Optimum Placement of Piezo-Polymer Power Harvester for Epicardial Pacemaker

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Abstract. The major drawbacks of current pacemaker are the battery replacement. Patient will need additional surgery to replace the pacemaker unit with the new one. Utilization of rechargeable battery has been proposed to overcome this problem. However, recharging a battery within the body is not feasible due to tissue-heating and battery’s charge-and-discharge life-time. By those reasons, the utilization of piezo-polymer is suitable for a self-powered pacemaker as energy harvester. Piezo-polymer has been widely used as energy harvesting but none for cardiothoracic implantable device. This study focuses on specific implementation of piezo-polymer for epicardial pacemaker. The proposed fundamental research aims to identify the optimum location on the heart to put the piezo-polymer. This research will be conducted by simulation of left ventricle of heart via ANSYS. Heart stress-strain Finite Element Analysis (FEA) will be employed to obtain the maximum harvested power. The result shows the location of myocardial contraction that produces sufficient kinetic energy for the placement of the pacemaker. The heart 3-dimensional images are taken from cardiac-CT or cardiac-MRI to search the optimum location on the heart for energy harvesting and minimize pacing energy. In conclusion, the left ventricular wall motion and deformation caused by the cardiac wall movements have been analysed based on the left ventricle model in the simulation to get the location of the maximum kinetic energy formed.

1. Introduction
Pacemaker is used to control an abnormal heart rhythm by providing and by inducing cardiac contractions with electrical stimulus to the heart [1]. Pacemaker is needed when the heart electrical system has a malfunction. In 2007, it is been estimated about 560,000 pacemaker implantation in North America and 680,000 in Europe [2]. Existing conventional and leadless pacemaker prototypes use non-rechargeable, long-life, and high-density battery to supply the power. One of the
drawbacks is, for example in paediatrics, the battery is still need to be replaced after couple of years, which means additional surgery to take out the pacemaker unit. To overcome this problem, utilization of rechargeable battery has been proposed.

One of challenges of the usage of rechargeable battery for pacemaker is recharging technique. Unlike the battery for lead-based pacemaker, which is located inside the generator exactly beneath the patient skin, battery of leadless pacemaker is located inside heart chamber; therefore, it is difficult to charge wirelessly. A technique has been proposed by using radio frequency (RF) [3]. However, RF needs space for antenna for power transmission, which is not possible for small size leadless pacemaker. Furthermore, efficiency of power transmission through RF is very low, with the mostly heat dissipation goes through antenna. Ultrasound based implanted battery recharging system has been demonstrated by [4]. Their in-vitro experiment successfully harvested 600mW through 10–15 mm of tissue depth. The drawback is power transmission using ultrasound can only be limited to a certain time due to heat effect on tissue and therefore, not suitable for leadless pacemaker.

The power may be obtained from several sources, such as: sound, solar, body heat, breathing, movement [5], muscle, joint movement, and glucose-based biofuel cell. Piezoelectric materials are one of the emerging concepts to provide self-energy harvested from human body. One of the promising materials for the pacemaker energy harvester is polymer piezoelectric (piezo-polymer). Although the electromechanical coupling factor is not as high as ceramic-based, piezo-polymer is biocompatible and more mechanically flexible; both are very important factors for implanted medical devices.

Energy harvesting by using piezoelectric materials may result in sufficient energy for pacemaker depending on the properties they have. One of the hypotheses provided by [6] has estimated that the power resulted from piezoelectric materials from heart movement could achieve hundreds of μJ.

2. Methodology

The methodology that will be applied by the study has been chosen in order to provide the useful information about the kinetic energy production at the left ventricle of heart. The idea of this research is to propose an ideal concept of leadless pacemaker which is “Implant and Forget”. For this purpose, a continuous electrical power supply from energy harvester is an essential factor. The kinetic energy may supply the energy in order to make the pacemaker to be self-powered continuously. Figure 1 shows the steps involve in this methodology.

![Figure 1. The flowchart of the methodology.](image-url)
Based on Figure 1, the data is collected for designing and running the simulation. There are 2 types of data which is the pre-processing data and post-processing data. The pre-processing data is collected in order to design the structure of the heart, according to the real organ. The data includes the dimension of the heart, the density, Young Modulus and Poisson ratio. The collected data will be inserted as the engineering data inside the simulation software.

The heart is cone-shaped. The base positioned upwards and tapered down to the apex. The largest compartment of the heart is usually slightly left side of the chest even though it may infrequently be offset to the right. An adult heart generally has a mass in the rage of 250-350 grams. The heart size is usually described as the size of its individual fist, with typical values of 120mm in length, 80mm wide and 60mm in thickness. The dimension of heart in Figure 2 is derived from the cross diameter of each atrium and ventricle [7].

Based on Figure 2, for the estimation of ventricular dilatation, the important female cross diameter of the left ventricle is $45.2 \pm 3.4$ mm diastolic and $30.5 \pm 3.5$ mm systolic. For the right ventricle, it is $30.7 \pm 3.8$ mm diastolic and $22.3 \pm 3.8$ mm systolic. For the determination of a left ventricular hypertrophy, relevant thickness of the septal wall measured in the short axis of the female left ventricle are approximately $8.0 \pm 1.0$ mm diastolic and $10.9 \pm 1.4$ mm systolic. Meanwhile, the measurement of male left ventricle cross diameter is $51.6 \pm 4.6$ mm diastolic and $33.8 \pm 3.6$ mm systolic. For the right ventricle, it is $37.1 \pm 5.9$ mm diastolic and $28.1 \pm 4.4$ mm systolic. For the left ventricular hypertrophy, the relevant septal wall thickness is $9.9 \pm 1.2$ mm diastolic and $13.6 \pm 1.9$ mm systolic [8].

Figure 3 and 4 show the geometries design of the heart and the left ventricle that is used for the simulation that have been constructed in 3-Dimension by using Solidworks software. The shape of heart is created by combining the triangular facet. The shape has only the surface of outermost layer which represent the heart wall. The left ventricle geometry then is saved as IGES file in order to import it into ANSYS 16.0 software for the Finite Element Analysis (FEA). The Dynamic Explicit is selected for the simulation because the study of the heart is undergoing the time-varying behaviour. In the software, it is compulsory to select the engineering data, trim the geometry, and set the boundary condition. Table 1 shows the engineering data that has been used in ANSYS.
Table 1. The Engineering Data for the simulation.

| Property                | Typical value |
|-------------------------|---------------|
| Modulus (MPa)           | 10-60         |
| Density (kg/m³)         | 1037          |
| Poisson ratio           | 0.4           |
| Bulk Modulus (MPa)      | 25            |
| Thickness (mm)          | 11            |

Based on Table 1, the engineering data is used as the input to simulate the geometry. The Post-processing data is the data that is the result provided after the simulation running. The provided data is the information regarding the location and the kinetic energy.

3. Results and Discussion

The results of finite element analysis are presented where the location of kinetic is formed. The result of the total deformation shows the colour contour that represents the movement of the left ventricle. The force from myocardial contraction and relaxation could provide piezo-polymer sufficient power to supply epicardial pacemaker with small dimension. This needs identification of the best harvesting placement and designing multilayer piezo-polymer. Figure 5 shows the total deformation of the left ventricle after the complete simulation and the location of the optimum kinetic energy produce for the placement of the pacemaker.

![Figure 5. Total deformation of the left ventricle after the simulation complete.](image)

Based on Figure 5, the optimum location of power harvesting for each pacing placement is located at the cardiac walls which have large movements (at the red contour). The kinetic energy that has been produced is greater than the other parts of the left ventricle. However, more rigorous conformation of the results is required in order to use this methodology for the calculation of actual kinetic energy values in the cardiac wall. Besides that, there are a few obstacles when the simulation is running. Most of them are the limitation of the hardware itself. The simulation takes too much time to complete and cannot accept the large scale design. The design need to be re-meshed and affecting the resolution of the design.
4. Conclusions

From the research, we can conclude several conclusions which are;

i. The myocardial contractility is able to produce sufficient force for piezo-polymer material to provide sufficient power for epicardial pacemaker pulse generator. It is a huge benefit towards self-powered pacemakers.

ii. The generated power from piezo-polymer could be optimized by providing best placement of the pacemaker on the heart epicardium. However, besides maximum power generated, the placement should also consider the location for effective pacing.

iii. The generated power from the piezo-polymer implanted on the heart epicardium could be improved by designing the piezo-polymer in multilayer topology and proper shape. The harvested power could be improved by properly tuning the Piezo-polymer resonance frequency that matches with the frequency of heart motion.

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