, the information from the wrist pulse signals is extracted. This is done by a modified Gaussian model where useful features are extracted from each single period wave at the wrist. Finally cross-correlation analysis and the statistical difference calculation are done to select the features [45].

5 CONCLUSION
Nadi Pariksha is one of the scientific techniques followed by Ayurveda, the science of life to examine the patient. It has its own importance and highness because of its multi-dimensional role in examining the patient and diagnosing the disease in various aspects. The characteristics of Nadi will give the identification of the normal features of the pulse of that person thereby analyzing the patients' health condition. The classical texts in Ayurveda explain the Nadi nature and its differences in a very qualitative manner using the traditional parameters like Gati, Vega, Sthiras, Bala, Akrut, Tapamana and Kathinya. These conventional parameters have a strong relationship with modern parameters like movement of pulse, arterial stiffness, wave velocity and variation in rate of pulse. In the context of Ayurveda, these modern parameters are studied to bring out the concealed secrets of Nadi Pariksha to attention. There are various sensors used for pulse diagnosis whose accuracy and durability varies based on the design. The focus should be made on pulse measurement techniques and development of instrument for Nadi Pariksha which will be cheaper and handy thereby taking a scientific method towards pulse diagnosis which is the demand of the day.

6 ACKNOWLEDGMENT
The authors wish to give thanks to VIT University, Vellore. This work was supported by VIT SEED Grant.

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Fig. 18 Pulse signal collection using ultrasonic blood analyzer [45]


[94] Dupuis and Eugene, IEEE Transaction on


