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Artificial Neural Network for *In-Vitro* Thrombosis Detection of Mechanical Valve

Hyuk Soo LEE[a], Sang Hoon LEE[b]

a, b. Laboratory of Biomedical Engineering, College of Medicine, Dankook University
San 29, Anseo-dong, Cheonan Chungnam, 330-714, Korea
Tel: +82-0417-550-6990, Fax: +82-0417-550-6993 E-mail: rainm@nownuri.net

Abstract

Mechanical valve is one of the most widely used implantable artificial organs. Since its failure(mechanical failures and thrombosis to name two representative example) means the death of patient, its reliability is very important and early noninvasive detection is essential requirement. This paper will explain the method to detect the thrombosis formation by spectral analysis and neural network. In order quantitatively to distinguish peak of a normal valve from that of a thrombotic valve, a 3 layer backpropagation neural network, which contains 7,000 input nodes, 20 hidden layer and 1 output, was employed. The trained neural network can distinguish normal and thrombotic valve with a probability that is higher than 90%. In conclusion, the acoustical spectrum analysis coupled with a neural network algorithm lend itself to the noninvasive monitoring of implanted mechanical valves. This method will be applied to the performance evaluation of other implantable artificial organs.

Keywords : Mechanical valve, Spectrum, Noninvasive Method, Neural Network

Introduction

People with heart problems have had their lives extended with the development of the artificial organs. Among others, clotting associated with prosthetic heart valves remains a major cause of morbidity and mortality. Although current prostheses do not meet ideal specifications with respect to many evaluation criteria, thromboembolism, valve durability, and endocarditis are the major causes of valve-related late postoperative morbidity and mortality [1]. The diagnosis of thromboembolism in patients with prosthetic heart valves may be difficult. The need for continuous monitoring of reliable operation in an implanted heart valve without any per-cutaneous apparatus has greatly increased. In this article, we propose a method to evaluate the performance and reliability of an implanted heart valve by analyzing the acoustic signals from the mechanical components. Such a approach has been frequently used in detecting degeneration of porcine bioprosthetic heart valves inserted in the mitral or aortic position [2]. Mechanical valve is one of the most commonly used implantable artificial organs. Since its failure(mechanical failures and thrombosis to name just two representative examples) means the death of patient, its reliability is of paramount importance and early noninvasive detection is an essential requirement. Measurements were made of acoustic signals under various operating conditions and calculated their PSD(Power Spectral Density) to estimate the mechanical or operating status of an implanted valve of LVAD [3]. The sound intensity from an LVAD(Left Ventricular Assist Device) was compared with that from a normal and clotting mechanical valve. This sound analysis method can be successfully applied to assess the operational performance of valve.

Material and Method

System Description

The LVAD is a paracorporeal, pulsatile, pneumatically driven system capable of left ventricular support. Compressed air and vacuum are supplied from an external console. The blood housing is injection molded from isoplast and nearly seamless, smooth segmented polyuretane. A diaphragm is actuated pneumatically. Mock circulatory system shown in Figure 1 has been developed at DanKook University and is employed in this experiment.

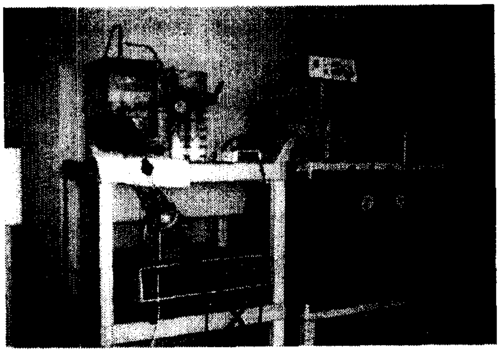


Fig 1. Mock circulatory System

A microphone(ACO Pacific, Inc., USA) and an amplifier were used to measure the sound from the mechanical valve(ATS valve) which is attached to the pneumatic left ventricular assist device. The microphone was attached to a coupler for the removal of environmental noise. The microphone is shown in Figure 2.

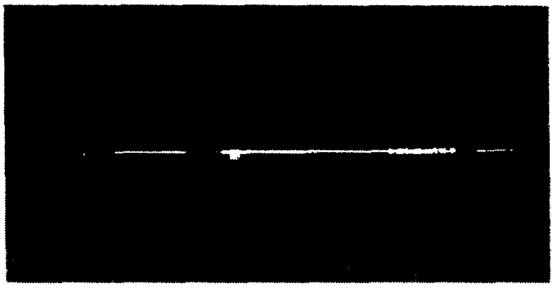


Fig 2. High sensitive microphone with coupler

An A/D converter(DaqBook 100, Iotech, Inc. USA) sampled the sound and the periodogram is the main algorithm to obtain spectrum. The thrombosis models are made by coating silicon on the valve disc, around the sewing ring. We made model of fibrous tissue growth across the orifice of valve(each 20%, 40%, 60%) by using silicon. The thrombosis models are depicted in Figure 3.

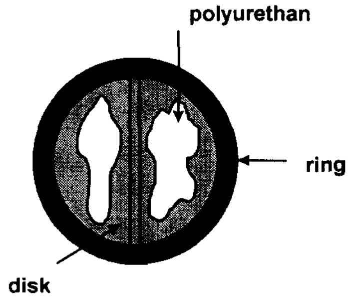
The performance of the measurement system was tested using 1 KHz sinusoidal wave. 1 KHz spectrum detected well as expected. Then the spectrum of normal and 5 different kinds of thrombotic valve were obtained. Each spectrum waveform shows a primary and secondary peak. The secondary peak changes according to the thrombosis model. In order quantitatively to distinguish the secondary peak of a normal valve from that of a thrombotic valve, a 3-layer backpropagation neural network, which contains 7,000 input nodes, 20 hidden layers and one output, was employed.

Sound Signal Processing

The power spectral density analysis seeks to describe the frequency content of a signal, a random process, or a system, based on a finite set of data. Estimation of power spectra is useful in a variety of applications, including the detection signals buried in the wide-band noise. The power spectral density of a stationary random process $x(n)$ is related mathematically to correlation sequence by the discrete-time Fourier transform :

$$P_{xx}(\omega) = \sum_{m=-\infty}^{\infty} R_{xx}(m)\ e^{-j\omega m} \qquad (1)$$

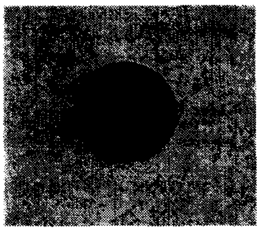
This frequency function has the property that its integral over a frequency band is equal to the power of the signal $x(n)$ in that band. The calculating program was implemented using MATLAB (The MathWorks, Inc., Natick, Massachusetts) on a personal computer (IBM PC Pentium 166, Korea).



(a)

(b)

(c)



(d)

(e)

Fig 3. Model of thrombosis
a) Model of thrombosis on disc
b) Model of thrombosis around sewing ring
c) Model of grown with fibrous tissue 20%
d) Model of grown with fibrous tissue 40%
e) Model of grown with fibrous tissue 60%

Artificial Neural Network Analysis

An artificial neural network consists of artificial neurons designed to imitate the first-order characteristics of the biologic neurons. A single neuron can perform certain simple pattern detection functions, the power of neural computation comes from connecting neurons into single-layer or multi-layer networks.

Training the neural network is accomplished by sequentially applying input data, while adjusting network weights according to a pre-determined procedure. During training, the network weights gradually converge to values such that each input vector produces the desired output value. Among the diverse network paradigms, a three-layer backpropagation neural network was chosen. It contains 7,000 input nodes, 20 intermediate or hidden nodes and one output node, as shown in Figure 4. The backpropagation learning rule is used to train nonlinear, multi-layered networks to perform functional approximation, pattern association, and pattern classification. The backpropagation learning rules are used to adjust the weights and biases of networks so as to minimize the sum-squared error of the network. This is done by continually changing the values of the network weights and biases in the direction of steepest descent with respect to error. This is called a gradient descent procedure. It is shown that changes in each weight and bias are proportional to that element's effect on the sum-squared error of the network.

Figure 5 shows the sum-squared error of the neural network. Strictly speaking, backpropagation is a learning algorithm, not a type of network. However, backpropagation is used primarily with one type of network. The spectrum of the acquired acoustic signal was calculated by discrete Fourier transformation. 7,000 values of the spectrum were used as input to the neural network. The output of the neural network can take on a value between 0 and 1, which corresponds to the normal and thrombotic valve state, respectively. Training the neural network was performed with 20 arbitrarily chosen spectra(10 normal and 10 thrombotic valves). The network used the log-sigmoid transfer function. The function generates outputs in the range of 0 and 1 as the neuron's net input goes from negative to positive infinity.

The log-sigmoid transfer function can be used without or with a bias. Also, training parameters must be provided to set how often progress is to be displayed, to limit the number of training epochs (10^5), to define an acceptable error (10^{-4}), and to set the learning rate (0.002). The trained neural network can distinguish normal and thrombotic valve with more than 90% probability. The network was implemented using MATLAB.

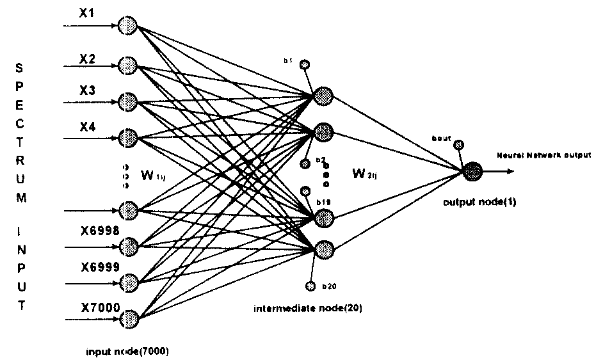


Fig 4. Three layer backpropagation neural network architecture

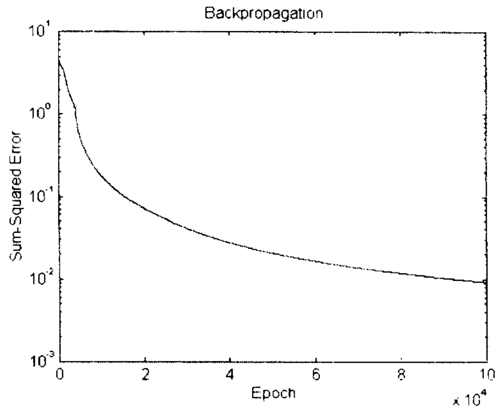
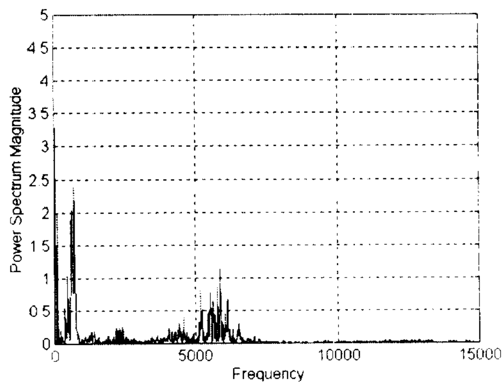


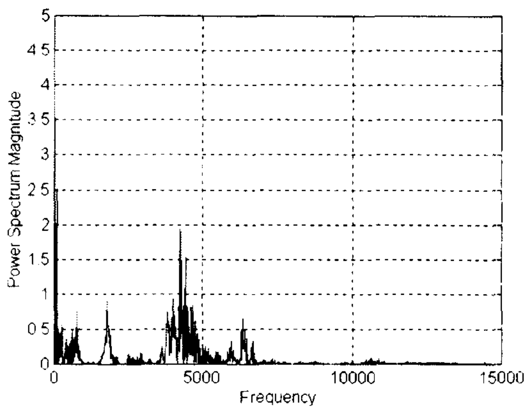
Fig 5. Sum-squared error of neural net work

Result

Figure 6 shows the spectra obtained from a microphone for a valve positioned in LVAD. The spectra are the magnitudes of a discrete Fourier transformation of the acoustic waveform. Inspection of Figure 6 reveals a trend toward decreased frequency for the thrombotic valve compared with the nonthrombotic valve under the same condition. During the training procedure, the ANN converged very well with the 20 arbitrarily chosen spectra: 10 thrombotic valves and 10 nonthrombotic valves. The result of the ANN output are summarized in Table 1 where output levels 0 to 1 denote the fail and the normal state, respectively. As shown in Table 1, the trained neural network is able to distinguish normal and thrombotic valve with a probability rate of over 90%.



(a)



(b)

Fig 6. Power spectrum density of valve
a) Power spectrum density of nonthrombotic valve
b) Power spectrum density of thrombotic valve

Table 1. Result of artificial neural network analysis on the acoustic spectrum in two different condition

No.	normal valve	fail valve
1	0.9956	0.9996
2	0.9962	0.0122
3	0.9934	0.0056
4	0.9825	0.0028
5	0.1267	0.0886
6	0.9848	0.0749
7	0.9993	0.0360
8	0.9686	0.0114
9	0.9977	0.0244
10	0.9999	0.0360

Discussion

The result of this study indicates that the valvular failure of an implanted LVAD can be detected by ANN analysis of an acoustic signal. Acoustic measurement has been used as a noninvasive diagnostic tool and is thought to be a good method for detecting possible mechanical failure of an implanted LVAD. The differences in the acoustic waveform or its spectrum are found difficult to detect by visual means or simple parametric calculation, but they are amenable to detection by sophisticated classification techniques, such as neural network analysis. This method is though to be possible to detect any progressive failure at a relatively earlier stage. With a multiple output node configuration, it could be used to classify the different types of failure from a single acoustic signal waveform. If a quantitative pattern recognition algorithm is combined with the proposed method, an automatic diagnosis and monitoring system for implanted valve will be realized.

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