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Diagnostics Using Computational *Nadi* Patterns

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Abstract—We present a computational model for the mapping of *nadi*-patterns (pulse and bioelectrical signals, etc.) using quantitative estimation of the *tridosha*—the diagnostic feature vector of the natural constitution qualitatively defined in *Ayurveda* (the Vedic Science of Medicine). Validation results on the healthy and diseased cases show promising applications of this novel technique—derived from a rare, ancient knowledge—in diagnosis and prognosis with special reference to the otherwise nondetectable psychosomatic disorders. Directions for future research and application-development are highlighted. © 2005 Elsevier Ltd. All rights reserved.

Keywords—Ayurveda, Nadis, Computational modeling.

1. INTRODUCTION

Perception of the patterns of *nadis* is an important method of diagnostics in Ayurveda—the Vedic Medical Science. The word *nadi* refers to pulse, nerves, veins, arteries, and any kind of channel for the passage of physiological and biological signals. Different types of *nadis*, such as *vat nadi*, *pranda nadi*, *sushmna nadi*, etc., are defined according to their functions. The ancient experts (*vaidyas*) of Ayurveda used to have correct diagnosis of the type and state of all kinds of bodily and mental ailments just by the sensation of the *nadis* at specific points in the body without using any stethoscope sphygmograph, polygraph, or any other instrument or tests. Not only that, they were able to have perfect early diagnosis of a disease or disorder much before its manifestation and even predict the date and time of death in certain cases by this method. As reported in authentic references [1], some *vaidyas* of the modern times also possessed this rare expertise.

Be those the parameters like the commonly observed respiratory rate, pulse rate, rhythm, and pressure of blood flow, electrocardiogram (ECG), echocardiogram, etc., or the special experimentally investigated parameters like elasticity and rigidity of arteries, muscle tension, bioelectrical

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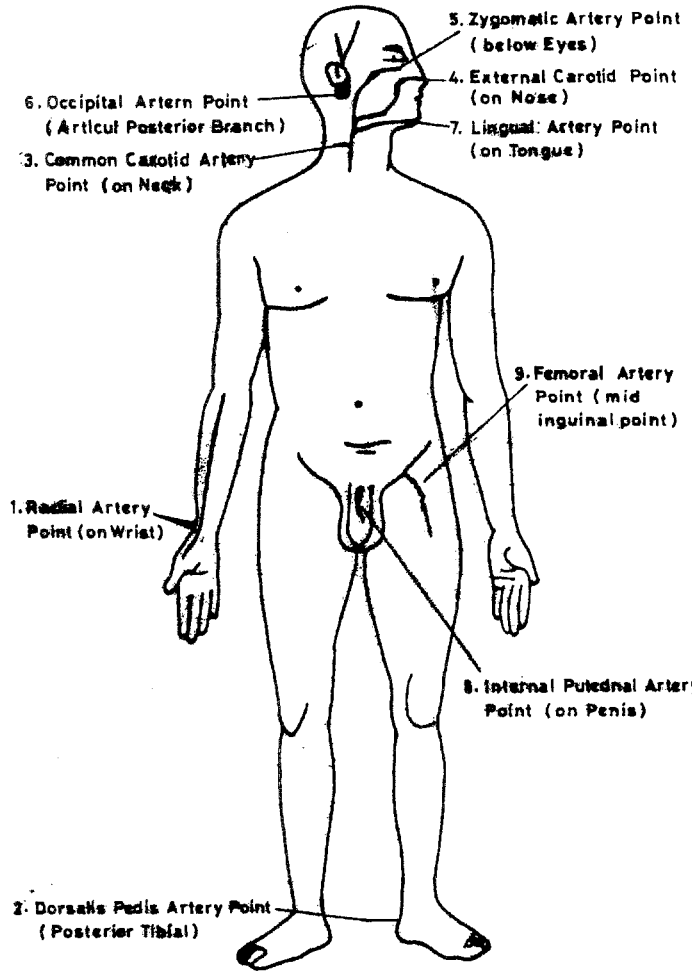


Figure 1. Points indicating the important positions of Nadis-sensation.

potentials, etc.—the information contained in and measured by all is supposed to be deciphered by the different patterns of *nadis*. The nine prominent points of the body at which the specific *nadis* are sensed by touch of the tips of one or more of the three central fingers are shown in Figure 1.

Hundreds of different patterns of *nadis* are described in the Ayurvedic literature, which are supposed to reflect the spectrum of the internal state of body and its biochemical and (electro) physiological functions. However, today, we may hardly find any expert who could sense or identify even few of them. Difficulties in designing sensitive instrumentation suited for this purpose further limit the study of this important science of diagnostics; hence the need for novel investigations.

In this paper, we present computational modeling of the *nadi* patterns using quantitative estimates [2] of the three vital components (*tridosha*) that represent one's natural constitution (*prakrati*). We present in Section 2, the relevant introduction to the *tridosha* and their relationship, as described in Ayurveda, with the *nadis*. The computational model is presented in Section 3 followed by results on some healthy and diseased cases in Section 4. Importance and scope of this work is also highlighted in the same section.

2. THE NATURAL CONSTITUTION FEATURES AND NADI-PATTERNS

Prakrati nidana—the basis of diagnosis and treatment under Ayurveda—describes one's natural constitution (*prakrati*) in terms of three basic functional elements or physical, mental, and

emotional energy patterns called the *tridosha*: namely, *vat*, *pitt*, and *kaf*. In terms of the physique and physiological activities of the body, the experts (e.g., [3,4]), describe *vat* as the energy of movement, *pitt* as the energy of digestion or metabolism, and *kaf* as the energy of lubrication and structure. Just as everyone has an individual face or fingerprint, according to Ayurveda, each person has a particular combination of *vat*, *pitt*, and *kaf*, which determines his or her normal constitution.

In ideal healthy case, an individual's *prakrati* (combination of the *tridosha*) should remain constant throughout his or her life. However, varieties of fluctuations at the emotional, mental, social, and environmental levels—e.g., passions, stress, irregular diet, food, weather changes, air-water pollution, etc.—tend to disturb it. Any imbalance in the natural level of any of the three *doshas* risks a health disorder or disease. The larger the deficiency or excess of one or more of the three *doshas*, the greater would be the chances and/or extent of the disease or disorder associated with that *dosha*.

Identification of the imbalance, if any, in the *tridosha* forms the basis of prognosis and diagnosis in Ayurveda. The modes of preventive care or treatment of diseases/disorders also deal with the control over the deficiencies or excess of the *doshas* and maintenance of their natural balance. However, the examinations and methods of characterization traditionally practised in this regard are qualitative or subjective in nature, thus hindering biostatistical analysis and scientific validation on par with modern medical sciences.

The patterns of *nadi* also depend on the level of *tridosha*. Interestingly, at some points, three distinct types of patterns are observed that correspond to the level and tendency of *vat*, *pitt*, and *kaf* respectively. For example, the most commonly observed *nadi* is the *jivanadi* (radial artery) for which the sensation of the three distinct patterns is said to be like that of—snake's

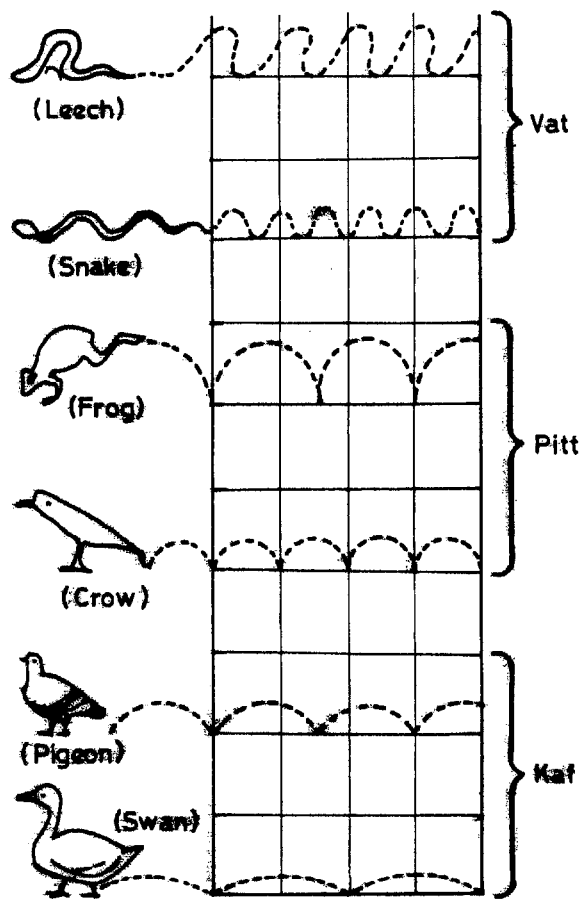


Figure 2. Typical pattern of Dosha-prominence.

curved scrawling for high level of *vat* which is experienced by the index finger placed at the knot below the wrist; frog's jumping for high *pitt* which is sensed by the middle finger at a point just adjacent to the fourth finger; a pigeon's or swan's smooth and slow movement for risen *kaf* which is experienced by the ring finger placed closed to the middle finger. The patterns based on these qualitative descriptions are like the ones shown in Figure 2.

The variation in the levels of *tridosha* causes changes in the frequency, rhythm, shape, regularity, thickness, etc., in the waveforms, and hence, in the overall patterns of the *nadis* at different points as per the effect of these variations upon the mind-body system of a person. It therefore appears to be important and useful to model the *nadi*-patterns as functions of the valid quantitative measures of the *tridosha* to help deeper analysis and provide new diagnostic applications. We present such a model in the following section.

3. COMPUTATIONAL MODELS OF NADI PATTERNS

We have recently obtained [2] a quantitative measure of the *tridosha* level (for *vat*, *pitt*, and *kaf*) by applying an algorithmic heuristic approach to the exhaustive list of qualitative features/factors that are commonly used by Ayurvedic doctors for identification of *prakrati*. The vector of these rather easily obtainable features or informative parameters is denoted by $\underline{X}$ here. A knowledge-based concept of worth coefficients and fuzzy multi-attribute decision functions [5] are used for regression modeling of the *tridosha* (or the *prakrati*-characterization) vector $\underline{Y}$ upon $\underline{X}$. This provides computationally simple formulae for estimation of $\underline{Y}$ for any given or observed $\underline{X}$. Statistical validation tests show accuracy of this unique measure with confidence level above 89%.

Using the above estimate of $\underline{Y} = (Y_v, Y_p, Y_k)$; where Y_v, Y_p, Y_k denote respectively the levels of *vat*, *pitt*, and *kaf*, we have conducted several simulation runs to generate different kinds of waveforms. The following model is found to be most comprehensive and sensitive to the individual and collective variations in the Y in generating waveforms similar to the patterns of *nadis*-perceived at the wrist-end of the radial artery.

THE MODEL. Here, suffix $i = 1, 2, 3$ correspond to the indicators for *vat*, *pitt*, and *kaf*, respectively. The parameters ϕ, γ, φ, θ denote positive thresholds. The *nadi*-pattern function is computed as shown below,

$$U_i^*(t,x) = \begin{cases} U_i(t), & \text{if } 0 < x \le g_i(Y_i); \\ & \text{where } g_i \text{ is a nondecreasing, bounded function,} \\ 0, & \text{o. w.,} \end{cases} \qquad \text{for } i = 1,2,3. \quad (1)$$

Hitherto 't' would represent the time and 'x' the thickness (of the *nadi*)

$$U_i(t) = a_i(t,Y)S_i(t,Y); \qquad \text{where } a_i(t,Y) = \begin{cases} +1, & (\text{if } S_i(t,Y) \ge 0, \\ -1, & \text{if } S_i(t,\underline{Y}) < 0, \end{cases} \quad (2)$$

where $S_i(t,\underline{Y})$ is given by equation (5) below for $i = 1$ and equation (6) for $i = 2, 3$.

Define,

$$\omega_i(Y_i) = \begin{cases} z_i Y_i, & \text{if } Y_i \le \phi_i, \\ h_i Y_i^2 & \text{if } \phi_i < Y_i \le \varphi_i, \\ \exp(q_i Y_i), & \text{if } Y_i > \varphi_i, \end{cases} \quad (3)$$

with the positive coefficients z_i, h_i, q_i selected so that

$$\omega_3(Y_3) < \omega_2(Y_2) \le \omega_1(Y_1).$$

Define (with positive coefficients α_i, m, n, r; $\alpha_3 < \alpha_2 < \alpha_1$)

$$f_i(\underline{Y}) = \frac{\alpha_i Y_i^m}{(1 + Y_j^n Y_k^r)}; \qquad \text{for } i = 1,2,3 \text{ and } j \ne i \ne k \varepsilon \{1,2,3\}. \quad (4)$$

Then, for $Y_1 \leq \gamma$

$$S_1(t, \underline{Y}) = \begin{cases} f_1(\underline{Y}) \operatorname{Sin}(\omega_1(Y_1)\, t), & \text{if } 0 < t \leq \dfrac{\pi}{2(\omega_1(Y_1))}, \\ f_1(\underline{Y})(1 - |\operatorname{Cos}(\omega_1(Y_1)\, t)|), & \text{o.w.;} \end{cases}$$

for $Y_1 > \gamma$

$$S_1(t, \underline{Y}) = \begin{cases} f_1(\underline{Y}) \operatorname{Sin}(\omega_1(Y_1)\, t - \theta), & \text{if } 0 < t \leq \left(\theta + \dfrac{\pi}{2\omega_1(Y_1)}\right), \\ f_1(\underline{Y})(1 - |\operatorname{Cos}(\omega_1(Y_1)\, t - \theta)|), & \text{o.w.;} \end{cases} \tag{5}$$

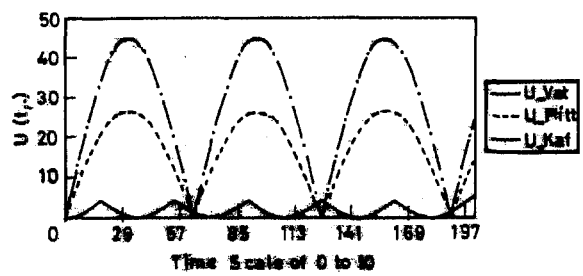
and,

$$S_i(t, \underline{Y}) = f_i(\underline{Y}) \operatorname{Sin}(\omega_i(Y_i)\, t), \qquad \text{for } i = 2, 3. \tag{6}$$

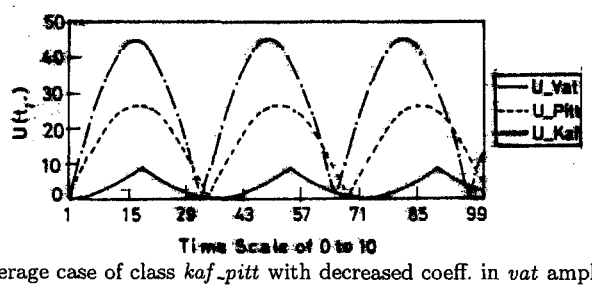
The computed mapping of *nadi* patterns for desired duration of time 't' and given set of values of parameters and $\underline{Y}$ can be interpreted for diagnosis/prognosis *vis-à-vis* the qualitative descriptions of the *nadis* for the healthy and large number of different diseases given in the Ayurvedic scriptures. The results of our computational experiments in this regard are presented below.

4. RESULTS AND DISCUSSION

Several computational experiments were conducted for computation of $U_i(t, .)$ with different sets of coefficients and threshold parameters and using $\underline{Y}$ as estimated for the real data[1] from normal and diseased cases. Some outputs are shown in Figures 3–12. The figures depict $U_i(t, x)$ at an arbitrarily point x. The thickness is not shown for clarity of the graphs. Here, the coefficients and threshold parameters were selected at random (subject to the satisfying the inequality constraints, if any, in the model) in the ranges shown below: z_i in $[1, 3.5]$; h_i in $[1.5, 3.2]$; q_i in $[0.01, 0.05]$; α_i in $[3, 7]$; m in $[1.5, 3]$ and n, r in the range $[0.5, 0.9]$; the thresholds ϕ in $[9.5, 18.5]$; φ in $[12, 28]$; γ in $[12.5, 22.5]$ and θ in $[0.2, 1.2]$.



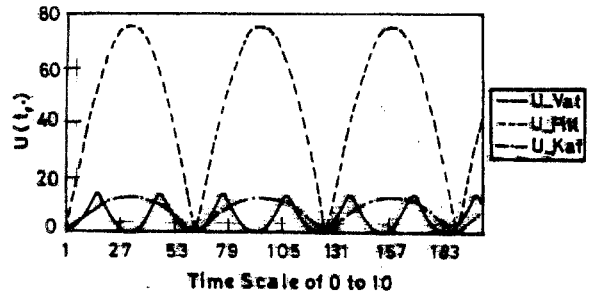
(a). Average case of class *kaf_pitt*.



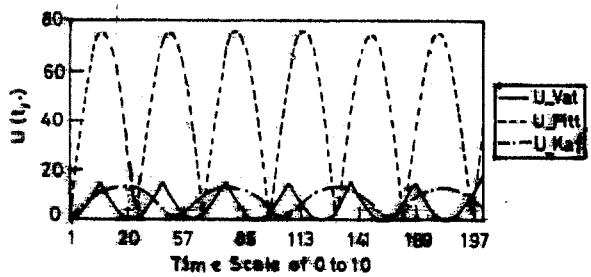
(b). Average case of class *kaf_pitt* with decreased coeff. in *vat* amplitude.

Figure 3.

[1]These were obtained from observations on $\underline{X}$ on the residents and trainees at Shantikunj, Hardwar. The data on normal cases were selected randomly from the samples used in [2]; there was a separate sample of diseased cases from the same population that was collected in consultation with the doctors in the Hospital at Shantikunj, Hardwar.



(a). Average case of class *pitt_kaf*.



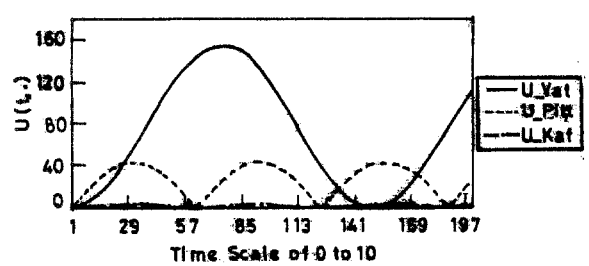
(b). Average case of class *pitt_kaf* with increased coeff. in amplitudes.

Figure 4.

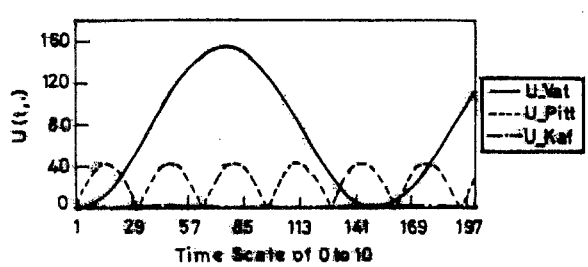
4.1. Computational Results and Diagnostic Observations

The *nadi*-patterns of average healthy cases (i.e., for which $\underline{Y}$ was equal to or closed to the average $\underline{Y}$ estimated in [2] for the respective class) in the different *prakrati*-classes are shown in Figures 3–7.

The general patterns as well as the frequency, shape of the peaks, etc., of the *vat*, *pitt*, and *kaf nadis* resemble that described qualitatively in the Ayurvedic science of *nadi*. The peaks of the *vat nadi* ($U_1(t,.)$) are sharper than the other two. It is having a pattern like the scrawling of a snake. The peaks are sharp but the cusps are very small in the *prakrati* classes where *kaf* or *pitt* are predominant (Figures 3 and 4). Its presence is most significant in the classes where it is

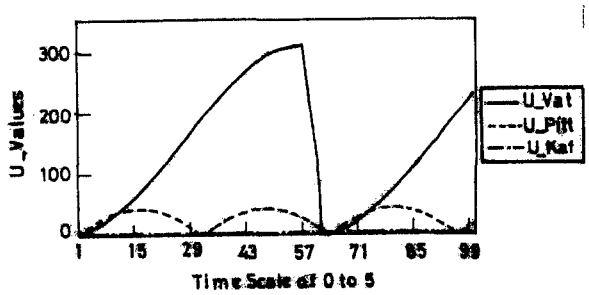


(a). Average case of class *vat_pitt* with high threshold.

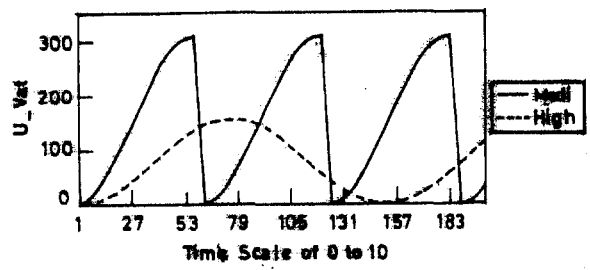


(b). Average case of class *vat_pitt* with high threshold and increased coeff. *pitt* amplitudes.

Figure 5.

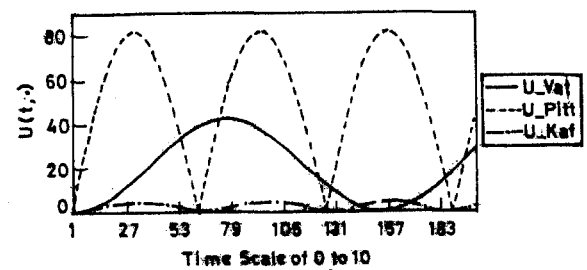


(c). Average case of *vat_pitt* class with threshold for *vat*.

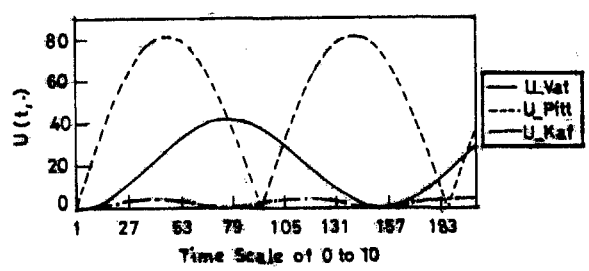


(d). Comparison of threshold effect on *vat nadi* in *vat_pitt* class.

Figure 5. (cont.)



(a). Average case of class *pitt_vat* with high *pitt* threshold.

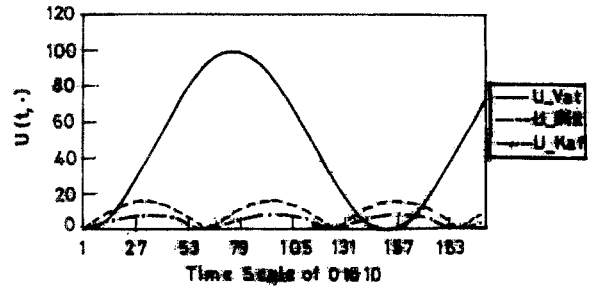


(b). Average case of class *pitt_vat* with high *pitt* threshold. Decreased coeff. in *pitt* amplitude.

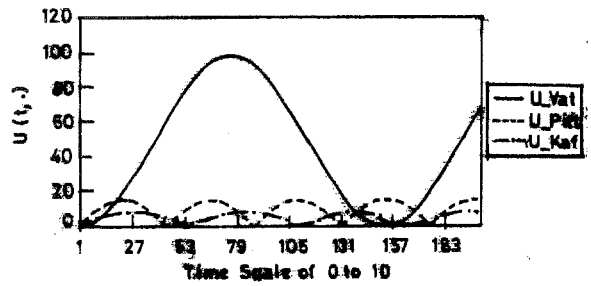
Figure 6.

the leading factor in the natural constitution (Figures 5–7). Its shape changes remarkably and resembles that of the tilted traces of the motion of a leech, in the cases (Figures 5d and 7d)) where its level, Y_1, is higher than the threshold for one's *prakrati* (natural constitution). For example, in case of a person whose general tendency may be "*vat-pitt*" but whose body is sensitive to increase in the *vat*-level or in case of a person whose natural constitution is not having *vat*-predominance, but in whom, the level of this *dosha* increases rapidly due to special meal or whether, etc., the changes in the *vat nadi* will be very sharply noticeable [1,6].

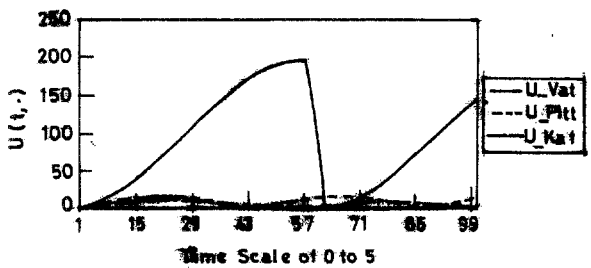
Occurrence of this pattern of type of leech-motion helps early diagnosis of *vat* related ailments in such people. The *nadis* of *pitt* and *kaf* become negligible or very slow in such cases in the *vat-kaf* class.



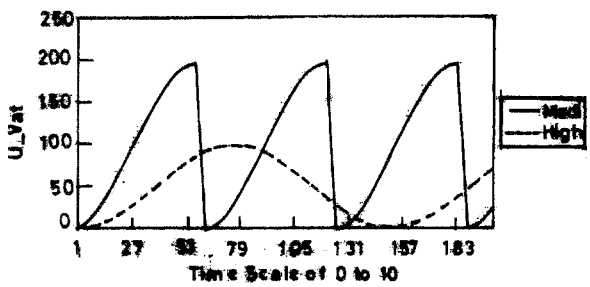
(a). Average case of class *vat_kaf*.



(b). Average case of class *vat_kaf* increased coeff. in *kaf* applitude.



(c). Average case of class *vat_kaf* with medium *vat* threshold.

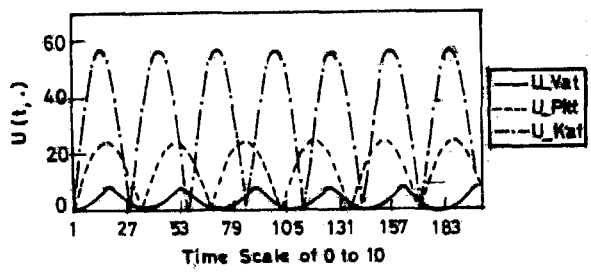


(d). Comparison of threshold effect on *vat nadi* in *vat_kaf* class.

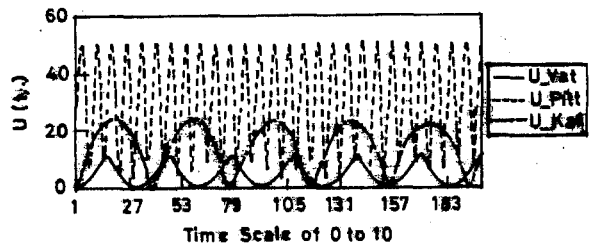
Figure 7.

The peaks of *kaf nadi* are prominent in the classes where this *dosha* is dominating and the other two are below the healthy thresholds (Figure 3). Its frequency is rather less or comparable with that of *pitt* and its has a shape of the smooth and steady movements of a pigeon or a swan in the classes where its level is secondary to *pitt* in characterizing the natural constitution (Figure 4). Its presence is hardly experienced in the classes where *pitt* or *vat* are predominant (Figures 5 and 6). Its pattern like the slow and graceful motion of a swan is most distinct in the classes where *pitt* is low and its role in the characterization of *prakrati* is secondary to that of *vat* (Figure 7).

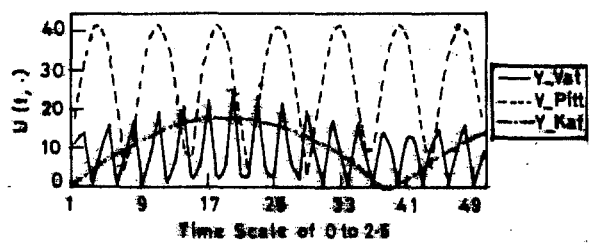
The steepness and frequency of the *pitt nadi* increases with its dominance in the natural constitution (Figures 3–6). That is why its presence is often perceived quite clearly at all the relevant points in the body. Its shape also changes from one class to the other but generally



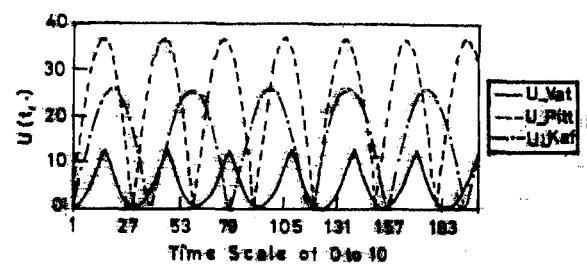
(a). *kaf* related problem in class *kaf_pitt*.



(b). *pitt* related acute problem in class *kaf_pitt*.



(c). *vat* and *pitt* related problem in class *kaf_pitt*.

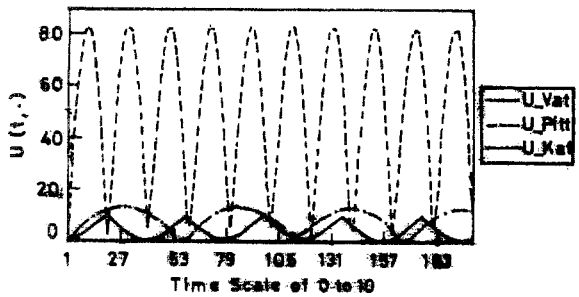


(d). *pitt* related some problem in class *kaf_pitt*.

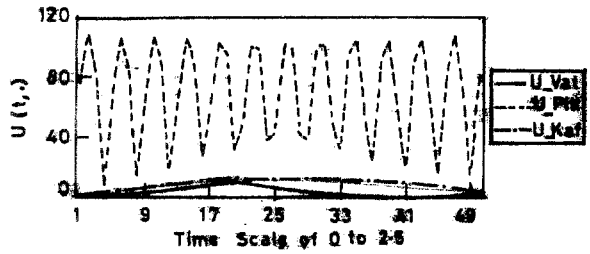
Figure 8.

resembles the successive jumps of a frog on a plan surface in the cases where either of *pitt* or *kaf* is primary or secondary in the *prakrati* (Figures 3 and 4). Its shape like the trajectory of the movements of a crow or a sparrow is mostly seen in the *vat-pitt* or the *pitt-vat* classes (Figures 5 and 6). It may be noted that the qualitative resemblance of the patterns of the three *nadis* with the different birds or reptiles cited here becomes clearer with the increase of the level of the corresponding *dosha*.

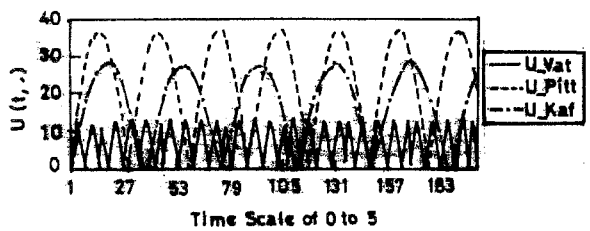
The results of computational mapping the *nadi*-patterns for the data on $\underline{Y}$ for some of the diseased cases are shown in Figures 8–12. The *prakrati* classes in each case were predicted by using the technique presented in our recent paper [2]. In each case, the computed pattern remarkably matches with what is described for the particular disease/disorder or group of diseases that is implied by the Ayurvedic diagnostics of diseases and disorders [1,4,7]. As described below, the prediction was mostly matched with what was diagnosed for the concerned patient by the medical doctors. In some cases, early diagnosis or detection of psychological problems was also made by our method; this was not possible by the clinical and lab-test based modern techniques.



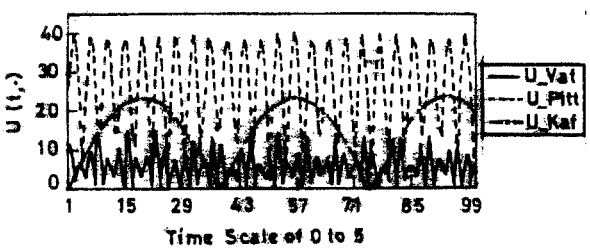
(a). *pitt* related problem in class *pitt_kaf*.



(b). *pitt* related acute problem in class *pitt_kaf*.



(c). *kaf* and minor *pitt* and *vat* related problem in class *pitt_kaf*.



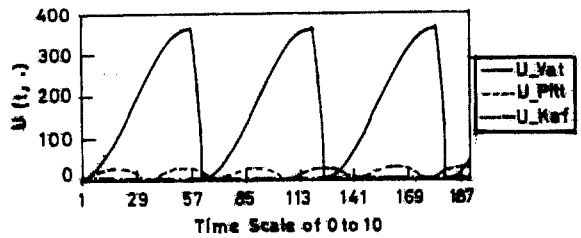
(d). *pitt*, *kaf*, and *vat* related rare problem in class *pitt_kaf*.

Figure 9.

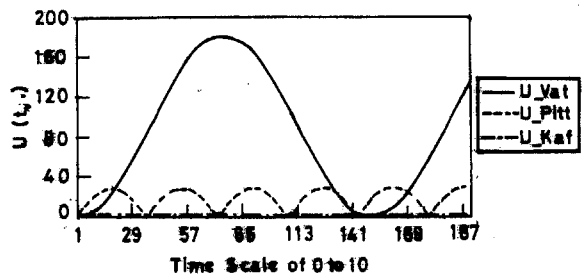
In the *kaf-pitt* class, the sharp peaks, high frequency, and slightly skewed pattern of the *kaf nadi* and normal pattern of the other two *nadis* (Figure 8a) indicates a *kaf*-related ailment. The thickness (not shown in the 2-D graph here) of this *nadi*-pattern was normal. As, the thickness would have been more and the frequency much low in case of *kaf*-related pulmonary or heart problems, this case is predicted here to be a case of common cold with body-ache and slight fever. This prediction was correct.

The rare, extremely fast, sharp peaked and little irregular pattern of the *pitt nadi* (in Figure 8b) with normal patterns of the *vat* and *kaf* in class *kaf-pitt* indicate a liver ailment with possible blood infection. The patient had complains of liver/stomach and waist pain.

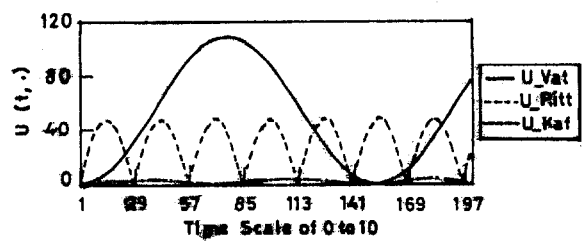
The high and relatively sharper and skewed *pitt nadi* and irregular (almost broken like) sharp peeked *vat nadi* pattern (Figure 8c) in *kaf-pitt* class accounts for great possibility of High BP and diabetes. Also a thick (thickness is not depicted in the figure) and very slow *kaf nadi* for this class shows the patient may have some heart problem as well. These predictions (diagnosis) were also found correct.



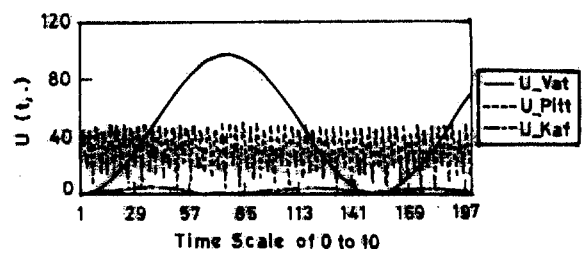
(a). *vat* related acute problem in class *vat_pitt*.



(b). *vat* related problem in class *vat_pitt*.



(c). *pitt* and *vat* related minor problem in class *vat_pitt*.



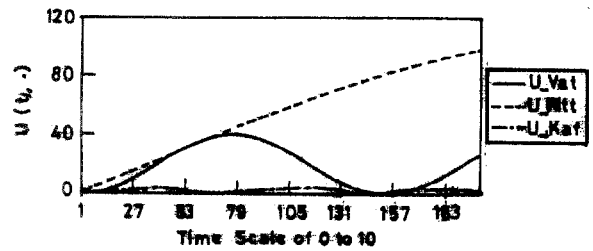
(d). *pitt* related acute problem in class *vat_pitt*.

Figure 10.

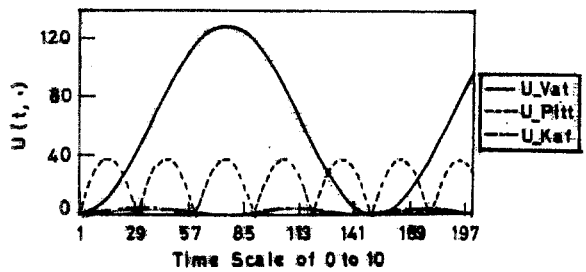
For yet another case in the *kaf-pitt* class, the normal *vat pattern*, little high but within average range of *kaf nadi*, and a high peeked, relatively fast but regular *pitt nadi* (Figure 8d) indicate the possibility of dysentery with some fever. The patient was having fever and had had some loose motions that particular day when $\underline{X}$ was observed.

The normal *vat* and *kaf nadis* for the class *pitt-kaf* and a high frequency, high peeked slightly irregular, and thin *pitt nadi* (Figure 9a) predicts *pitt-jwara* (high fever due to some infection in the blood). The patient did have a high fever but the cause was not confirmed.

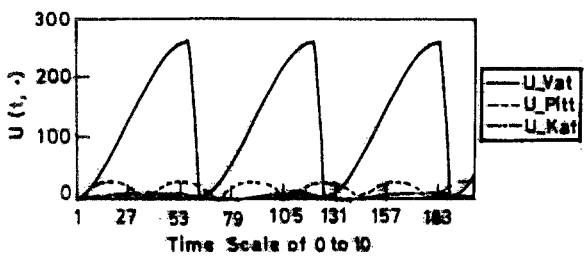
The almost broken (piecewise continuous), irregular, and rapid *pitt nadi* pattern (Figure 9b) a very slow *vat nadi* indicate typical psychosomatic disorder of Aggression with likelihood of hypertension; this coupled with a very slow, thicker (thickness not shown), and low *kaf nadi* for class *pitt-kaf* imply a possibility of some sexual abnormality or sex related psychological complication. The patient did not have any physical ailment but had mentioned about tension, fear, and anger due to some sexual complications in the secret column (to be seen only by the Ayurvedic doctor) of the questionnaire given by the doctor for the data on $\underline{X}$.



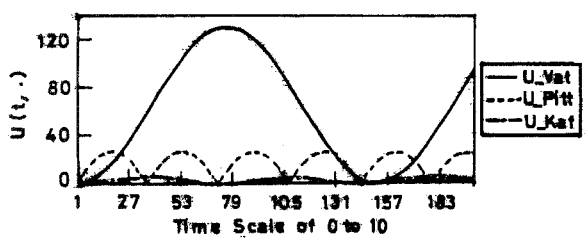
(a). *pitt* related major problem in class *pitt_vat*.



(b). *pitt* related minor problem in class *pitt_vat* with *vat* significance.



(c). *vat* related prominent problem in class *pitt_vat*.



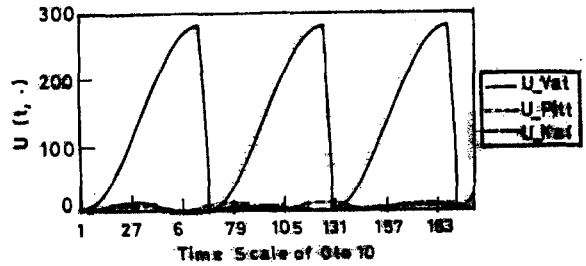
(d). *vat* related some problem in class *pitt_vat*.

Figure 11.

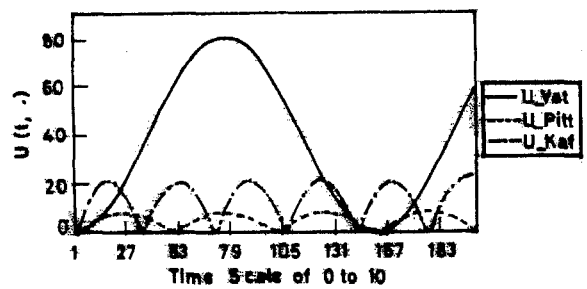
Rapid *vat nadi*, thick (thickness not seen in the 2-D graph), and higher than normal pattern of *kaf* with relatively high peaks of *pitt nadi* (Figure 9c) in the *pitt-kaf* class indicate the possibility of gastric problems and cold-cough. This diagnosis was correct; the patient was suffering from chronic cold and often used to have stomach upset and gastric problems.

A slow and relatively thicker (thickness not shown) *kaf nadi* for the *pitt-kaf* class with broken (piecewise continuous type), rapid, and irregular *pitt nadi* and with a rare, very fast oscillatory but asymmetric *vat-nadi* (Figure 9d) indicate many complications; most likely predictions are—acute stress problem, headache and congestion-type feeling, and breathlessness, with fever. The patient did have the latter three types of problems; stress was not diagnosed by Allopathic tests. This is typical case that signifies the importance of *nadi*-observation, as the stress-driven problems of this kind usually lead to acute cardiac ailments that are often diagnosed only after the damage has been caused.

The "leech-movement" type skewed, and high peaked *vat nadi* in Figure 10a, and a slow and high peaked pattern of this *nadi* in Figure 10b with low *pitt* and almost negligible *kaf nadi*



(a). *vat* related prominent problem in class *vat_kaf*.



(b). *kaf* related problem in class *vat_kaf*.

Figure 12.

(the latter is quite usual for the class *vat-pitt* unless there is a *kaf*-related problem) in both the figures respectively indicate the possibilities of asthmatic breathlessness and constipation. No information was available on confirmed diagnosis in the first case though the patient had some breathing trouble; the patient in the second case did complain of constipation.

The *pitt nadi* pattern in little higher range for the class *vat-pitt*, negligible *kaf nadi* and slow but high *vat* is a common case of minor but could be persistent acidity problem that might bring fatigue and sleeplessness (Figure 10c). This prediction also was correct. Similar was the case shown in Figure 11b, where, because of the natural tendency class *pitt-vat*, these patterns together indicate constipation and acidity.

An irregular, broken, and damped oscillatory pattern of the *pitt nadi* with slow but high *vat nadi* and negligible *kaf nadi* in the *vat-pitt* class (Figure 10d) indicate complicated problem of white discharge and possibility of blood or intestinal infection. The patient in this case had complaints of leuchoria, weakness and irritation. It may be noted that the possibilities of blood or intestinal infection predicted by *nadi*-analysis are important towards early diagnosis of cancers and such prior detections cannot be made by the methods of modern medicine.

The extremely slow but high and little thick (thickness not seen in the 2D graph) *pitt nadi* pattern in Figure 11a with normal *vat* and negligible *kaf nadi* (the latter is quite usual for this class) in the *pitt-vat* class is indicative of low BP and depression. This prediction was found correct.

Very low *pitt* and negligible *kaf nadis* with relatively faster leech-movement type and thick (thickness not depicted in the figure) *vat nadi* pattern (Figure 11c) show the possibility of a neurological or spinal disease. Although the patient showed some symptoms of such a problem, the diagnosis of a brain or spinal-disease could not be confirmed by Allopathic tests in want of proper scanning facilities.

A slow, low but visible, and thick (thickness not seen in the 2D graph) pattern of *kaf nadi* with a low *pitt* for the *pitt-vat* class (Figure 11d) with slow but high-side *vat nadi* indicate the possibility of congestion and some body-stiffness/sprain problem. The patient did complain of the latter and of reddishness in eyes.

A low but thick *kaf nadi* (thickness not shown in the figure) and a very low and little irregular in the beginning *nadi* of *pitt* with leech-movement type skewed *vat nadi* (Figure 12a) in the *vat-kaf*

class indicate the possibility of sinus and joint pains, body-stiffness with or without constipation. Except the stiffness the other health-problems were confirmed.

The little fast and relatively sharp and high peaked pattern of the *kaf*, with normal *pitt* and slow and higher side pattern of *vat nadi* in the class *vat-kaf* (Figure 12b) indicate the possibility of chronic cold and frequent indigestion. Here again, the predictions matched with the reality.

4.2. Importance and Scope

The good validation results show that computations of *nadi*-patterns by models of the kind presented here would make possible 'seeing' the *nadis* even in the absence of an expert *vaidya* of this science and without any instrument. Moreover, the *nadi-vaidyas*, if any present today, can perceive only certain qualities of *nadi*; finer details of the large number of possible patterns and the effects of continuous variation in the *doshas* cannot be studied by them. The computational model can do that accurately with desired level of sensitivity of variation in the parameters and with practically no cost. The computational simplicity of our model and the results also support this potential of our method.

Analysis of *nadi*-patterns gives greater insight into disease-characterization, and hence, in diagnostics and therapeutics. The ability of our model to make early diagnosis and detect some of otherwise unnoticed psychosomatic disorders and likely brain diseases supports and signifies novel applications in this regard. It is important to note that the *nadi* mapping by our model could also be used along with other methods of diagnostics.

The models like ours could be easily extended for incorporation of parameters other than the *doshas*; for example, biochemical, pathological, hematological, electro-physiological parameters, etc., could also be used. Also, the *nadi* patterns in case of specific diseases could be interpreted in terms of these parameters to elucidate deeper understanding of the role of the *doshas*. Studies of this kind would not only provide newer and comprehensive diagnostic techniques, but also set a promising basis for collaborative research in Ayurveda and Allopathy.

The diagnostic rules based on descriptions of *nadis* in Ayurvedic texts could be formulated as diagnostic heuristics in terms of certain geometrical and quantitative features of the *nadis* and linked with the modules for computation of $\underline{Y}$ and computation of corresponding *nadi* patterns to develop a fully automated diagnostic utility. We are currently looking into the development of a knowledge-based system of this kind.

Mathematical and computational modeling would be of essential use in designing an instrument for recording of the *nadi* patterns at different points on the body.

Increasing interest of researchers and pharmaceuticals in herbal medicine in view of larger market demands have boosted new interest in Ayurveda since a decade; the approach however is mostly confined to chemical analysis and thus, has not offered any great benefit of the herbs that are supposed to be obtained by pure Ayurvedic approach. It would therefore be useful to look into scientific research from the angle of the latter; for example, extended applications on estimation of $\underline{Y}$ and simultaneous computation of the *nadi*-patterns under different doses of (herbal or *bhasm*) medicines would be of significant use in Ayurvedic drug-response analysis. We aim to work in this direction.

The computational approach would help detailed quantitative analysis of the *nadi* patterns with respect to the *tridosha*. This would also allow reverse-analysis (e.g., at what level of one or more *dosha* a particular diseased state could become 'incurable', etc.). The drastically transformed patterns of *nadis* in a few cases with change of thresholds for a particular class in our experiments show interesting possibilities of such applications along with applications in prognosis and in identifying rare multiple manifestations of the same cause of an ailment. Thorough sensitivity analysis of our model with respect to variation of the threshold and other parameters would be required for such studies. The computational models and simulations may also be useful in testing certain new or yet unconfirmed hypotheses of Ayurveda and neuropathy.

Applications of our computational modeling in the studies *vis-à-vis* the qualitative spectrum of *nadi*-patterns for mental and neurological diseases described in the Ayurvedic scriptures would be of great significance in deciphering some of the yet unresolved complexities of the brain, nervous system, bioelectrical impulses, and mental functions.

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