The Health Benefits of Stress

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Stressed Out

Everyone knows that stress is bad for your health. It causes heart problems and is usually blamed for aging young and, really, who needs wrinkles? We are constantly told to relax and not get stressed (a fine way to stress anyone out!). Experts on television tell us that stress is a major factor in health problems later in life, but what if stress is also the solution to some of the biggest problems with advances in medical device technology?

Motivated

Medical device technology relates to anything from blood pressure cuffs to pacemakers and beyond. I am particularly interested in implantable devices, i.e. any device placed inside the body such as a pacemaker which regulates the heartbeat. These devices have to be as small as possible to fit in the correct location inside the body and they need to be reliable and ideally need to last the lifetime of the person — or as long as the person needs the device. This causes a big problem for electronic systems because battery technology has not advanced dramatically over the last few decades. There have been improvements to batteries such as the move to lithium-ion batteries and thin film batteries, i.e. batteries which are made using very thin materials so that they are not so large. However, these batteries are still new and are used in research. They do have excellent qualities such as a large capacity and many recharge cycles but these batteries still have the typical storage lifetime of the average battery. Using a rechargeable battery with our technology could show a big advancement in current implantable technology.

Another thing we can be proud of is that the batteries in pacemakers these days are not nuclear powered, although some of the earlier models were. Still, there is a major problem. Figure 1 shows a standard pacemaker of today as well as the amount of space taken up by the battery. Evidently, the battery accounts for a significant portion of the size of the pacemaker. This battery typically lasts around 10 years, which was not an issue previously as people did not live as long as they currently do. Now it is not uncommon for people to need pacemakers for decades and replacing this battery in a pacemaker requires additional surgery. This additional surgery comes with both financial costs and risks to the patient.

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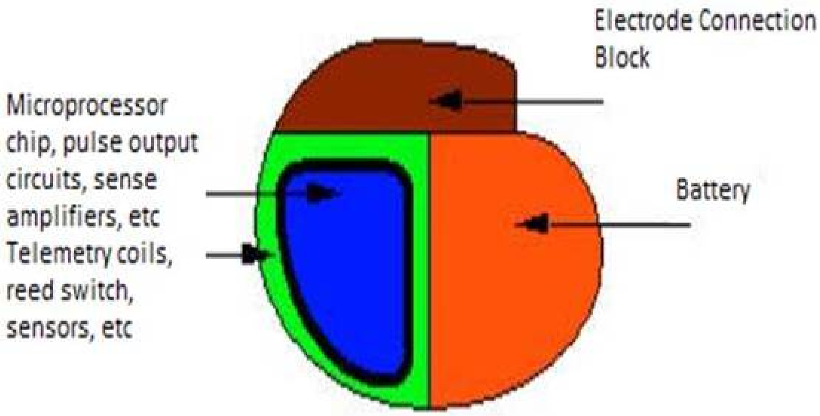

Figure 1: Typical relative size of pacemaker battery. Source: Mallela et al., Indian Pacing and Electrophysiology J. 2001, 4(4): 201-212. Reproduced here under the terms of the Creative Commons Attribution License.

Health through Stress

My research focuses on solving the problem of large battery size and short battery life by looking at ways of recharging the battery. If the battery can be regularly recharged or the device can be powered directly without the need of a battery then space can be saved and surgeries to replace the expiring battery can be avoided; after all, the reliability of the pacemaker battery is extremely important. I use a piezoelectric material in my work. A piezoelectric material is simply a material that responds to any sort of stress — bending, pulling, stretching or crushing — by generating an electric voltage. This means that if the material is stressed, for instance by keeping the edges fixed and pushing on the centre, an electric voltage is created and the electrical energy can then be stored. This stored energy can either be used to power the device directly or to recharge a battery depending on the amount of energy available.

In my work a piece of the material is placed into an artery. The blood flowing through the artery then stresses the material. Since blood flow is pulsating, the material will be moved in different directions over the course of a pulse. This is important because piezoelectric material only generates a voltage as it is being stressed.

There are a number of issues associated with this type of energy harvesting. Firstly, the devices have to be very small to fit into the artery. This means that the amount of piezoelectric material is small and because the power available is dependent on the thickness and size of the material, as well as the amount of stress to which it is subjected, the power output is small. Secondly, the devices cannot interfere too much with the flow of the blood because even a reduction of 5% in flow could prove fatal. This has been a major concern of the research to date. Furthermore, the voltage generated is AC. AC stands for alternating current and is the type of current which is available from the mains electricity supply but most devices, including implantable devices, run from a direct current (DC) supply. For non-implantable devices a rectifier is used to convert the AC mains to DC to power the device (e.g. computer, phone, and tablet). The battery in a pacemaker provides DC current. For this reason, part of my research is to change the current from AC to DC while using the least amount of power to do this. If less power is wasted converting the current, then more power will be available to supply the pacemaker itself or other implantable devices.

Once the voltage has been generated by the piezoelectric material and rectified (changed from AC to DC) it must then be either stored for future use or sent directly to the pacemaker. Currently the design considered is to send all the power to a battery and then use this battery to power the pacemaker as and when it needs it. This provides more challenges because batteries can only be recharged a maximum number of times before they are no longer usable (this is typically in the region of 1000 cycles). It is also generally considered to be better for battery lifetime to charge it to maximum and then to allow it to discharge to its minimum voltage rather than continually topping up the battery charge before it has reached its minimum voltage. To facilitate this optimum battery management, a super capacitor can be used to hold the generated charge until the battery requires it. A capacitor is a storage device which can be charged and discharged much more often than a battery and a super capacitor has the benefit of having a large capacity and a low leakage current. Leakage current is the current which is lost even when nothing is connected to the capacitor. All laptop users are familiar with the effects of leakage. If a fully charged laptop is left turned off for a few weeks, the laptop will not have full charge (and may even have no charge) when it is turned on again. This is due to the leakage current of the battery.

Don't Stress the Results

Stressed Models

I do a lot of modelling. It is a huge part of my research. This type of modelling does not require a catwalk or extreme dieting, however. I make simulations of what would happen to my devices and what effect they would have on the blood flow. These models have been used to decide which shape the devices should take to give the maximum power for the minimum effect on blood flow. What these models have shown is that using a traditional cantilever device as in figure 2(a) has a much larger effect on the flow than using more unusual designs such as the diaphragm of 4000μm diameter (thin piece of material in a circular shape) with the hole in it, as shown in figure 2(b).

The colours in figure 2 illustrate the stress in the material with blue being low stress and red being high stress. Other models have been created with the devices in a tube which represents the artery. These models give results for the effect on the flow and the power output of the devices. It was decided, based on these results, that the best choice of design

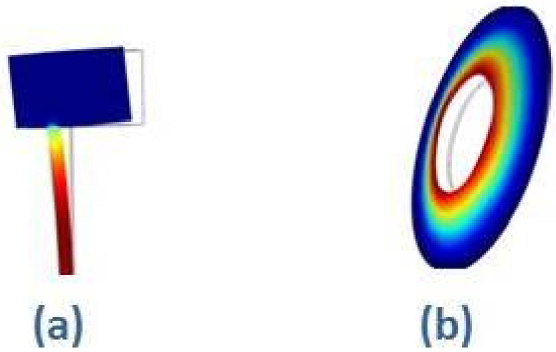

Figure 2: (a) Cantilever (b) Diaphragm with 2000μm hole. COMSOL Images: Rosemary O'Keeffe

was the diaphragm with a hole in the centre. Further models were created to determine what size the hole should be to give the maximum power output with minimum effect on flow. From these results it was determined that a hole of 2000μm diameter gives the best results. The results of the models are summarised in table 1.

Racing Pulse

Models need to be compared to physical devices to prove that they are accurate. Physical devices must also be tested to identify issues which are not apparent in the models or not taken into account due to the limit of the complexity available in the simulator. Simulators solve equations to approximate the real world conditions and the more complex a model the longer it takes to solve and the more likely it is to introduce errors. This means that the simulator makes assumptions to approximate the real world and for this reason all simulation data must be compared to real world data to verify the result. To this end, various devices were fabricated using the fabrication laboratory in Tyndall National Institute. These devices are made by depositing layers of material onto a silicon wafer (i.e. a silicon disc). To make a piezoelectric device, metal is required on both sides of the piezoelectric material to access the induced piezoelectric voltage. These devices use titanium as the bottom metal and aluminium as the top metal and the piezoelectric material is aluminium nitride. This material is particularly interesting as it only develops piezoelectric properties if it is grown in the correct way and part of the work involved

Table 1: Voltage on Device and Fluid Velocity for different hole diameters in diaphragm device

Hole Diameter (μm)	Voltage Output (V)	Fluid velocity (m/s)
2000	0.21	0.44
2500	0.19	0.44
3000	0.11	0.44
Pipe with no device in it	N/A	0.46

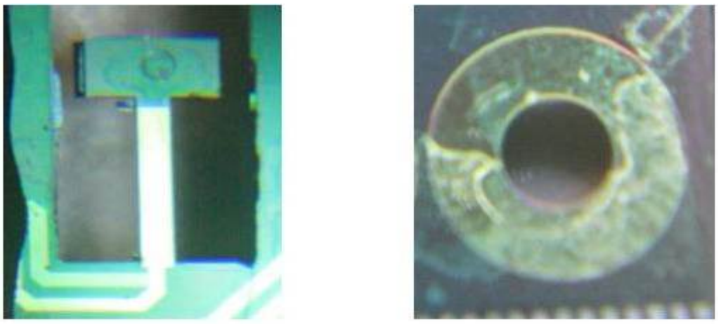

Figure 3: (a) Fabricated Cantilever (b) Fabricated Diaphragm with hole. Images: Rosemary O'Keeffe

in this research was looking at ways to get the best piezoelectric material possible. The fabricated devices are shown in figure 3.

The fabricated devices were placed into the flow from a perfusion machine (recognisable from medical shows on TV as the device used to pump blood through the body when doing a heart transplant). This machine produces a pulsating flow with the same characteristics as that which the devices would experience if they were placed in an artery. This provides results on the power and the effect on the flow which is similar to what would be expected in a real system (i.e. implanted in a person).

Conclusions and Future work

To date, the results have been promising and it is possible that an array of these devices will be able to provide enough energy to make them viable as energy harvesting devices. The next step is to look at the circuitry which will be needed to change the current from AC to DC and possibly to boost the output so that the power is larger. This type of device could also be used in other fluid networks besides biological systems such as measuring the water flowing in a pipe. In a non-biological system, the devices would probably be used to power a flow meter or similar device. There is a lot of work still to be done but results have been promising and, hopefully, soon we will have proof that stress can be good for your health!

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