

Evaluation of Cardiac Pacemakers: An Electronics Perspective

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ABSTRACT: Microelectro mechanical systems are playing a crucial role in the rapid development of medical field. Biomems is a subset of microelectro mechanical system. It includes mems devices for biological applications such as pacemakers, biosensors. Pacemaker is a small device placed in chest to help control abnormal heart rhythms. Its main components consist of pulse Generator, battery, leads and electrodes. The electrode is an uninsulated termination of the lead which is in direct contact with the heart. The geometry and material of electrode are very important factors for its working which can be studied using COMSOL Tool based on FEM. FEM is a numerical method for solving the problems of engineering and mathematical physics. To solve the problem, it subdivides a large problem into smaller simpler parts called finite elements.

KEYWORDS: BioMems, Pacemaker, FEM, Electrode, Heart

I. INTRODUCTION

Bio-MEMS is an abbreviation for **Biomedical (or Biological) Microelectromechanical Systems**. MEMS devices are manufactured using similar micro fabrication techniques as those used to create integrated circuits. They often, however, have moving components that allow physical or analytical functions to be performed by the device. Although MEMS can be aseptically fabricated and hermetically sealed, biocompatibility of the component materials is a key issue for MEMS used in vivo. Interest in MEMS for biological applications (BioMEMS) is growing rapidly, with opportunities in areas such as biosensors, pacemakers, immunoisolation capsules, and drug delivery. [11]

The cardiac pacemaker was the first electronic device ever surgically implanted inside a human and is a demonstration of the success that can be achieved through the collaboration of the medical and engineering fields to solve medical problems. It is one of the few examples of widely used implantable devices that can be considered truly biologically integrated, and which has addressed the issues of device function, reliability, biocompatibility, sensing, and response to biological feedback. In light of our consideration of the potential for implantable MEMS, perhaps the most important aspect of the cardiac pacemaker is that it functions as an actuator or regulator for patients with cardiac arrhythmias, and is capable of restarting or correcting the beating of the heart. In this sense, the pacemaker works in tandem with the body's own cardiac system, interacting physically and electrically with the tissue of the body to correct malfunctions. There have been many technological advances and rapid clinical progress during the past 40 years. Indications for permanent pacemakers have been greatly expanded to address a wide variety of specific cardiac arrhythmic problems.

On the other hand, the introduction of microprocessors and miniaturization technologies has transformed the pacemakers from bulky, single-chamber, asynchronous (fixed rate) units to small, multiprogrammable, dual chamber, and rate adaptive devices with diagnostic functions. The obvious advantages of rate adaptive over fixed rate pacing

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have driven great interest in the development and implementation of rate adaptive pacemakers. The key technology in this development is the incorporation of one or multiple special sensors that can measure physiological signals so that pacing can be adjusted to match the cardiac output to the metabolic need. A sensor for rate adaptive pacing would ideally closely mimic the response of the sinus node with quick response to the different levels of exercise. Many sensors have been investigated, but none of them truly meets this goal. Accelerometer-based activity sensors (using piezoelectric crystals) are the most popular sensors used today. There are other sensors based on minute ventilation, Q-T interval, oxygen saturation, central venous temperature, rate of rise of ventricular pressure (dp/dt), pre-ejection interval (PEI), peak endocardial acceleration (PEA), and intracardiac impedance. Combinations of sensors have also been investigated. The combination of an activity sensor with a minute ventilation sensor, for example, has been shown to provide more physiological response to exercise. [3]

II.HUMAN HEART AND PACEMAKER

The human heart is an organ that pumps blood throughout the body via circulatory system. It consists of four chambers: two upper chambers (atria) and two lower chambers (ventricles). The right atrium and right ventricle make up the right heart. The left atrium and left ventricle make up the left heart. A wall of muscles called septum separates two sides of the heart. The heart's outer wall consists of three layers. The outermost wall is epicardium. The middle layer is myocardium, contains the muscle that contracts. The inner layer is endocardium, is the lining that contacts blood.[12]

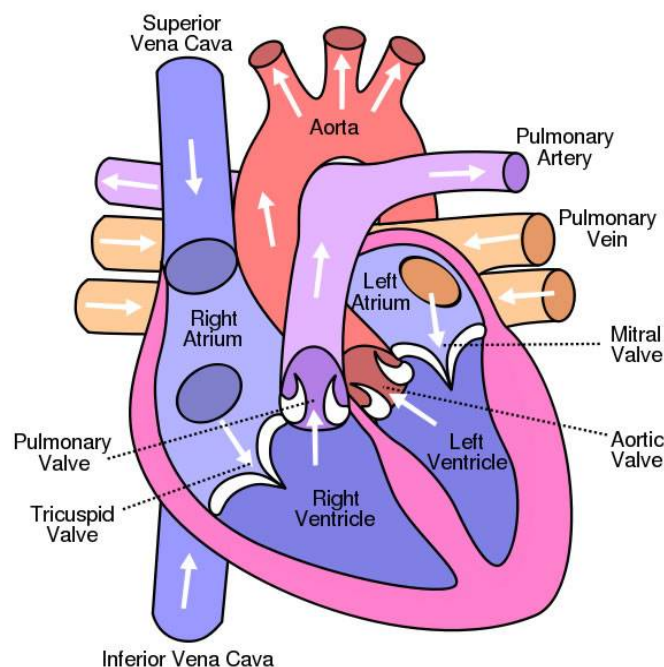


Figure 1: Human Heart

Figure shows a well labeled diagram of human heart. The arteries carry oxygenated blood away from heart and veins carry deoxygenated blood towards the heart. This can be well understood from the direction of arrows shown in figure.

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Cardiac Pacemaker is a device placed under the skin on your chest, just under patient's collarbone. It makes the beating of heart regular. A person needs pacemaker when the heart beats too fast or too slow or if heart misses a beat or there is a block in the heart's electrical pathways.

Sino Atrial Node (Natural Pacemaker) is a group of cells positioned on the wall of right atrium near the entrance of the superior vena cava. Cells in SA node spontaneously depolarize resulting in contraction approximately 100 times per minute. The native rate is constantly modified by the activity of sympathetic and parasympathetic nerve fibers so the average resting cardiac rest in adults' humans is about 70 beats per minute. Because the Sino Atrial node is responsible for the rest of the heart's electrical activity, it is sometimes called the primary pacemaker. [10]

Secondary Pacemaker (Atrioventricular Node and Bundle of His):- If the SA node doesn't function properly and is unable to control the heart rate, a group of cells further down the heart will become ectopic pacemaker of the heart. These cells are atrioventricular node which is an area between left atrium and right ventricle. It takes over the pacemakers responsibility. The cells of the AV node normally discharge at about 40-60 beats per minute and are called secondary pacemaker. [7]

Artificial Pacemaker is a medical device which uses electrical impulses delivered by electrodes contracting the heart muscles to regulate the beating of heart. The primary purpose of a pacemaker is to maintain an adequate heart rate when the heart's natural pacemaker is not fast enough or there is a blockage in the heart's electrical conduction system. Modern pacemakers are externally programmable and allow a cardiologist to select an optimum pacing for an individual patient. [8]

III. COMPONENTS OF A PACEMAKER

A permanent pacemaker has three main components described as follows:-

Pulse Generator:-A pulse generator has a sealed lithium battery and an electronic circuitry package. The pulse generator produces the electrical impulse that make the heart beat.

Leads or Wires:-leads are the insulated wires that conduct electrical signals from the pulse generator to the heart. The leads also relay signals from heart to the pulse generator. One end of the lead is attached to the pulse generator and other end of the leads is positioned in the heart chambers. Pacemaker can sense when the heart's natural rate falls below the rate that has been programmed into the pacemaker's circuitry. Pacemaker leads can be positioned into the right atrium, right ventricle or positioned to pace both ventricles depending upon the condition requiring the pacemaker to be inserted. An Atrial arrhythmia can be treated with an atrial permanent pacemaker whose lead is located in the atrium. When the ventricles are not stimulated normally, a ventricular pacemaker whose lead is located in the ventricle is used. It is possible to have both atrial and ventricular arrhythmias and there are pacemakers whose leads are placed in both atrium and ventricles. Pacemakers that pace the right atrium or right ventricle are called **single chamber pacemaker**. Pacemaker that pace both the right atrium and right ventricle and require two leads are called **dual chamber pacemakers**. Pacemakers that pace the right atrium and both the right and left ventricle are called **biventricular pacemakers**. [9]

Pacemaker Electrodes:-The two types of electrodes are Working electrode and counter electrode.

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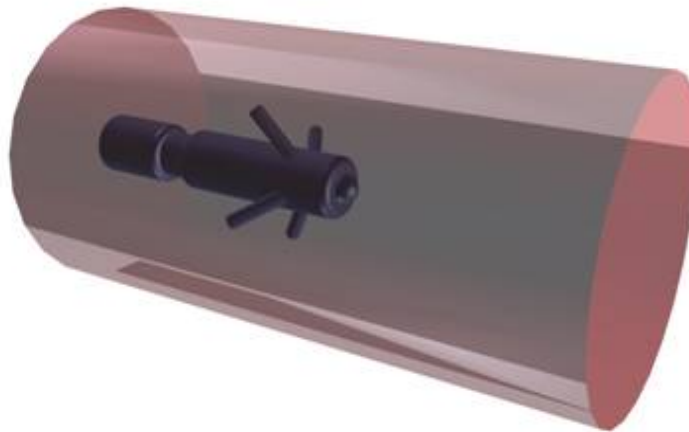


Figure 2: Pacemaker Electrode

Figure shows the electrodes in a darker shade while the surrounding modelling domain is shown in lighter shade. The working electrode consists of a hemisphere placed on the tip of supporting cylindrical structure. The counter electrode is placed in the waist of this structure.

IV. LITERATURE REVIEW

- (1) **JOEL VOLDMAN et al. [1999]** presented a work on the “**Micro Fabrication in Biology and Medicine**”. Micro fabrication uses integrated circuit manufacturing technology supplemented by its own processes to create objects with dimensions in the range of micrometers to millimetres. These objects can have miniature moving parts, stationary structures or both. Micro fabrication has been used for many applications in biology and medicine. These applications fall into four domains: tools for molecular biology and biochemistry, tools for cell biology, medical devices and biosensors. Micro fabrication can confer different types of advantages, such as higher surface-area-to-volume ratio, small size, small sample volumes, geometrical control, constrained geometries, single-cell analysis, batch processing, high throughput, or integration. When used appropriately, these can significantly impact current biological or medical problems. Often, very simple micro fabricated solutions exist. A danger exists, though, in proclaiming this technology a panacea for a large portion of biological or medical problems. Such assertions are doomed to failure; entrenched, mature conventional technologies will continue to dominate much of biology and medicine. Micro fabrication technology is meant to supplement, not replace, these established technologies. In the future, expect to see even more cooperation between micro fabrication and biology and medicine. Commercial technologies based on micro fabricated devices will start to become part of the biological and medical-diagnostic tool kit. In addition, basic biology should see an increase in the numbers of micro fabricated devices custom-built to answer individual questions. These devices will likely contain a higher level of sophistication, taking advantage of the new micro fabrication technologies and/or more complicated structures.[1]
- (2) **L. A. GEDDES and R. ROEDER [2002]** presented a work on “**Criteria for Selection of Materials for Implanted Electrodes**”. In this paper four important criteria which must be considered while choosing the material for implanted electrode are discussed. (1) Tissue response, (2) allergic response, (3) electrode-tissue impedance, and (4) radiographic visibility. This paper discusses these four criteria and identifies the materials that are the best candidates for such electrodes. For electrodes that make ohmic contact with tissues: gold,

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platinum, platinum–iridium, tungsten, and tantalum are good candidates. The preferred insulating materials are polyimide and glass. The characteristics of stimulator output circuits and the importance of the bidirectional waveform in relation to electrode decomposition are discussed. The paper concludes with an analysis, the design criteria, and the special properties and materials for capacitive recording and stimulating electrodes. Based on the above mentioned four criteria, it is necessary to distinguish between stimulating and recording electrodes. From the study by White and Thomas (1974) the best metals are platinum, iridium, and rhodium, the latter being less visible radio graphically. Gold is also a candidate for recording (non-current carrying) electrodes. The choice for stimulating electrodes is platinum, platinum–iridium, gold, tungsten, and rhodium, the latter being a little less visible radio graphically. For capacitive stimulating electrodes, tantalum pent oxide has the highest dielectric constant, followed by iridium oxide. Aluminum oxide is a candidate with a lower dielectric constant. [2]

- (3) **AMY C. RICHARDS GRAYSON et al. [2004] presented a work on “MEMS Technology for Physiologically Integrated Devices”** MEMS have many characteristics that make them appealing for biological applications, including the ability to control their physical and chemical characteristics on the micrometer and nanometer scale. Additionally, the exact temporal control that can be achieved over MEMS operation makes the devices particularly attractive for drug delivery applications where precise dosing is required. The microchip for drug delivery developed in our laboratory, for example, is capable of pulsatile release of drugs by opening= various reservoirs on command. The addition of hydrogels, biosensors, and other features that are responsive to the local environment of the device will allow MEMS to operate in a more closely integrated manner with the biological surroundings. Further, the application of MEMS technology in novel areas such as stent fabrication and immunoisolation capsules offers the potential for significant improvements in biological integration of a wide range of implantable devices. The growing interest in combining living cells with micro fabricated devices, and in using micro fabrication technology for tissue engineering and drug delivery, may ultimately lead the way to fully integrated, MEMS-based devices that could augment or replace entire biological systems in the human body.[3]
- (4) **LAURENT DUMAS et al. [2007] presented a work on “How Genetic Algorithms can Improve Pacemaker Efficiency”** In this paper we propose the use of genetic algorithm as a tool for improving a pacemaker efficiency in a defective heart. Such a device is generally used when the electrical activity of the heart is deficient and consists in applying electrodes on several points at the surface of the heart. By optimizing the position of these electrodes with respect to well chosen criteria, we show the significant gain that can be achieved with this technique compared to a less systematic positioning. In this paper we have considered the problem of positioning the electrodes of a pacemaker in a disease heart. To achieve it efficiently, we have approached a numerical approach based on the use of a cost function. This problem can be solved using a genetic algorithm. Numerical results clearly show the large influence of the positioning of electrodes on the electrical activity recovery of heart.[4]
- (5) **SHIFALI KALRA and SANJAY MARWAHA [2013] presented a work on “Design and Optimization of Pacemaker Electrode using Finite Element Method”** The optimized design and simulation of a pacemaker electrode has been presented in this paper for modeling of current distribution in human heart using Finite Element Method. The pacemaker electrode is placed inside the heart and helps to keep a normal rhythmic activity of the patient’s heart. This model deals with the current and potential distribution around the pacemaker electrode and studying the effect of the electrode tip size on the current and potential distribution. A 3D model of pacemaker electrode has been presented in this paper for maintaining normal rhythmic activity of heart. This work also performs the analysis of the potential distribution on the surface of the electrode and the current distribution inside the human heart for different electrode tip size. [5]

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(6) S. IMAN ZONOORI et al. [2014] presented a work on “Performance Analysis in Pacemaker Electrode and Study Effect Electric Resistance. In recent years, there has been an increasing use pacemaker electrode that is placed inside the heart and helps the patient’s heart to keep a normal rhythm. In this paper, performance of pacemaker electrode and electric resistance are investigated. These structures are modeled and numerically tested by using Finite Element Method (FEM) by using Comsol Multiphysics. The created virtual models using 3D simulation and computation software proved that used shield around the heart body for reduce the effects of EM fields. In this model deals with the current and potential distribution around one pair of electrodes and study the position of the counter electrode affects the electric resistance of the pacemaker electrode. The model shows that the anchoring arms of the device have little influence on the current density distribution. Moving the location of the counter electrode closer to the anchoring arms on the device has little influence on the current distribution. The position of the counter electrode affects the electric resistance of the pacemaker electrode, which is important when designing the electric circuit, in which the pacemaker electrode is included.[6]

V. CONCLUSION

The Pacemaker is an example of amalgamation of microelectromechanical systems with medical field. While implanting its electrodes in human body elements of the electrode must be carefully chosen as some patients may be allergenic to a particular element. Moreover the element must be radio graphically visible. The geometrical parameters of electrodes such as tip size affect the current and potential distribution around the electrodes. The distance between working and counter electrode affects the electrical resistance of electrodes. These parameters can be well studied by modeling pacemaker electrode using COMSOL multiphysics.

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