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Electrical Impedance Plethysmography - Effect of Electrical Field through Normal and Stented Artery

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Abstract. A stent in the body of a cardiovascular patient, though may not have any harmful effect whatsoever, but it does effect the conductivity levels of an artery. The properties of a stented artery differ from a normal artery, since a stent is usually a typical stainless steel mesh. This paper investigated a non-invasive technique for the study of change in electrical field through the normal as well as stented artery using electrical impedance plethysmography.

Keywords; Impedance Plethysmography; Stented Artery; Comsol Multiphysics

1. Introduction

PERCUTANEOUS Coronary Intervention, commonly known as Angioplasty, or Coronary Angioplasty, is considered as a non-surgical method for the treatment of the narrowed or stenotic arteries of the heart due to Coronary Heart Disease. The stenotic artery is due to the buildup of fatty cholesterol that causes a blockage of blood flow to myocardium. The development of stenosis in an artery is termed as Atherosclerosis. The gradual increase of cholesterol in the coronary arteries can lead to Coronary Heart Disease, which can lead to hardening or rupturing of the artery as well as reduction in the oxygenated blood flow of the heart.

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Angioplasty is done in patients who fall prone to arterial blockage, and in order to help the flow return to normal, a thin catheter with a stent at its tip is guided through the network of blood vessels right on to the affected artery where a minute stent is placed alongside the wall of the artery to unblock it. The stent itself forms a support to arterial wall reducing the chances of artery blockage again as shown in fig 1.

Among the types of stent available during the treatment, the most common ones include bare metal stents, including a mesh-like tube thinnest wire of the 316L Stainless Steel. The recent advancements also employ the cobalt chromium alloy, however, the implementation of our research has been upon the 316L Stainless Steel [1]. Also consideration has been given to the drug-eluting stents, which serves the purpose of slow blockage of cell proliferation. The electrical properties of a stented artery differ from normal artery since a stent is usually a typical stainless steel mesh, causing a dubious change in the electrochemical property of the stented artery itself.

The method of electrical impedance plethysmography has been utilized for the analysis of cardiovascular function in space flights, which led to the interest in the usage of electrical impedance plethysmography or the electrical impedance phlebography as a non-invasive method for the analysis of cardiovascular fluid dynamics and output [2]. As the blood pressure varies in the body, a change in the fluid dynamics of the artery is observable which is then helpful in calculation of the impedance of the artery [3].

When the subject of consideration is the arteries, the method is innovated to impedance arteriography which observes the pulsatile flow of arteries to record a relative electrical resistance on a graph. Impedance arteriography can help record simultaneous readings of an electrocardiogram and additional parameters like pulse arrival and transit times. One of the problems that is controversial when it comes to stenting is the compliance mismatch within the artery. With the help of studying surface field norm, we can also determine a developmental design to minimize the mismatch and avoid the errors like graft failure and incompatibility.

This paper investigated a non-invasive technique for the study of blood volume through the normal as well as stented artery using electrical impedance plethysmography.

2. Materials

The purpose of electrical impedance plethysmography was to ensure the safe and proper placement of electrodes so that it penetrated the radial artery. Arteries, unlike veins are placed deep within the muscle under the distinct layers of stratum corneum, epidermis and dermis. After undergoing the ultrasound of Radial artery, Temporal Artery and Dorsalis Pedis, Radial Artery was chosen for its proximal location. The model of the skin layers is briefly described in fig. 1.

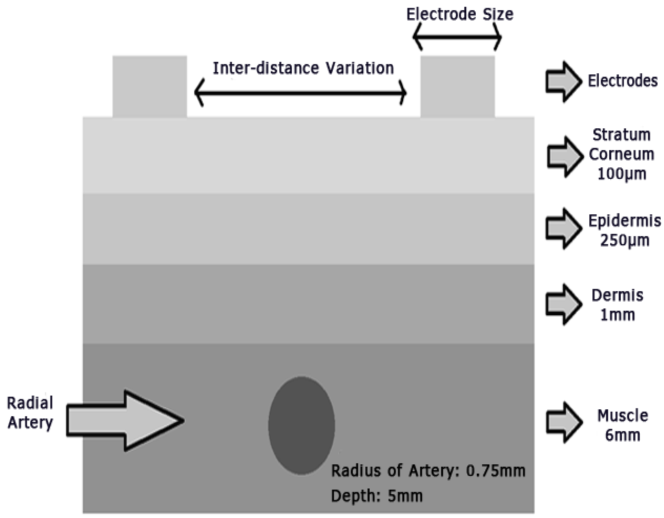

Fig. 1. Model of depth of layers of the skin with respect to skin surface

Average stents available in the market range in materials from Stainless Steel (140um), Nitinol (136um), and Cobalt- Chromium-Molybdenum Alloy (124um) to Tantanium (78um) depending on the diameter of the mesh [5]. Each material has its own advantages and disadvantages and hold different preferences at each healthcare facility. Their choice for researchers varies on the basis of their electrical and physiological reactivity when introduced within the bloodstream. Few of these factors can include the surface electric charge, free surface energy and blood clotting.

The levels of reactivity of any metal surface that are placed in contact with the living organism tissues can lead a strong impact, which is why we need to select a material that is highly biocompatible. The net charges of electrical potential and surface electric charge are also taken into consideration as most of the materials that are used by the stent manufacturers are metals or alloys. Most of these metals and alloys, when placed in an electrolytic solution, display a positive charge, whereas the internal environment of the body is negatively charged [6].

3. Methodology

Blood is stated to have a considerable amount of electrical conductivity and inversely reflects the electrical impedance of a body segment at any given time. The basic methodology for the simulation of the research was the implementation of the design of the two surface electrodes that were providing a feedback network for the transmission of sustainable voltages and recording the difference between the rate of the change in the electrical field norm versus the inter-distance and changeable size of the surface electrodes. A comparative study for the ideal placement of the electrode had to be observed to ensure that the penetration of the electrical voltage is reachable to the surface artery without damaging the neighboring cells and tissues.

For building the skin model in order to simulate, Comsol Multiphysics 4.32 was used instead of traditional Matlab and other programming software due to its user-friendliness, time-saving and promising results. The stent used for this study was Stainless Steel for its physiological parameters of conductivity, permittivity, heat capacity and density are built into the software [4].

Using the design of a bi-electrode system and judging the size and the distance between the electrodes, we can assess the optimum positioning of the electrodes that are to be placed on the surface of the skin along with the electric field that should be generated. This field should be of a value that is bearable to the stented artery. A constant current is allowed to flow through the body segment allowing a generation of an electric field norm which senses an amplitude that is directly proportional to the electrical impedance being produced within the radial arterial region.

4. Results

A graph was plotted to study the relation between the inter-distance and the electrical field to study the initial conductivity differences when measuring the electrical impedance of a stented vs a normal artery, which is shown in the figure 2.

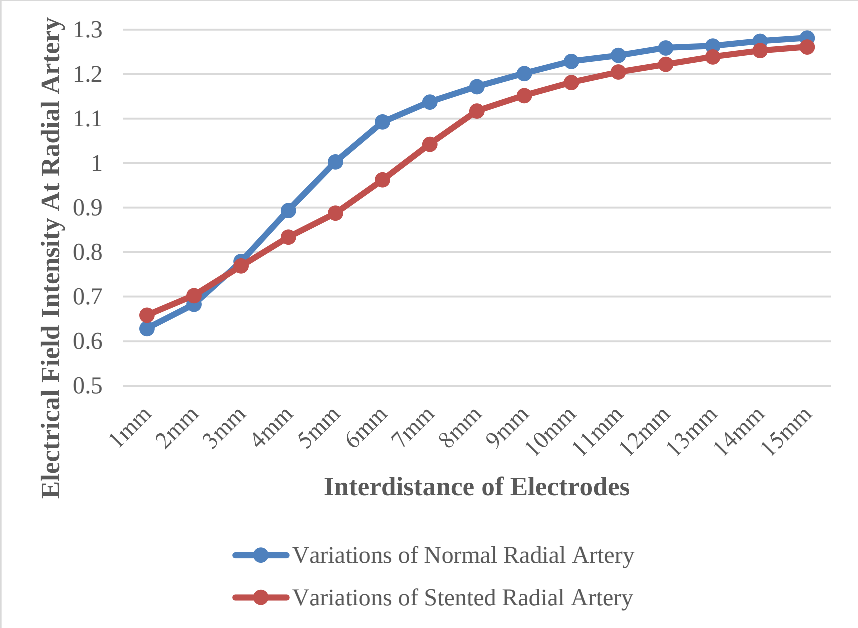

Fig. 2. Varying inter-distance of electrodes and study of its effect on a stented radial artery as well as a normal artery at a range of 1mm to 15mm with an observation of the electric field norm at the center of the radial artery.

5. Conclusion

From our analysis of the study, it can be concluded that the optimum placement of electrodes for electrical impedance plethysmography depends on the size and the inter-distance of the electrodes. When comparing the normal and the stented artery, it was studied that the electrical field penetrated more at the normal artery where the physiological parameters of the meshed stent were not a barrier.

Through our research paper, we can help improve the alloy that we use within the metallic stent to create more feasible and patient-friendly stent which presents itself as a minimal threat to the external parameters a body can be exposed to under given circumstances. These results can also lead a way to a better degradable material that withholds a longer time within the human body without risking the physiological health of the patient.

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