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Lifelong pacemaker powered by heart-beats using bio-compatible animal bones

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Abstract- **Several different models of permanent implantable pacemakers, both simple and programmed, have become widely used in recent years. They are run by batteries and these batteries needs to be replaced after certain period of time. So a new approach can be done for the Pacemaker construction using Bio-Compatible animal bones. Bones are now well accepted as piezoelectric materials. Piezoelectric materials have the ability to transform mechanical strain energy into electrical charge and, vice versa, to convert an applied electrical potential into mechanical strain. Bones shows both the direct and the converse piezoelectric effects. This property provides the bones with the ability to absorb mechanical energy from heart-beats and transform it into electrical energy that can be used to power the pacemaker.**

1. INTRODUCTION

In the early 1970s cardiac pacemakers were powered by mercury-zinc batteries. These batteries would run the simple circuitry of these early pacemakers for a maximum of 3 years. Most often however, the mercury cells would fail in barely 20 months, which forced patients to undergo frequent surgeries to perform device replacements.

Nuclear batteries were also introduced in the pacing industry around 1973 to prolong the longevity of the implanted device. However, by the mid-1970s, nuclear pacemakers were displaced by devices powered by lithium cells. The lithium-powered units had a calculated longevity of approximately 10 years.

Now a new approach can be made to increase the life time of the pacemaker using biocompatible bones. The piezoelectric property of bone discovered earlier can be utilized to power pacemaker installed in human body using the vibrations produced by the heart beats. The bone functions as a transducer or a sensor, converting mechanical energy to electrical energy or vice versa. The bone shows piezoelectric effect both in the solid and in the powdered form. Thus biocompatible bones can be utilized for the construction of pacemaker which can utilize the heart beat vibrations to power the device.

2. PACEMAKER & ITS BASIC OPERATIONS

Arrhythmias are treated by Pacemaker. These are problems related to the rate or rhythm of the heartbeat. During an arrhythmia, the heart can beat too fast, too slow, or with an irregular rhythm. A heartbeat that's too fast is called tachycardia. A heartbeat that's too slow is called bradycardia. During an arrhythmia, the heart may not be able to pump enough blood to the body. This may cause symptoms such as fatigue (tiredness), shortness of breath, or fainting. Severe arrhythmias can damage the body's vital organs and may even cause loss of consciousness or death.

Arrhythmia symptoms, such as fatigue and fainting can be relieved by using pacemaker. A pacemaker also can help a person who has abnormal heart rhythms resume a more active lifestyle.

The Heart's natural pacemaker – the SA node – sends out regular electrical impulses from the top chamber (the atrium) causing it to contract and pump blood into the bottom chamber (the ventricle). The electrical impulse is then conducted to the ventricles through a form of 'junction box' called the AV node. The impulse spreads into the ventricles, causing the muscle to contract and to pump out the blood. The blood from the right ventricle goes to the lungs, and the blood from the left ventricles goes to the body.

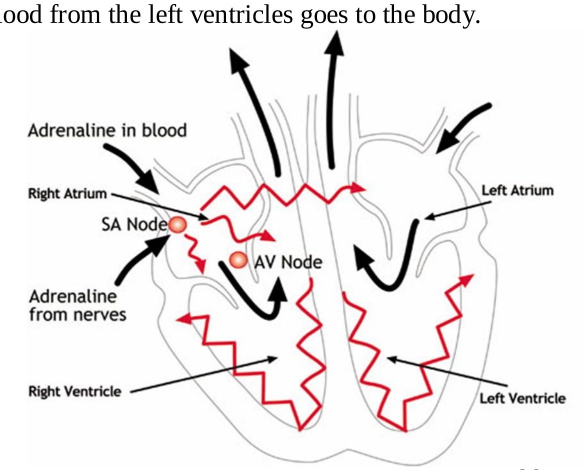

Figure. 1. Heart's Natural Pacemaker [1]

Now an implanted pacemaker system has a pulse generator (the actual pacemaker) and one, two or three electrode leads. Pacemakers with one lead are called Single-chamber pacemakers. Pacemakers with two leads are called dual-chamber pacemakers. A pacemaker with three leads is called a bi-ventricular pacemaker.

The pacemaker has two parts - the power supply (or battery) and the electronic circuit. It is sealed in metal to stop body fluids leaking in. The whole pacemaker weighs only about

20 to 50 grams (1 to 2 ounces) and is smaller than a matchbox. Most pacemakers are powered by a lithium battery. Pacemakers usually last between six and ten years before they need to be replaced.

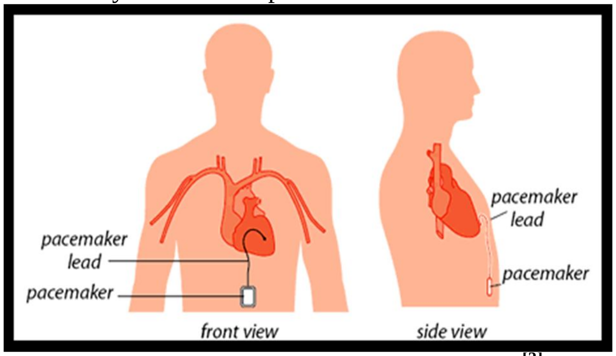

Figure. 2. Pacemaker Implantation[2]

The electronic circuit in the pacemaker draws energy from the battery and turns it into electrical impulses. These are conducted down the electrode lead to the heart. Each electrical impulse sent by the pacemaker stimulates the heart to contract and produce a heartbeat. The rate at which these electrical impulses are sent out is called the 'discharge rate'. Now the challenge is to create pacemaker using biocompatible bone material. Bone being a piezoelectric material can be used to generate sufficient electricity using the vibrations produced by the heart beats. Thus it will be "Battery-Free" and smaller in size.

3. PIEZOELECTRIC EFFECT

A piezoelectric substance is one that produces an electric charge when a mechanical stress is applied (the substance is squeezed or stretched). Conversely, a mechanical deformation (the substance shrinks or expands) is produced when an electric field is applied. This effect is formed in crystals that have no center of symmetry. Each molecule has a polarization, one end is more negatively charged and the other end is positively charged, and is called a dipole. This is a result of the atoms that make up the molecule and the way the molecules are shaped. The polar axis is an imaginary line that runs through the center of both charges on the molecule. In a mono-crystal the polar axes of all of the dipoles lie in one direction. The crystal is said to be symmetrical because if you were to cut the crystal at any point, the resultant polar axes of the two pieces would lie in the same direction as the original. In a poly-crystal, there are different regions within the material that have a different polar axis. It is asymmetrical because there is no point at which the crystal could be cut that would leave the two remaining pieces with the same resultant polar axis. In order to produce the piezoelectric effect, the poly-crystal is heated under the application of a strong electric field. The heat allows the molecules to move more freely and the electric field forces all of the dipoles in the crystal to line up and fact in nearly the same direction.

4. PIEZOELECTRIC EFFECT OF BONES

From the different experiments conducted by Eiichi Fukuda and Iwao Yasuda it was observed that bone shows piezoelectric effects. The specimens were cut out from the femur of man and ox. They were dried completely by heating. The piezoelectric constants were measured by three different experiments, that is, measurement of the static direct effect, the dynamic direct effect and the dynamic converse effect. It was found that the maximum value of the piezoelectric constants amounts to $6x10^{-9}$ c.g.s.e.s.u., which is about one-tenth of piezoelectric constant d_{11} of quartz crystal. The specimens were boiled in hot water and afterwards dried completely showed little change in piezoelectric effect. The origin to piezoelectricity in bone maybe ascribed to piezoelectric effect of the crystalline micelle of collagen molecules.

The bone of femur is comprised of outer hard layers of collagen and inner soft tissues. If one takes out these tissues, the most parts of bone look like a hollow cylinder except the two ends which has weird shapes. It basically consists of highly oriented collagen fibres and inorganic crystals, called apatite, imbedded among collagen fibres. The axis of the bone is designated as the direction of length of the cylinder.
Femur of a man and an ox were taken and small square plates of bones were cut out from them. The length of the edge of square plates of bone was cut out from the outer layer of the femur of a man and an ox. The length of the edge of square plates was about 90 to 15mm. The thickness was about 2 to 3mm. Specimens obtained from the femur of man had been air-dried for a week or so in a desiccators containing calcium chloride before measurements. Specimens obtained from the femur of ox were heated up to about 120^{o}C for about 5 hours for drying. Some specimens were boiled in the hot water for about 2 hours and then dried by the same way.
And now a very thin silver foils were attached to the square planes by means of alcoholic solution of shellac and those were used as electrodes.

5. MEASUREMENT OF THE ELECTRIC CHARGE PRODUCED IN BONES DUE TO DIRECT PIEZOELECTRIC EFFECT.

In this paper we are mainly concerned with the direct piezoelectric effect. It was already shown in a paper[4, 7)] by Kanika Singh and in a paper[3)] by Eiichi Fukuda and Iwao Yasuda which is discussed in brief under this column. The direct effect could be observed easily by the static method

Table 1
BONE SAMPLE CHARACTERISTICS [4]

Different Parameters	Solid Bones	Bone Powder
Density (Kg/cubic m)	1980	2770
Capacitance (pF)	53.70	14.60
Loss Factor (tan δ)	0.0275	0.040
Dielectric Constant (K^3T)	64.10	23.20
Resistivity (ohm/cm)	$17.5X10^{-7}$	$52.0X10^{8}$

Charge Constant ($d_{33}X10^{-12}$ C/N)	55.0	30.5
Voltage Constant ($g_{33}X10^{-3}$V m/N)	95.0	148.0

The pressure was applied on the side plane of specimen by a lever mechanism and the electrical charge appeared on the square plane was led to the grid of the UX-54 vacuum tube and the deflection of a galvanometer inserted in the plate circuit was read. The dielectric constant, voltage constant and other parameters have been calculated by using the conventional relationships taken from the paper [5, 6] Table 1 gives the average piezoelectric parameters of bone samples used in the present work.

The direct piezoelectric effect can also be measured dynamically by the same apparatus as it was done to measure the converse piezoelectric effect. When electrodes of specimen are earthed and A.C. voltage is applied to the Rochelle salt crystal, the oscillating force is transmitted to the quartz and the bone. Then the output voltage of quartz due to the direct piezoelectric effect of quartz plates can be amplified and measured by the voltmeter.

6. EXPERIMENTAL RESULT

Here we are considering only the direct piezoelectric effect and thus showing the experimental results3) for direct piezoelectric effect of bone

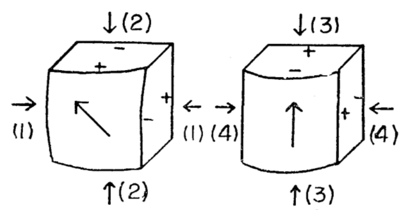

Figure. 3. Specimens of Bone[3]

Signs represent those of electric polarization which appear in square planes when pressure is applied on each side plane. When the pressure is applied on each side plane as represented by the small arrows with numbers. The sign and the amount of polarization vary considerably with the direction of pressure. The relation between polarization and applied pressure in the case of direction (1) is represented in Figure. 4. The circles and triangles donate the charge appeared on the bone plate when the pressure is applied and removed respectively. There signs are, therefore, reverse.

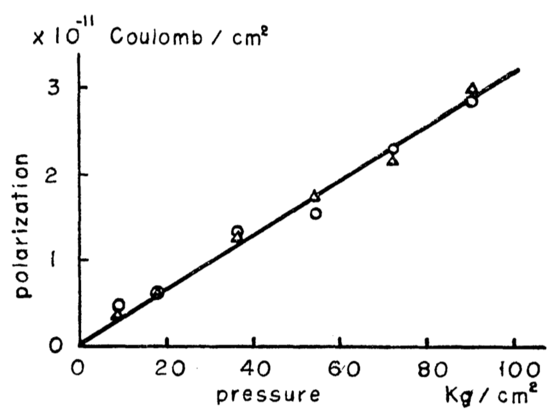

Figure. 4. The Direct Piezoelectric Effect of Bones[3]

7.WHERE TO PLACE THE PACEMAKER IN THE BODY AND ITS SIGNIFICANCE

This pace maker should be as close as possible to the heart so that it can easily pick up the vibrations from the heart thus enhancing the pacemaker to work efficiently.

With this new technology the size of the pacemaker install in the body can be reduced since the battery can be omitted in this new form. In the conventional pacemaker which is powered by battery once installed in the body needs to be changed after a certain period of time. So the patient had to go several surgeries. But in this new form of pacemaker powered by the vibrations produced by the heartbeats once installed need not be changed.

Also the reason for selecting bones as piezoelectric materials is due to its biocompatible nature.

8. CONCLUSION

This paper revolves around the use of an energy efficient, self sustainable pacemaker device using a readily available bio-compatible material i.e. bones. Bones as piezoelectric material can also be used as stepping stone in the development of various other energy efficient technologies in future.

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