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DEVELOPING A DIAGNOSTIC TOOL FOR TYPE 2 DIABETES BASED ON TRIDOSHA ANALYSIS THROUGH NADI PARIKSHA.

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ABSTRACT

In *Ayurveda*, *Nadi Pariksha* (pulse based diagnosis) is considered as the foremost examination method in *ashtavidha rogi pariksha* for assessing the healthy state, diagnosis and prognosis of the disease. **Aim:** The aim was to differentiate the pulse waveforms in Non Diabetes (ND), Pre-diabetes (PD) and Type 2 Diabetes mellitus (T2DM) individuals using modern data analysis technique and by comparing the *dosha* predominance in them according to *Ayurvedic* concept of *nadi pariksha*. **Methods and Material:** The database for this study was generated in India from three cities of 376 individuals categorized into ND, PD, and T2DM group, with age ranging between 30-70 years screened using American Diabetes Association (ADA) diabetes risk test. Along with medical information their pulse waveforms were recorded using Nadi Tarangini device and subsequently analyzed. **Results:** On first observation of data, 309 individuals of 376 showed *vata* predominance, which is accordance with the ayurvedic literature. Fourier coefficients, wavelet coefficients and auto-regressive modeling coefficients were computed. The 10-fold cross validation accuracy of the random forest classifier was 86.84%. High precision of 95.24% in T2DM was achieved, indicating that the classification process returned substantially more relevant results than irrelevant. **Conclusion:** The *vata* predominance and good classification numbers indicate the possibility of detection of diabetes using modern data acquisition and analysis methods. Nadi Tarangini can be effectively used as a computer-aided diagnostic tool in T2DM and also to evaluate the effect of *Yoga, Ayurveda* and any other intervention, though further studies are warranted.

Key Words: *Nadi pariksha, Diabetes, Tridosha, Nadi Tarangini*.

INTRODUCTION

Diabetes is known since the evolution of civilization. The ancient Indian physicians had a sound knowledge of Diabetes. *Sushrutha* (500 BC) an ancient Indian Surgeon had described it as '*Madhumeha*' (excretion of sweet urine) [1]. *Charaka* and *Sushrutha* described the clinical features and complications of Type 2 Diabetes Mellitus (T2DM) vividly, emphasizing the importance of diet and exercise in the management of diabetes. They categorized diabetes into 2 groups as obese and lean and prescribed strenuous exercises for the obese diabetics [2].

T2DM mellitus is a group of metabolic diseases characterized by hyperglycemia resulting from defects in insulin secretion, insulin action, or both. It is the most prevalent form of the disease and is often asymptomatic in its early stages and can remain undiagnosed for many years [3]. The prevalence of diabetes for all age-groups worldwide was estimated to be 2.8% in 2000 and 4.4% in 2030. The total number of people with diabetes is projected to rise from 171 million in 2000 to 366 million in 2030. The urban population in developing countries is projected to double between 2000 and 2030. The world prevalence of diabetes among adults (aged 20–79 years) will be 6.4%, affecting 285 million adults, in 2010, and will increase to 7.7% and 439 million adults by 2030. Between 2010 and 2030, there will be a 69% increase in numbers of adults with diabetes in developing countries and a 20% increase in developed countries [4]. Chronic diseases such as heart disease, stroke and diabetes are leading causes of death in the US [5]. It affects more than 21 million Americans [6], and the death rate from diabetes has increased 45% since 1987 [7]. From 1980 to 2005, prevalence of diabetes among the US population rose from 5.8 million to 14.7 million [8]. Approximately 9.6% of Americans aged 20 years or older (a total of 20.6 million people) have diabetes [9].

India has the largest diabetic population in the world. Changes in eating habits, increasing weight and decreased physical activity are major factors leading to increased incidence of type 2 diabetes [10]. With India having the highest number of diabetic patients in the world, the sugar disease is posing an enormous health problem in the country. Calling India the diabetes capital of the world, the International Journal of Diabetes in Developing Countries says that there is alarming rise in prevalence of diabetes, which has gone beyond epidemic form to a pandemic one. The International Diabetes Federation estimates that the number of diabetic patients in India more than doubled from 19 million in 1995 to 40.9 million in 2007. It is projected to increase to 69.9 million by 2025. Currently, up to 11 per cent of India's urban population and 3 per cent of rural population above the age of 15 has diabetes. Diabetes affects all people in the society, not just those who live with it. The World Health Organization estimates that mortality from diabetes and heart disease cost India about $210 billion every year and is expected to increase to $335 billion in the next ten years. These estimates are based on lost productivity, resulting primarily from premature death [11].

Therefore after looking at the fast growing rate of mortality and morbidity caused by diabetes across the globe, this paper is motivated in a need for developing diagnostic tools for the early detection of diabetes.

METHODS

We studied the *dosha* predominance in non diabetes, pre diabetes and type 2 diabetes mellitus subjects, and further variations in the pulse waveforms for detection of diabetes using data analysis techniques.

The data was collected using Nadi Tarangini (NT) [12], developed in India by council for scientific and industrial research (CSIR) [13]. As shown in Figure 1, NT is a portable and non-invasive pulse acquisition system using pressure sensors. The pulse waveforms collected using NT are shown to contain the important subwaves of a pulse waveform, namely percussion wave (P), tidal wave (T), valley (V) and dicrotic wave (D) as shown in Figure 2. The correctness of the nadi tarangini hardware was checked through the cross sectional study as shown in Figure 3, and it was observed to be satisfactory.

1.1 FORMAT OF THE COLLECTED DATA

The complete database contains information and pulse signals of 376 patients suffering from Diabetes , Pre Diabetes and Non Diabetes along with associated co morbidities such as Retinopathy, Neuropathy, Hypothyroidism, Menopause, Chronic Gastritis, Hypertension and Cardiac conditions(such as IHD[Ischemic Heart Disease] /CAD[Coronary Artery Disease]) etc to name a few. There are also post operative patient such as S/P CABG [Coronary Artery Bypass Graft] S/P PTCA [Percutaneous Trans Luminal CORONARY Angioplasty], S/P Hysterectomy, S/P Prostectomy etc. In addition, patient's information of age, gender, profession, etc. was also recorded in the database. While collecting the data, following points were strictly obeyed.

- **ETHICS: Written Informed consent** was obtained from all subjects
- **Sampling time:** 6am to 1pm and 2pm to 4pm
- **Inclusion Criteria**
  - Gender: both male and female.
  - Age: 30-70 years
  - Informed consent
  - ADA (American Diabetes Association) qualified and non qualified individuals
- **Exclusion Criteria**
  - Those with poor concentration and hyperactive.
  - Individuals on sleep medication
  - Those who are not willing to undergo the study.
  - Those with co morbid conditions, chronic debilitating disorders, on regular medications

The pulses were obtained by placing these sensor at the predetermined positions on wrist for 1 minute. Immediately after that, the Nadi was sensed using fingertips for verification. All the three patterns of the pulse wave component (VPK) as described in the ayurvedic scriptures were got on the LED screen. We provide three examples here.

1.1.1 Example no 1: T2DM OR DM

Figure 4 shows the pulse wave form, captured from right wrist of a 66 years old male with weight 59.2 kg and height 165 cm (5 '.5") and blood pressure measuring 150/80 mm of Hg. He was a known case of Type 2 Diabetes Mellitus (since10years), Hypertension (7 Yrs), Dislipedemia (abnormal increased cholesterol) (since 3-4 Months) and was on regular treatment. The vata and kapha dosha wave forms resemble in their shape, size, pattern, amplitude, frequency, rhythm. Vata wave form is showing extra movements compared to kapha wave form. Pitta waveform shows long sharp frequent waves which are having short breadth when compared to vata and kapha waveforms.

1.1.2 Example no 2: Non – DM (ADA Disqualified)

Figure 5 shows the pulse wave form, captured from Left wrist of a 51 years old Female with weight 51 kg and height 5 '.2" and blood pressure measuring 114/76 mm of Hg. She was a Non Diabetic and was known case of chronic gastritis and Low back Pain since 20 years and was on regular treatment.

The vata and pitta dosha wave forms are resembling in their shape, size, pattern, amplitude, frequency, rhythm to some extent .Kapha waveform shows long short irregular and haphazard waves which vary in their breadth when compared to vata and kapha waveforms

1.1.3 Example no 3: Pre – DM (ADA Qualified)

Figure 6 shows the pulse wave form, captured from Right wrist of a 61 years old Male with weight 61 kg and height 5 '9" and blood pressure measuring 100/78 mm of Hg. He was a Pre Diabetic (American Diabetes Association Qualified) and was known case of Hypertension since 20 years and was on regular treatment.

1.2 OBSERVATIONS

Collecting the complete database, these are the common properties that we observe.

- The vata wave forms were broad showing a regular shape , size , pattern, amplitude, frequency, rhythm and pitta dosha wave forms are sharp and shorter in breadth when compared to vata and they resemble in their shape , size , pattern, amplitude, frequency, rhythm to some extent . Kapha waveform shows short irregular and haphazard waves which vary in breadth when compared to vata and kapha waveforms.
- The pulse signals vary in rhythm, amplitude, frequency, slopes and so on. A pulse signal from healthy subject shows a typical waveform with regular rhythm, stable amplitude, and balanced shape. A disorder will cause alterations in the physiological processes and thus in the acquired pulse signals, leading to different patterns.

DATA ANALYSIS

As stated above, the pulse waveforms show variations in patterns. The goal is to develop a variety of pattern recognition methodologies, to extract useful features from the pulse signals, and to study variations with diabetes. The frequency spectrums in the pulse signals were studied through the Fourier transform [reference], the time-frequency spectrums are studied through the wavelet transform [reference] and the time-varying processes are studied through the auto-regressive modeling [reference]. All the parameters are finally provided as input to the random forest classifier for classification. The flow diagram of the analysis procedure is explained in Figure 7.

Out of the whole dataset, only data of 309 subjects which showed vata predominance was taken for the subsequent study of analysis for detection of diabetes. This ensures that the patterns of same dosha are compared to each other as opposed to cross sampled comparing.

1.3 DATA ANALYSIS METHODS

1. Basic features: For every pulse signal, firstly basic features are computed, namely mean, standard deviation, total amplitude, positive amplitude, negative amplitude, total energy, positive energy and negative energy. These features were computed as they resemble the "feel of fingertip" and constitute towards visible features of the pulse.
2. Fourier features: The Fourier features were computed to capture the frequency components in the pulse signals. Fourier transform is the mathematical transformation of time domain signals to frequency domain. It is a reversable process. Fourier transform and inverse

fourier transform are defined by the following equations:

$$F(K) = \int_{\infty}^{\infty} (\ )$$

In this paper, Fourier transform is computed using Fast Fourier Transform (FFT) algorithm, as FFT is proven to be more efficient for analysis of a finite series and it also requires less number of calculations. We used sampling frequency of 500Hz, and in the analysis first 300 Fourier coefficients are used.

3. Wavelet features: To capture the time-space properties of the pulse signals, we used wavelet features. The wavelet transform is similar to the Fourier with the main difference being Fourier transform decomposes the signal into sine and cosine i.e. the functions are localized in Fourier space whereas the wavelet transform uses functions that are localized in both the real and Fourier space. The wavelet transform can be expressed by the following equation:

$$W(a,b) = \int_{\infty}^{\infty} (\ )\ {}^{*}_{(\ ,\ )}(\ )$$

In this paper, the wavelet transform is computed using discrete wavelet transform using three mother wavelets, namely 'haar', 'db4' and 'coif4' up to levels 7. Total number of coefficients for every pulse signal is 1942.

4. Auto-regressive features: The autoregressive model is commonly used to observe how the output variable depends linearly on its own previous values. In this study, AR coefficients are used to extract certain time-varying processes in the pulse signals. The AR(p) model is defined as:

$$X_t = c + \sum_{i=1}^{p} \varphi_i X_{t-i} + \varepsilon_t$$

The auto-regressive features were computed for two sets of levels of 4 and 10 and total number of coefficients for every pulse signal is 16.

Random forest classifier: Random forests are an ensemble learning method for classification (and regression) that operate by constructing a multitude of decision trees at training time and outputting the class that is the mode of the classes output by individual trees. The method combines Breiman's "bagging" idea and the random selection of features in order to construct a collection of decision trees with controlled variation. In this study, the random forest classifier is implemented in Weka [26] with parameters as 'unlimited' number of trees and depth of 10.

RESULTS AND DISCUSSION

As mentioned in section 3, our dataset contains total 309 Vata signals from various subjects. Based on diagnosis and classification of diabetes according to ADA, three groups are formed, namely 'non-diabetic' (ND), pre-diabetic (PD) and Type 2 Diabetes mellitus (T2DM). As shown in Figure 7, all the pulse signals are first provided as input to the feature extraction methods of Fourier transform, wavelet transform and auto-regressive modeling. The resulting features are used in the random forest classifier. In the classification process, following setup is used: Out of the whole dataset, approximately two third of the randomly chosen data was used as a training set and remaining one third of the data was used as a testing set. And the classification was performed for three sets ND, PD and DM. *The 10-fold cross validation accuracy of the classification process is 86.84%.* The classification results are summarized in Table 1. The precision and recall numbers are as given in Table 2.

Though the cross-validation accuracy is not very high, it is comparatively good considering this is the first work of its kind of detecting diabetes using Nadi Tarangini and data analysis system. The High precision number in DM means that the classification process returned substantially more relevant results than irrelevant, which is very important in the detection of the diabetes.

In future, the other classification numbers can be improved through two steps. More rigorous well-sampled data collection is needed and secondly, weighted classification process is to be applied to remove the biasness towards bigger class. There are no studies seem to done earlier in this aspect. This study will help to screen the diabetes, pre diabetes and non diabetes population and thus acts as a major non invasive, easy accessible tool to diagnose pre diabetes and diabetes population. There are further scopes for future studies which pave way for accurate diagnosis of various disorders.

CONCLUSIONS

This study was successfully implemented to validate Nadi Tarangini and differentiate the pulse waveforms in Non Diabetes (ND), Pre-diabetes (PD) and Type 2 Diabetes (DM) Mellitus individuals using modern data analysis technique and by comparing the dosha predominance in them according to Ayurvedic concept of nadi pariksha.

The vata predominance in the collected data and good classification numbers indicate the possibility of detection of diabetes using modern data acquisition and analysis methods. Each of the signals show variations in the parameters Amplitudes, Frequency, Rhythm, and therefore carry different patterns with different information. We studied and analyzed all the pulse signals collectively using different machine learning algorithms to provide a non-invasive, easy-to-use and quick in response diagnostic device Nadi Tarangini, which eliminated all the human errors in the Nadi-Nidan performed manually by Ayurvedic practitioner for diagnostics. Considering projected number of 366 million diabetic patients in 2030, such system with further studies can be effectively used as a computer-aided diagnostic tool in future.

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Figure 1. Nadi tarangini hardware comprising of three pressure sensors, transmitter cum digitizer, interface and computer

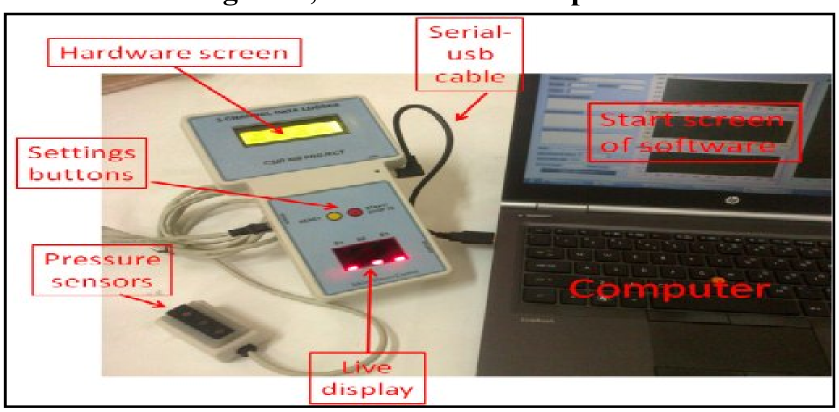

Figure 2. Typical PTVD pulse waveform

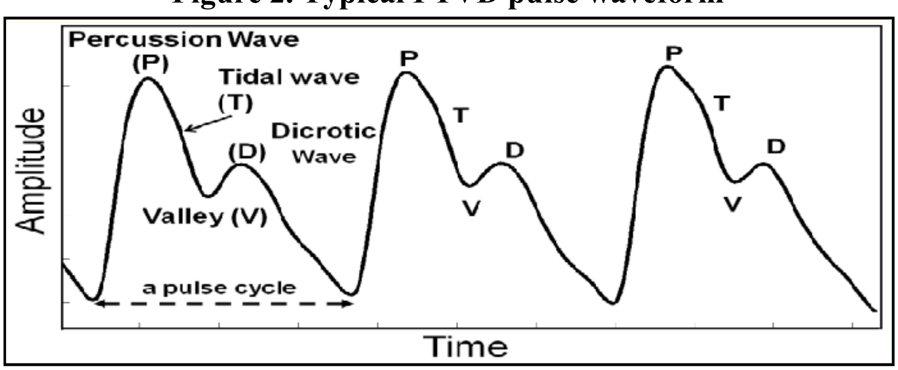

Figure 3. Cross sectional design study

1st day ADA Guidelines was filled by the subject/ by the therapist, taken for study

The correct recordings from the nadi tarangini instrument is taken from the right wrist (Radial pulse) in males and left wrist in females and saved in the form of graphs.

The data is denoised and mean is calculated from y axis (time in milli seconds of the amplitudes) and later the total mean of the data is collected in the end of the study. So the percentage and dosa predominance of vata wave, pitta wave and kapha wave are calculated and compared with the nadi pareeksha of ayurveda and predominant dosa calculated by nadi tarangini are matched or not in the end of the study

The pulse is calculated using the peaks (x Axis) in the signals and are compared with the manual nadi pareeksha of ayurveda and was tested wether they are matching or not.

Thus the instrument proved to its standards comparing the results with ayurvedic nadi pareeksha.

Figure 4. Example of pulse waveform of T2DM subject

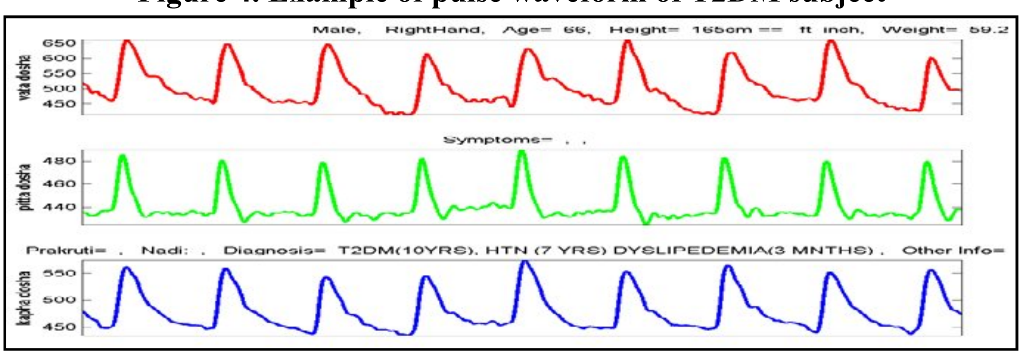

Figure 5. Example of pulse patterns in Non-DM (ADA Disqualified) subject

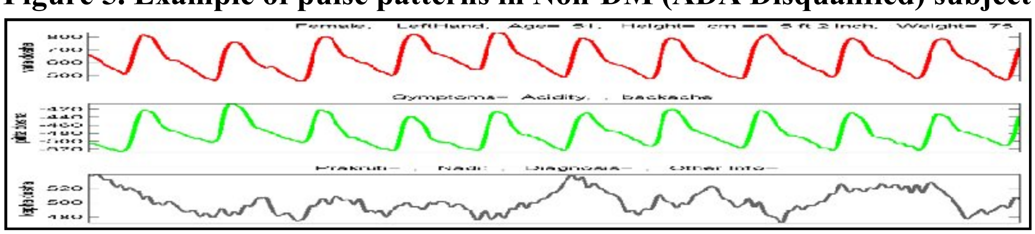

Figure 6. Example of pulse patterns in Pre – DM (ADA Qualified) subject

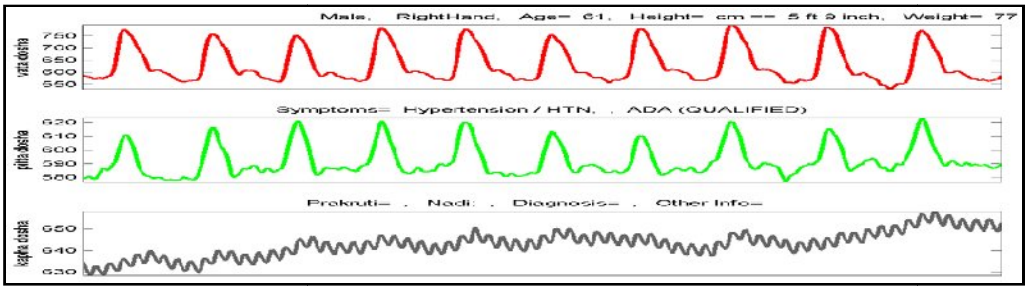

Figure 7. Flow diagram for detection of diabetes

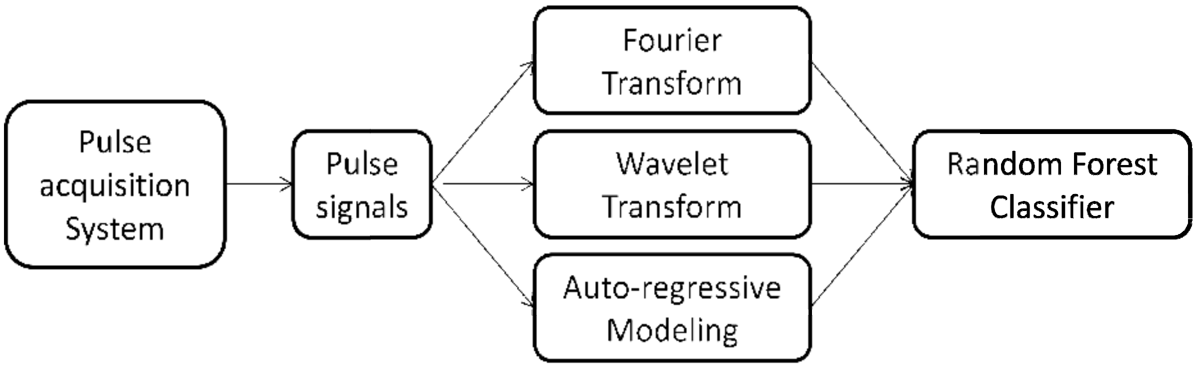

Table 1. Results of classification on the pulse database

		Output		
		Non-diabetic (ND)	Pre-diabetic (PD)	Diabetic (DM)
Input	Non-diabetic (ND)	20	2	10
	Pre-diabetic (PD)	0	6	4
	Diabetic (DM)	2	1	60

Table 2. Precision and recall numbers of the classification results

	Precision	Recall
Non-diabetic (ND)	62.5%	90.91%
Pre-diabetic (PD)	60%	66.67%
Diabetic (DM)	95.24%	81.08%

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