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HUMAN SKIN MODEL SERVING IN ELECTRICAL STIMULATION OF ANTERIOR TIBIAL ARTERY

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ABSTRACT

Cardiac activities are one of the vital signs of life. To monitor these activities there are several methods including electrocardiography (ECG), photo plysthesmography, electrical impedance plythesmography. The purpose of the paper is to design external electrodes placed on the uppermost skin layer called stratum corneum which are capable of stimulating human anterior tibial artery without damaging it. This artery is present along the length of human tibia bone or shin bone .The designed electrodes are diminutive enough to attach with any easily wearable device. These electrodes when supplied with potential stimulate the artery helping in the procedure of electrical impedance plethysmography, this method is simple and low-cost.On the other hand, Electrical Impedance Plethysmography appears to be the most practical solution as compared to the above mentioned techniques of monitoring cardiovascular activities By varying electrode size and the distance between the electrodes we can skillfully judge the point where the electric field reaches the artery. The simulation of this model is done by Comsol Multiphysics.

KEYWORDS

Electrodes, anterior tibial artery, potential, stimulate Electrical impedance plethysmography (EIP), electrode size and distance, comsol multiphysics.

INTRODUCTION

The skin is the largest organ of human body and protect organism from various environmental factors. A defective barrier has its origin in a disturbed skin physiology. So, it is very important to assess the skin condition for medical studies. The measurements of the skin electrical impedance are a noninvasive and fast method for assessing the skin. The electrical impedance of the skin can be used to measure skin moisture ,to monitor skin irritations and allergic reactions, to detect skin cancer , to investigate the transdermal drug deliveries and many other. (Romanian ,J. 2008). Electrical impedance plethysmography takes its origin when a normal heart beat is initiated by a small pulse of electric current. This tiny electric "shock" spreads rapidly in the heart and makes the heart muscle contract, helping in way for pumping blood, when this blood reaches the vessels its flow results in changing resistance of arteries, which is the basic principle of this procedure.Electrical impedance plethysmography is the method of determining changing tissue volume due to change in blood flow.The first publications concerning this method date back to the 1930s and1940s.[Kubicek, W. G 1970] The method reached clinical value about 20 years ago based on the research work by Kinnen, Kubicek.EIP can be useful to study the peripheral circulation using an inflated cuff for blocking the venous flow and monitoring the blood volume increase in the limb. Scientists [Van De Water, J. M., 1971] have made technical and theoretical studies of the impedance plethysmography technique for measuring the blood flow in human limbs. The hitch of the method is that the signals may contain motion artifacts and the flow cannot be completely blocked hence resulting in incorrect analysis.Bioelectric impedance may also be used in determining the body composition. In this procedure the impedance is measured between one arm and one leg by feeding a current. The determination of the body composition is based on measurement of the resistive and reactive components of the body impedance [Baumgartner, R. N., 1989]. With this method it is possible to estimate several parameters of the body composition such as total body water, fat free mass, body cell mass, and caloric consumption [Kushner, R. F., 1986].Hence EIP seems to be useful but the method undoubtedly has some disadvantages. These include the errors caused by aortic valve insufficiency, severe mitral valve insufficiency for example, septal defects. The method does not give any indication of the presence of these pathologies, and they must therefore be diagnosed
by other means. The method is also difficult to apply to patients with atrial fibrillation. (Wikswo, 1975)

On the other hand, impedance plethysmography is noninvasive and harmless. The accuracy of the method in careful examinations of patients, excluding the previously mentioned groups, gives capable results. (Geselowitz, 1971) This project shows the model of major human skin layers signifying the depth of anterior tibial artery. Here the two electrodes are used to stimulate the artery thus aiding to examine the volume of blood flow and pulsations and more importantly it can also be useful in the method of electrical impedance plethysmography. As the volume of blood flowing through the artery changes, resistance of the artery will change respectively resulting in varying impedance. If this impedance is measured through the method of EIP the model played a crucial role for diagnosing different diseases related to vessels.The preeminent part of the model is its compact electrode size and inter-distance between them, which is determined by changing inter-distance and area of electrode and considering best dimensions where electric field is endurable by the artery.The model is also least effected by motion artifacts as designed electrodes are small enough to be attached with easily wearable devices which can be fasten on the body.

MATERIAL AND METHOD

EIP is the technique of determining occlusions in vessels, whenever blood flows through the artery the change in impedance resulted which is the basic principle of this method.Considering the human skin on which EIP electrodes are placed and the artery affecting through the potential provided on electrodes, the model can be drawn to inspect the best position and dimensions of electrodes to stimulate the anterior tibial artery.In Initiation of the model, considerable point were to spot the depth and dimensions of anterior tibial artery which was achieved by performing A-scan and B-scan of ultrasound respectively. The images are as follows:

Fig-1: Showing ultrasound scan of anterior tibial artery

After spotting the actual artery position, model was constructed in a software named COMSOL MULTIPHYSICS. Comsol Multiphysics software facilitates all the steps in the modeling process, defining geometry, meshing, specifying physics, solving, and then visualizing results.The model of skin was drawn by considering four (Van De Water, J. 1971) main layers sequentially named as stratum corneum , epidermis, dermis and layers of sub cutaneous fat & muscles.

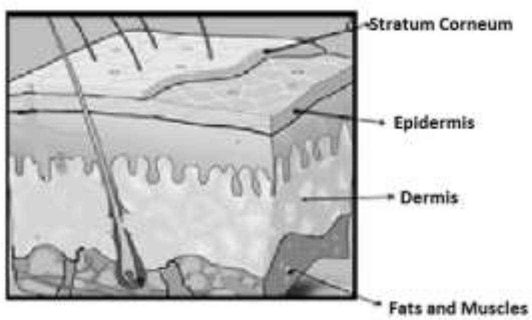


Fig-2: Showing layers of human skin

In order to electrically stimulate the skin model, one must be familiar with some important characteristics of human skin which includes electrical conductivity and relative permittivity. Every layer has different value of electrical conductivity but the relative permittivity for all the layers is taken in the model as constant 1.

Table-1: Demonstrating values for electrical conductivity of skin layers and blood.

LAYERS OF SKIN	ELECTRICAL CONDUCTIVITY
1. Stratum corneum	0.0005 S/m
2. Epidermis	0.95 S/m
3. Dermis	0.2 S/m
4. Fats and muscles	0.66 S/m
5. Blood	0.8 S/m

The final geometry of model appeared as follows in COMSOL window:

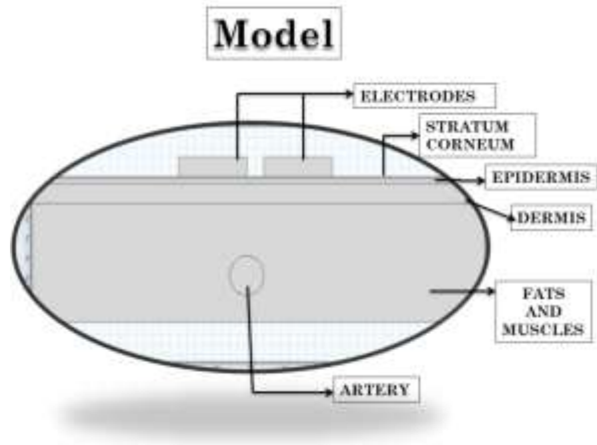


Fig-3: showing basic model in COMSOL MULTIPHYSICS

A. BASIC IDEA OF THE RESEARCH

The basic idea of research is based on the *MAXWELL'S EQUATION OF CHANGING VOLUME OF BLOOD IN ARTERY*, the equation is given as:

$$\Delta V = \frac{\rho L^2}{Z_0^2}\left(\Delta Z_\rho + \Delta Z_v\right) \qquad (1)$$

Here,
ΔV = change in arterial blood volume.
L =inter-distance of electrodes
ρ = blood or artery's resistivity
Z_o = basal impedance when there is no blood flow
Z_ρ = impedance due to change in blood resistivity
Z_v = impedance due to change in blood volume

B. SKIN MODEL

In COMSOL skin layers and electrodes are represented through rectangles and the anterior tibial artery is represented through a circle. The electric potential provided at the electrode is 1volt which remains constant throughout the simulation.The diameter of *anterior tibial artery* in ultrasound was found to be 2mm and it is 4.2mm deep from skin surface.

Table-1: The measurements of skin layers

SKIN LAYERS	WIDTH (mm)	HEIGHT (mm)
A. Stratum corneum	50	0.1
B. Epidermis	50	0.25
C. Dermis	50	1
D. Fat and Muscles	50	6

Figure-4: Final model, rainbow colors representing generated electric field in model

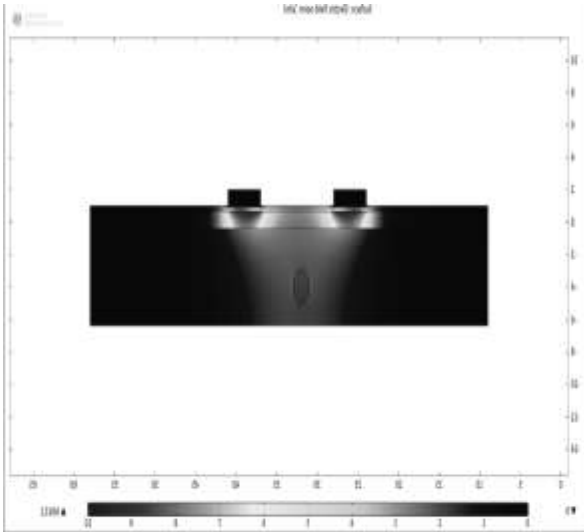
C. SIMULATIONS

In order to design electrodes and find inter-distance that proves to be elegant to stimulate artery without being detrimental for the skin, two types of simulations were performed:

a. Simulation for inter-distance;
b. Simulation for area.

SIMULATION FOR INTER-DISTANCE

By changing inter-distance between electrodes electric field was observed, the best resulting value was found to be 1.3 V/m at a distance of 10mm.



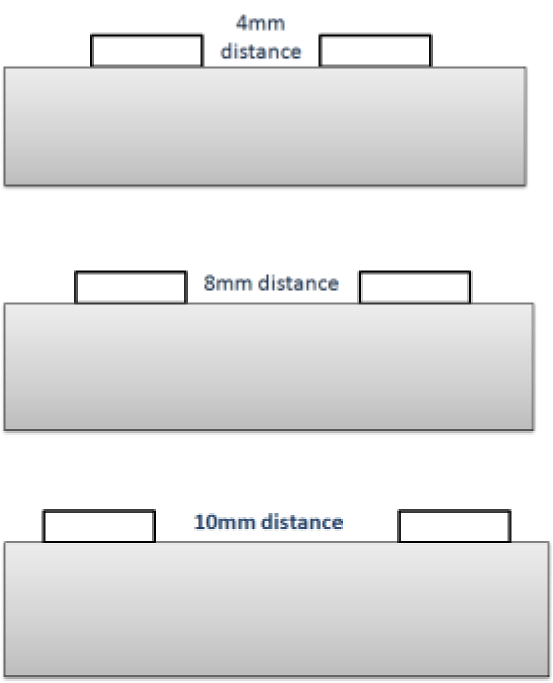


Fig-5: Varying inter-distance of electrodes.

SIMULATION FOR AREA

When the width of electrodes was changed by 1mm to 10mm keeping the inter-distance of electrodes constant as 10mm, the satisfying resulted value of electric field was found to be 1.36 S/m when the area of electrodes was 3*1 mm^2.

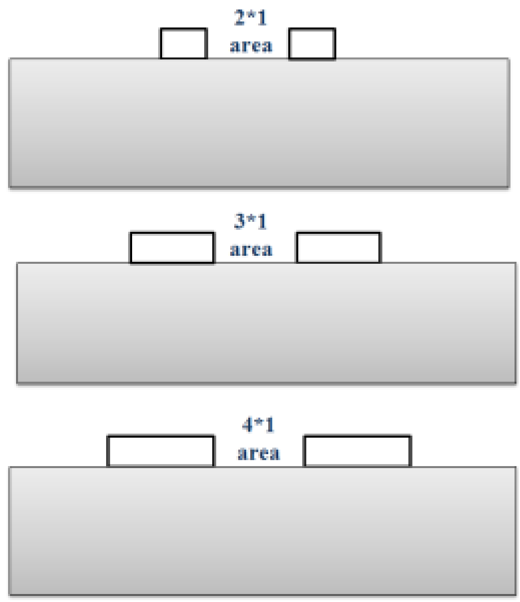


Fig-6: Changing area of electrodes.

RESULT

Acquiring satisfying values for electric field the optimal results of simulation are drawn as:

- The area of electrode = 3*1 mm^2
- Inter-distance between electrodes = 10mm

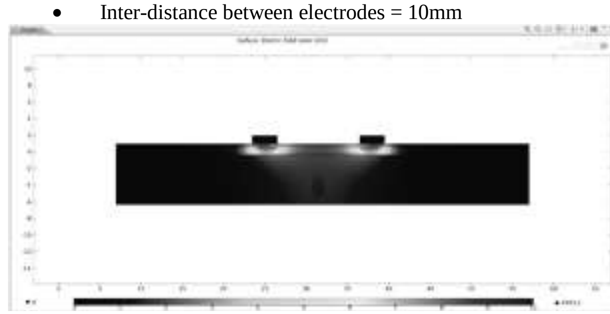
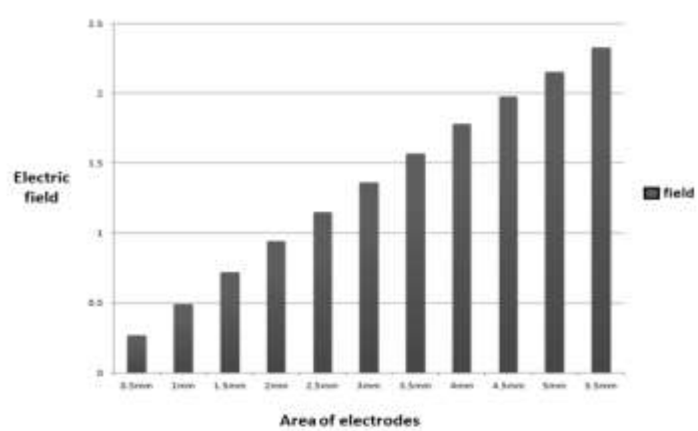
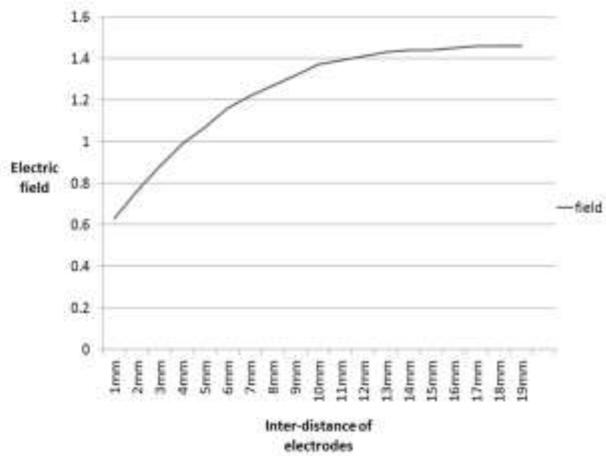


Fig-7: final model showing electrodes size and inter-distance.

Due to changing area of electrodes resulting electric field graphically appeared as follows:



By changing inter-distance of electrodes respective electric field graphically appeared as:



At the selected dimensions and inter-distance of electrodes value of electric field was found to be 1.37 S/m. This field was strong enough to stimulate anterior tibial artery without being perilous.

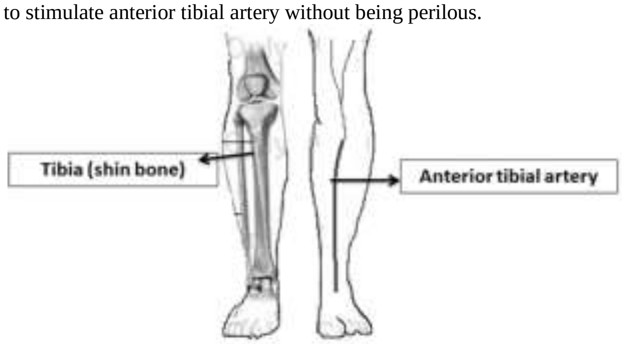


Fig-8(a): labeled diagram of tibial bone and artery

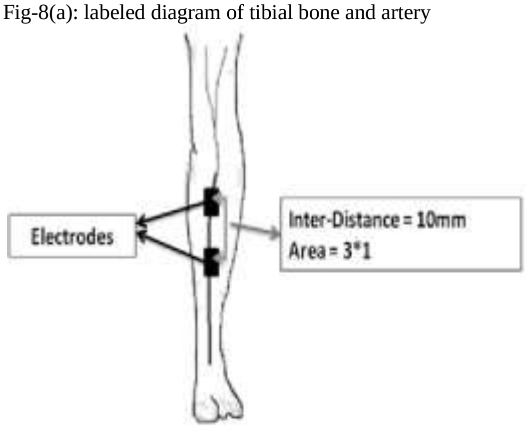


Fig-8(b): Placement of electrodes to stimulate tibial artery.

CONCLUSION

The designed electrodes are capable of producing sufficient amount of electric field to stimulate anterior tibial artery. There size and placement has been tested by simulation results hence these electrodes can be useful in different procedures, example: to estimate volume of blood flowing through the artery, pulsation rate and more importantly the electrodes are well organized to be used in the method of Electrical impedance plethysmography.

DISCUSSION

Modeling and simulation plays a vital role in scientific researches these days. It provides an enormous platform for different physiological processes to be modeled and simulated and study their behavior in different circumstances without actually testing it in real life in order to develop new remedies in medicine's world. The 2006 National Science Foundation (NSF) Report on "Simulation-based Engineering Science" [9] showed the prospective of using simulation technology and methods to modernize the engineering science.The results of this research are also achieve by modeling the human skin along with the artery and electrodes, simulating it to get required amount of electrical field that can be useful for the procedure of EIP. T he size and distance between two electrodes that are capable of producing sufficient electric field is found to be $3*1mm^2$ and 10mm respectively.The conclusion derived by changing area of electrodes and distance between electrodes is the varying effect of electric field around artery. As the size of electrodes increases the amount of ions increases in electrode material providing increased electric field. In case of distance between electrodes at one point the value of electric field became constant representing the complete penetration into the artery hence increasing distance afterward produce no change in the value.

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