COMPUTATION OF PARAMETERS FOR FEED FORWARD NEURAL NETWORKS IN THE INTERPRETATION OF IMPEDANCE CARDIOVASOGRAMS

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Abstract: The Impedance Cardio-vasograph (ICVG) system is based on the principle of impedance plethysmography and records normalized dZ/dt waveforms from various segments of the limbs. The amplitude of these waveforms is directly proportional to the blood flow index in the limb segment. Time elapsed from the ventricular contraction to the highest point on the waveform is known as pulse arrival time, which gives the time taken by the blood to reach that particular body segment. Thus parameters like Blood Flow Index (BFI) and Differential Pulse Arrival Time (DPAT) at different locations in both lower extremities (upper thigh, knee, calf and ankle) are computed from these measurements. It requires expertise on part of the clinician to make the diagnosis as the control values of the above parameters have larger standard deviations and all the values have to be considered simultaneously due to interdependence of the parameters. Therefore a neural network system is designed for interpretation of the haemodynamic parameters for the diagnosis of peripheral arterial occlusive diseases. The designed network identifies the presence of anatomical block or narrowing and also the status of collateral circulation in the lower limbs. The collaterals after the site of occlusion are classified as good, moderate or poor as an aid to the physician. The network identified cases with athero-sclerotic narrowing satisfactorily and was also able to categorize cases where changes are observed only in one extremity, other remaining normal as in the cases of hemi-Leriche's syndrome. An additional parameter CVS (Coefficient of venous Statis) is calculated which is useful for the diagnosis of primary and secondary varicosity of the veins. The ICVG system developed at the Electronics Division of Bhabha Atomic Research Center, Mumbai, India is a versatile system with an in built real time calibration for the impedance signals and patient safety as per IEC standards. It is user friendly, menu driven and provides raw as well as sliding average for continuous monitoring as well as study of therapeutic response.

Introduction

Estimation of peripheral blood flow has been one of the most important applications of Impedance Plethysmography[1]. Impedance Plethysmography introduced as far back as in 1940 is used to measure electrical impedance of any part of the body using either constant current method or bridge method and the variations in the impedance are recorded as a function of time [2],[3]. Since blood is a good conductor of electricity, the amount of blood in a given body segment is reflected inversely as in the electrical impedance of the body segment. Pulsatile blood volume increase in the body segment caused by systemic blood circulation therefore, causes proportional decrease in the electrical impedance [4].This knowledge was, however, sparingly applied in clinical medicine for the diagnosis of peripheral arterial occlusive diseases. A new waveform called the Normalized Impedance Plethysmographic waveform has been introduced for the easy assessment of peripheral blood flow [5]. The waveform is obtained by taking the natural logarithm of the instantaneous impedance of the body segment and then differentiating with respect to time [6]. The waveform thus obtained has its amplitude proportional to the blood flow index in the body segment and free from geometric variations of the limb [7].
The evaluation of Nyboer's parallel conductor theory forms the physical basis of Impedance Plethysmography [2].

$$dV = -\rho b \frac{L^2}{Z^2} dZ \qquad (1)$$

Where ρb is the resistivity of blood and dv and dZ represent change in the blood volume and change in the impedance of the body segment regment respectively.

Materials and Methods

For the assesment of the peripheral blood flow in a particular limb the change in impedance dz is replaced by the product of the maximum amplitude and duration of the systolic wave[8].

$$dV = -\rho b \frac{L^2}{Z_o^2} (dz / dt)_m \, T \qquad (2)$$

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Z_o is the basal impedance of the limb, T is period during which the systolic blood flow takes place and $(dz / dt)_m$ is the maximum amplitude of the dZ/dt waveform

Further $\rho b\ L^2$ is replaced by $Z_o V$ so that equation 2 becomes

$$dV = \frac{(dz / dt)_m}{Z_o} T \qquad (3)$$

Blood Flow in ml per 1000 cc of body tissue per cardiac cycle can be thus estimated as

$$1000 \frac{(dz / dt)_m}{Z_o} T \qquad (4)$$

Since $(dz / dt)_m / Z_o$ is directly measurable as the maximum amplitude of the Normalized dz/dt waveform and T does not vary significantly from person to person and location to location it is convienient in clinical practice to use anothr parameter called Blood Flow Index(BFI) to represent arterial blood flow.

BFI = Maximum Amplitude of NdZ/dt waveform.

The time elapsed from ventricular contraction to the highest point on the obtained waveform is known as the Pulse Arrival Time (PAT). It was observed that BFI and PAT changed significantly in patients with Peripheral Arterial Occlusive Diseases as compared to Normal subjects. The parameter Differential Pulse Arrival Time (DPAT) is obtained by subtracting the PAT value of a proximal location from that of a distal location.

In view of the technological advancements a PC Based Impedance Cardiovasograph System was developed which not only provides an impedance signal free from any body segment but also gives a real time built in calibration for these waveforms [9]. An impedance change up to 5 ohms/sec can be easily obtained with a sensitivity of 0.05 ohms /sec [10],[11]. About two hundred patients in the age group of 10 to 75 years, who presented at various surgical OPD's of K.E.M hospital and J.J. Hospital at Mumbai, India, were subjected to this study.

The Table 1 gives the representative data for the subject (Indoor/OPD Reg No 666)

Location	Right Leg		Left Leg	
	BFI	**DPAT**	**BFI**	**DPAT**
THIGH	**0.20**	**00**	**0.43**	**30**
KNEE	**0.51**	**160**	**0.63**	**30**
CALF	**0.39**	**00**	**0.55**	**00**
ANKLE	**0.31**	**00**	**0.88**	**40**

Table 1: Parameters for subject (Indoor/OPD Reg No 666)

Arteiography of the right leg in this patient shows thrombo-embolic occlusion of the right femoral artery with reformation at popliteal level and moderate distal arterial runoff. The above parameters along with the target outputs were given to the neural network for training. Normal healthy volunteers were used to avoid possible failure of accurate identification of dZ/dt peaks in various pathological cardiovascular states.

Fig. 1 shows typical ICVG waveforms recorded from neck, thorax and various locations such as thigh, knee calf and ankle in both the lower extremities of the subject in the supine position.

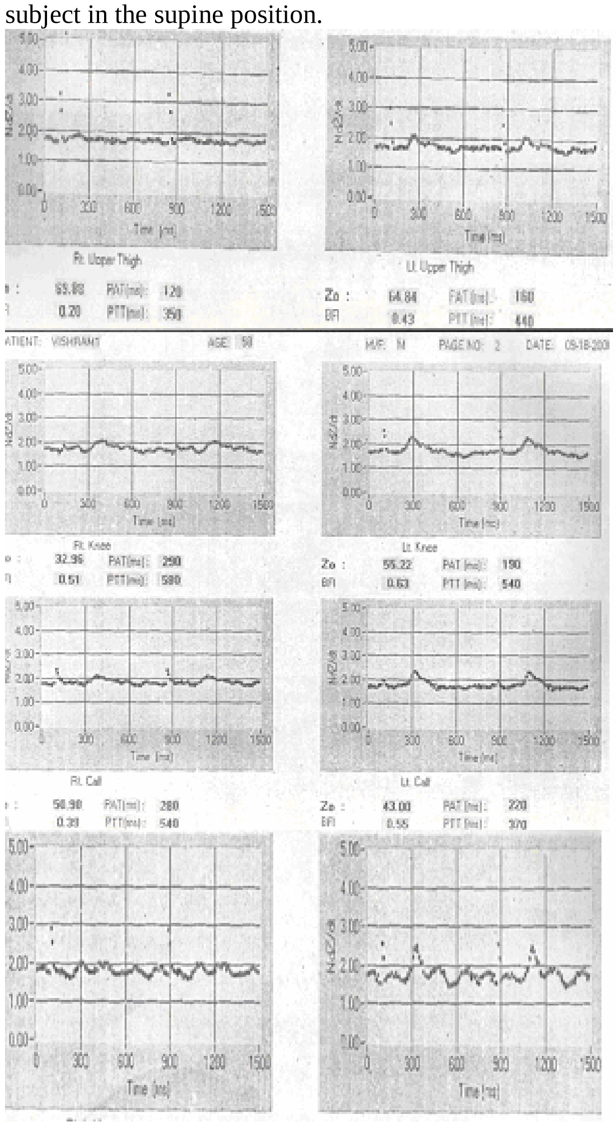

Figure 1: ICVG Waveforms for subject (Reg. 666)

The following observations are used to diagnose peripheral vascular disease using Feed Forward Neural Networks.

(i) Significant increase in the value of BFI on elevation of the limb indicates varicosity of veins.

(ii) Significant decrease in the value of BFI with increase/decrease in the value of DPAT indicates decrease in arterial blood flow due to an arterial occlusion/narrowing of the artery respectively.

(iii) In case of an occlusion the collateral circulation is said to be good, moderate or poor depending upon the value of BFI being more than 40%, 25% and 10% respectively in the distal segments.

(iv)No further decrease in the value of BFI at locations distal to the sight of occlusion indicates patency of the distal arteries; otherwise a second occlusion is suggested.

The developed neural network uses the Perceptron classification. The Perceptron neurons are trained on examples of desired behavior. The training is done with 'adapt' function which presents the input vectors to the network one at a time and makes corrections to the network based on the results of each presentation. This guarantees that the linearly separable problem is solved in a finite number of training presentations. A bias value is provided for each of the 14 input vectors. Input neurons without a bias will always have a net input to the transfer function of zero when all of its inputs are zero. However, a neuron with a bias learns to have a net transfer function input under the same conditions by learning an appropriate value for the bias. The program, which determines the status of all the locations in both the limbs, is executed when all the neural nets for each of the locations have been trained and the values of the weights and biases saved.

Results

The output produced by the Neural Network for (Reg No 666) was in good agreement the angiography as follows

Location	Right Leg	Left Leg
Thigh	Narrowing	Narrowing
Knee	Block	Narrowing
Calf	Moderate Collaterals	Narrowing
Ankle	Moderate Collaterals	Narrowing

Out of 40 patients suspected with peripheral vascular diseases, three subjects recorded ICVG data within normal limits and as many recorded decreased value of BFI as well as PAT suggesting generalized narrowing of the blood vessels due to atherosclerosis. The digital subtraction angiogram shows tapered narrowing of distal descending aorta and infra-renal portion of abdominal aorta with highly irregular outlines. However one patient with established diagnosis of Narrowing (by angiography) recorded a False Negative diagnosis.

Five patients were diagnosed with atherosclerotic affection of the aorta (normal value of BFI and significantly decreased value of DPAT at the thigh level). Two of these patients were diagnosed with an occlusion subsequent to the Block.

Two subjects were diagnosed with Leriche’s syndrome while six were cases of Hemi-Leriche’s syndrome. In the later case diagnosis of the other limb was Normal.

About 50% of the cases diagnosed were suffering from femoral Block with varying collateral conditions. One of the above cases was diagnosed with a Further Block at the ankle bilaterally. Aortogram of the patient showed complete occlusion of superficial femoral artery. The distal part of femoral, popliteal and leg branches were not seen to be opacified.

In femoral blocks BFI at knee is always lesser than BFI at thigh in the affected leg. In high femoral blocks there is significant decrease in the value of BFI at the thigh level and marked decrease at the knee level. DPAT is significantly increased at the knee level. Whereas in mid-femoral occlusions the decrease in BFI at the thigh level is very little with marked decrease in BFI and increase in DPAT at knee level. Low femoral blocks are characterized by normal BFI at thigh level and decreased BFI with increased DPAT at the knee level. The values of BFI and DPAT at distal locations depend upon the status of collateral circulation and distal arterial run off.

Four subjects were diagnosed with a Block above the ankle unilaterally. Arteriogram in these patients shows external iliac, common femoral, superficial and deep femoral arteries to be normal. Posterior tibial at and below the ankle was not visualized for the other limb.

There was however one subject diagnosed with a Block above the ankle in both limbs. Arteriogram of both legs revealed external iliac, common femoral, superficial and deep femoral arteries to be normal. Posterior tibial was seen up to distal calf level.

Coefficient of venous statis (CVS) is computed from the value of blood flow as the ratio of BFI in elevated position to the value of BFI in supine position. Significant increase (>15%) in the value of BFI on elevation of the limb indicates primary or secondary varicosity of veins. Only after ruling out the possibility of venous disorders does the neural network make further diagnosis of any arterial occlusive disease. The occlusive impedance Phlebograph

when supplemented with coefficient of venous statis increases the sensitivity of non-invasive diagnosis of chronic DVT.

The network also calls ‘significant’ a decrease(or increase in the value of the parameters if it lies outside the range of control values or it is 20% less (or more) than the corresponding value in the opposite extremity or the value at proximal locations in the same extremity, provided that such a change is consistent at distal locations. Three such cases are also included during the testing of the network.

Conclusions

The ability to make Plethysmographic observation merely by applying electrode to the skin has been found appealing to both patients and physicians. The online ensemble averaging employed in this system yields 40 db signal to noise ratio in addition to minimization of respiratory artifacts. It has been demonstrated that the neural network can perform the classification task at the expert level of performance. The perceptron algorithms used for training helps us in determining which data conflicts with the previously trained data. The algorithm itself is a constant guide throughout the training process. Furthermore the algorithm trains quickly and also requires less iteration as compared to the Back propagation algorithm. It is made to train till the error between the predicted output and the target is zero. The Impedance Cardiovasograph serves as a non-invasive screening procedure prior to Invasive and expensive angiographic studies or operator dependent Doppler studies.

Further work

Work is in progress where a software controlled system is being developed using ‘C for Virtual Instrumentation’ under the Lab Windows platform where the data i.e. BFI and DPAT values will be directly procured from the patient and then tested with our neural network program.

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