The Design and Implementation of the Electrotherapeutic Device for Blood Viscosity Attenuation

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ABSTRACT

A small current through low frequency is able to treat patients by attenuating or malfunctioning mechanism of microbes which flow through the blood. In addition, the performance delivery of oxygen and nutrients in blood are improved. With the advance, blood viscosity and hematocrit are coincidentally approached to normal level, adaptive flow-rate. This paper proposes the conceptual design and implementation of an electrotherapeutic device used for modality application. The design is based on a certain square wave varied from 4 to 5 Hz with a stimulating current and voltage adapted from 0.241mA to 1.027mA and from $15V_{pp}$ to $64V_{pp}$, respectively. Applying the wave form to blood model in testing environment, the experimental results show that the viscosity is reduced to satisfy level.

Keywords: Blood viscosity, hematocrit, electrotherapeutic.

1. INTRODUCTION

For recent years, the study of hemorheology becomes great interest in the fields of biomedical engineering and medical research. Hemorheology plays as an important role in atherosclerosis hemorheological properties of blood consisting of blood viscosity, plasma viscosity, hematocrit, red blood cell (RBC) definability and aggregation, and fibrinogen concentration in plasma. However, a number of parameters such as pressure, lumen diameter, blood viscosity, compliance of vessels, peripheral vascular resistance are well-known physiological parameters affecting to the blood flow, but the blood viscosity is also an important key physiological parameter. The significance of the blood viscosity has thus not been fully consideration [1].

Blood viscosity in patients with coronary arterial disease such as ischemic heart disease and myocardial infarction [2] were measured. Their results illustrated that the viscosity of whole blood might be associated with coronary arterial diseases. In addition, D. P. Briley et al. [3] reported that whole blood viscosity was significantly higher in patients with peripheral arterial disease than that in healthy controls. Correlation between the hemorheological parameters and stroke was investigated by J. M. Leiper et al. [4]. They found that stroke patients showed two or more elevated rheological parameters, which included whole blood viscosity, plasma viscosity, RBC and plate aggregation, RBC rigidity, and hematocrit. Both whole blood viscosity and plasma viscosity were significantly higher in patients with essential hypertension than in healthy ones, whereas RBC deformability was decreased. Others conducted hemorheological studies to detect the relationships between whole blood viscosity and smoking, age, and gender [5]. Smoking and aging might cause the elevated blood viscosity. In addition, males' blood possessed higher blood viscosity, RBC aggregability, and RBC rigidity than premenopausal females' blood, which was attributed to monthly blood-loss [6].

The effect of hematocrit on increasing viscosity, flow rate, and the equivalent physiologic compensation ratios was investigated by Yildrim Çinar et al. [6]. The blood samples were taken from 32 healthy individuals and centrifuged for 5 min at 3000 rpm to obtain 2.5 mL of erythrocte mass from each. At each step 0.5 mL of plasma was consecutively added in a total of 17 steps. The hematrocrit and viscosity change performed by capillary meter was measured . Their results illustrated that a 10.99% increase of hematocrit in the range of 60.16% and 25.32% produced an increase of 1 unit relative viscosity, which is approximately a 30% increase in blood viscosity for a healthy individual.

Treatment and monitoring blood viscosity regulations were discussed by Chen Gan et al. [7]. The blood viscosity was increased moderately when treating diseases with extremely reducing viscosity. There are however two regular methods applied to improve the blood viscosity.

Invasive methodology: for examples, transfusion is commonly used to restore blood volume and improve the delivery of oxygen and nutrients in the blood. Martini et al. [8] studied exchange transfusions of homologous packed red blood cells using the awake hamster window chamber model, and observed the moderate elevation of hematocrit (10% above baseline), which causing an increased cardiac index, increased oxygen transport and consumption, and a reduction in total peripheral vascular resistance. Developing blood substitutes was taken into account,

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where some hemoglobin-based oxygen carriers caused transient systemic hypertension and reduced cardiac output [9]. In the hemorrhagic shock model, viscous blood substitutes limit vasoconstriction and improve functional capillary density and oxygen content.

Non-invasive methodology: for instances, the laser acupuncture treatment method was studied by John Zhang et al. [10]. After using the laser treatment for 90 days, both the systolic and diastolic blood pressures were decreased significantly (P<0.01). The mean systolic blood pressure was 129.6±14.7 mm Hg before the treatment and was reduced to 122.5±17.2 mm Hg (P<0.001). The mean diastolic blood pressure was 85.6±8.0 mm Hg before treatment and was reduced to 77.2±8.7 mm Hg (P<0.01). It was concluded that low-level laser treatment of acupuncture points resulted in lower blood pressure. Radio frequency treatment was considered in many applications [11] [12]. The three-dimensional mathematical model for the study of radiofrequency ablation (RFA) with blood flow for varicose vein was proposed by S.Y. Choi et al. [13]. The model designed to analyze temperature distribution heated by radiofrequency energy and cooled by blood flow includes a cylindrically symmetric blood vessel with a homogeneous vein wall. The simulated blood velocity conditions are U = 0, 1, 2.5, 5, 10, 20, and 40 mm/s. The lower the blood velocity, the higher the temperature in the vein wall and the greater the tissue damage. The region that is influenced by temperature in the case of the stagnant flow occupies approximately 28.5% of the whole geometry, while the region that is influenced by temperature in the case of continuously moving electrode against the flow direction is about 50%. The generated RF energy induced a temperature rise of the blood in the lumen and leads to an occlusion of the blood vessel. The result of the study demonstrated that higher blood velocity led to smaller thermal region and lower ablation efficiency.

From the previous works, the non-invasive method based on low radio frequency (LRF) is taken into account to relieve the blood hypertension and the blood viscosity. Although radio frequencies have provided advantages for clinical applications, there is an issue regarding electromagnetic radiation of high frequency which is effected to organics' structure due to ionizing reformulation or mutation [11]. Therefore, low radio frequency becomes an alternative for the modem therapeutic research considering on non-destructive concept.

2. STATE OF THE ART

There are two domain issues on blood viscosity and pressure consideration, i.e. 1) measuring and extracting the relationship between blood viscosity and blood pressure, 2) improving blood viscosity and blood pressure.

Measuring and extracting the relationship between blood viscosity and blood pressure: Masashi Saito et al. [14] evaluated the viscoelastic properties of blood vessels from carotid pulse wave observed by noninvasive technique, piezoelectric transducer and an ultrasonic diagnostic equipment. Since the reflected wave is generated by the reflection of the incident wave at the peripheral artery after propagating long distance along blood vessels, the characteristics of that wave depend remarkably on arterial stiffness. As a result, the maximum values of the reflected wave increased with advancing age. The result was in good agreement with the increasing elasticity of blood vessels due to age. Hematocrit is evaluated noninvasively based on the ultrasonic estimation of shear rate-viscosity curve, which is uniquely formed by the hematocrit [15]. In vivo measurements for healthy subjects revealed that the proposed method provided reasonable the hematocrit estimations.

Improving blood viscosity and blood pressure: The viscosity of blood has long been used as an indicator in the understanding and treatment of disease, and the advent of modern viscometers allows its measurement with ever-improving clinical convenience [16]. The effect of hematocrit on blood pressure via hyperviscosity was evaluated by Yildirim Çinar et al. [6]. Their results showed that the decreasing in hematocrit levels resulting from addition of 0.5 mL of plasma at 17 consecutive steps onto 2.5 mL of erythrocyte mass causes a significant decrease in viscosity at each step. Mohamed A. Elblbesy [17] introduced a simple method used by clinical laboratory workers. The method extrapolated the blood viscosity from hematocrit and total serum proteins. The simple syringe method was used to measure relative blood viscosity (RBV) and relative plasma viscosity (RPV). A volume of 2 ml of whole blood was allowed to flow freely through a syringe and the time of flow was estimated and then divided by the time of flow of the standard to obtain RBV.

There are a few research considering on non-invasive therapy. The clinical application of Electrotherapeutic Modalities was proposed by A.J. Robinson and L. Snyder Mackler [18]. They determined the frequency of use of eight forms of electrical stimulation and ultrasound in clinical practice. The frequency and type of electrical stimulation used depended on the availability of electrical stimulators and the adequacy of entry level training in electrotherapy. The results of this study suggest the need for additional electrical stimulators in physical therapy clinics, training for physical therapists, and research in electrotherapy. Nikola Tesla [19] had gathering a group of researchers studying on electro-therapeutics for diagnostic, radiographic and therapeutic work. The laser acupuncture treatment method was presented in [10].

This paper is therefore primarily focused on applying the radio frequency features to design an electrotherapeutic device for blood viscosity attenuation. The paper organization is as follows: design concept is illustrated in section 3, implementation and investigation results are reported in section 4. conclusion and future work are described in sections 5and 6.

3. DESIGN AND ARCHITECTURE

With small heat and several degrees of frequency of a square wave, the mechanism of microbes is able to attenuated and mulfunction. In addition, the quality of oxygen and nutrients in the blood [10] are improved. Hence, the design of the electrotherapeutic device is based on the concept of applying the pulse radio frequency from 4 Hz to 5 Hz, where the output current and voltage are varied from 0.241 mA to 1.027 mA and from 15 V_{pp} to 64 V_{pp}. Since there is non-impact to a patient or an user, the low frequency and the small current and voltage are predefined [20].

3.1 Design Concept

Since the blood viscosity, v, is the resistance of the blood tissue against flow, the simplest formula to explain its' behavior is Poiseuille's law as illustrated in Equ. (1).

$$v = \frac{\pi r^4 t dP}{8\eta dL}, \qquad (1)$$

where a different cross sectional pressure value dP is $P_1 - P_2$ at input P_1 and output P_2 on a cylinder of blood vessel. t is measuring time. dL is a short length of the blood vessel. r is a radius value of the targeted blood vessel. From Equ. (1), the blood viscosity contradicts the blood viscosity coefficient η, which is a proportional function of temperature T as illustrated in Equ. (2) with a limited range of temperatures.

$$\eta = Ae^{E_a/RT}, \qquad (2)$$

where E_a is an activation energy value with a constant A. R is an ideal gas constant value with a temperature T. From Equs. (1) and (2), the blood viscosity is therefore enhanced by increasing blood temperature with small current and simultaneously stimulating on blood vessel with low pulsed frequency.

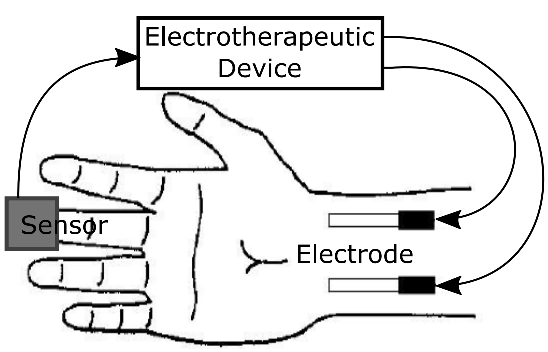

Fig.1:: The blood electrotherapeutic device with varied low radio frequency from 4 Hz to 5 Hz

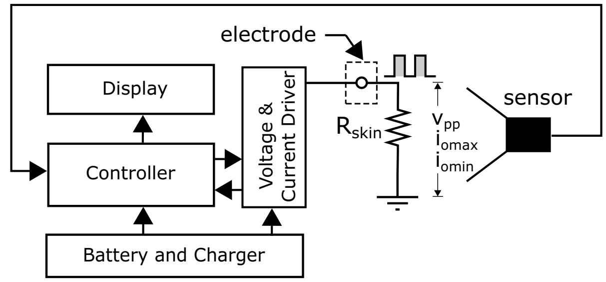

Fig.2:: The blood electrification device with low radio frequency at 4-5Hz

Table 1:: Testing characteristic of the blood electrotherapeutic device, where a skin resistance R_{skin} is defined at 22kΩ

V_{pp} (V)	V_{rms} (V)	I_{rms} (mA)
64	22.6	1.027
15	5.3	0.241

3.2 Architecture

The architecture of the proposed blood electrification system is shown in Fig. 2. Since the main purpose of the architecture is targeted for home use, the portability and low power design concept are applied. There are four modules on the system working as following concepts.

Processing module: the 8-bit microprocessor PIC18F2550 is selected, where the controller provides low power functionality at runtime. In Idle state, it is waiting for blood viscosity information detected by the optical sensor. These information are then calculated for adapting the voltage and current on the driven module as well as displaying on the OLED display.

Actuator module: the voltage and current driven module and two copper plates sized 15mm × 40mm are grouped. This module simultaneously drives the current, voltage, and frequency from 0.241mA to 1.027mA, from 15V_{pp} to 64V_{pp}, and from 4Hz to 5Hz, respectively. The two copper plates are stuck to skin at wrist position on stimulation step.

Sensor module: this module, proposed for future work, is used to obtain blood viscosity, where optical-based sensor is available. The monitored viscosity is obtained and forwarded to the processing module for the current and voltage adaptation.

Display and charger module: managing display and charging battery are manipulated by this module. The information regarding status, power level, blood viscosity, and functional utility are indicated on OLED display, where a user is able to interact through graphic user interface. The power level of DC supply is determined by voltage and current detector circuits, where these data are then forwarded to the processing module for computation.

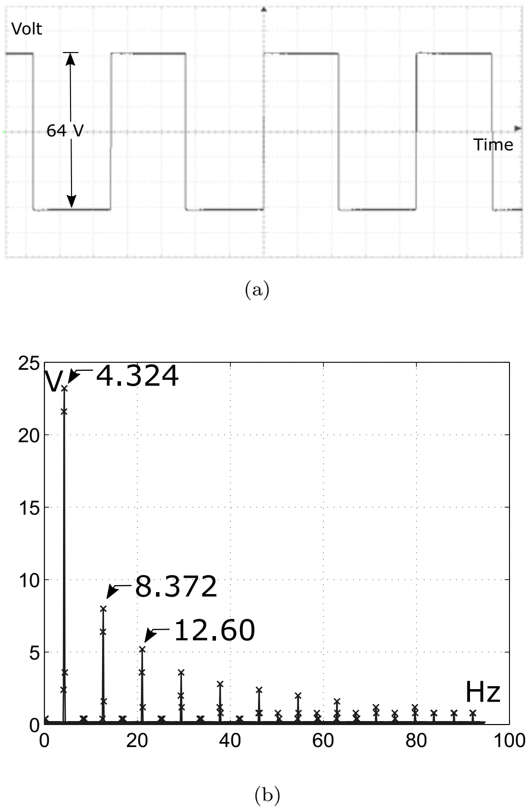

Fig.3:: a) continuously square wave generated by the proposed device with variable frequency from 4Hz to 5Hz and adaptable voltage from $15V_{pp}$ to $64V_{pp}$, b) the spectrum of the square wave in several degree of harmonics.

4. INVESTIGATION RESULTS

There are four steps on preparation to use the electrodes for the blood electrotherapeutic application as follows: 1) preparing cotton sleeves or cotton covers for the electrodes, 2) placing the cotton sleeves over the electrodes, where a dropper bottle is a handy way to wet the cotton and to keep the covers damp during use, 3) placing the covered electrodes directly over the two arteries on the wrist: the radial and ulner arteries, and holding the electrodes in place with a wrist strap. The characteristic of the blood electrotherapeutic device, where a skin resistance R_{skin} is defined at 22kΩ is illustrated in Table 1. Since the skin resistance for each individual is unstable depending on several factors such humidity, sweat, etc., for testing measuring or adjusting the skin resistance is required. Afterward, the levels of current and voltage for stimulation can be determined. Fig. 3a shows the continuously square wave generated by the proposed device with variable frequency from 4Hz to 5Hz and adaptable voltage from $15V_{pp}$ to $64V_{pp}$. The spectrum of the square wave in several degree of harmonics is depicted in Fig. 3b.

5. CONCLUSION

The aim of this paper is to propose the conceptual design of the electrotherapeutic device. The non-invasive based device is mainly used to enhance the blood viscosity which is a cause of diseases. The blood vessels are stimulated by the small current varied from 0.241 mA to 1.027 mA and simultaneously the pulse frequency fluctuated from 4Hz to 5Hz. With this condition, the temperature of the fluids within the blood vessels is increased while the viscosity coefficient μ and the blood viscosity v are increased and reduced accordingly. The implementation is focused for home use and portability; therefore, the low power 8-bit microcontroller is obtained. The two copper plates sized 15mm$\times$40mm are selected for the current and pulse radiation. By applying the wave form to blood model in testing environment, the experimental results show that the viscosity is reduced to satisfy level.

6. FUTURE WORKS

Since the proposed design has included a blood viscosity sensor, where a optical-based sensing technique is decided for our implementation, the integrated and investigated whole system become our future work. In order to achieve our target, laboratory testing and clinical testing on tissues and a certain group of sample, where their information will be analyzed and synthesized statistically, will be our tasks.

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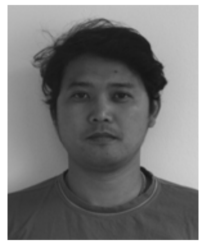

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