Pacemaker for treating arrhythmia

Navrit Bal, Daniel Grubb, Aditya Aiyer, Edward Wu
University of California, Berkeley

Introduction

The pacemaker device serves to replicate the function of the heart's natural pacemaker cells which are located in the SA (sinoatrial) node of the heart. A pacemaker is only needed when there is some problem with the pacemaker cells - this results in an arrhythmia. There are three main types of arrhythmias: tachycardia, when the heart beats too quickly, bradycardia, when the heart beats too slowly, and irregular heartbeat, which includes fibrillation.[1]

In the late 1920's, the first pacemaking device was created, which was an external device that could stimulate the heart with electric pulses. In the early 1950's, the first portable pacemaker was created, which were again external, but could be wheeled around and needed to be plugged in. In 1958, the first completely implanted, battery operated pacemaker was created. Over the course of the rest of the 20th century, continued improvements were made including better batteries, electrodes, and leads. In the 1990's, improved pacemakers with microprocessors were created. [2]

Function

Pacemakers deliver low power electrical pulses (order of ~ -40 to -70 mV) to help restore a regular heartbeat. They can be used to treat tachycardia, bradycardia, and abnormal heartbeat by normalizing the electrical pulse that travels across the heart, starting at the SA node (sinoatrial node - natural pacemaker), and causes it to contract. The SA cells directly dictate the rate of the heart contractions by making periodic potential changes with a 3 phase system. They can monitor and record info about the patient such as cardiograms and blood pressure. Typical battery life is approximately 5-10 years depending on the usage. This paper shall only discuss single chamber pacemakers.

3 Phase system

"There are 3 phases, in order phase 4 cardiac potential, phase 0 upstroke and phase 3 repolarization. These act similarly to the cardiac muscle cell contraction phases."[3] This is shown in Figure 1 below.

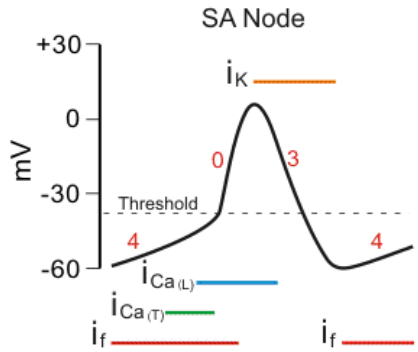


Figure 1[4] - Action potential of the Sinoatrial node of the human heart - the 3 phase system.

- 4 - The not stimulated state, recovering the ions released from the previous cycle. This is the membrane potential when the cell is not being stimulated. Normal resting membrane potential in the ventricular myocardium is about -60 to -70 mV.
- 0 - Phase 0 is the rapid depolarization phase. These signals are received effectively as binary signals - neuron spikes. This gradient is directly proportional to the net ionic current, which acts by fast Na+ channels. “If resting membrane V (y axis in figure 1) becomes too positive, the cell may not be excitable, and conduction through the heart may be delayed, increasing the risk of arrhythmias.”[3]
- 3 - Ca channels close and K channels open, this causes a repolarization of the cell to a more positive potential.

More information fully detailing these phases can be found at [4].

Components

There are pacing leads and their respective electrodes, which connect the device to the right atrium and or the right ventricle. There is a pulse generator, which actually makes the low power electrical periodic pulses. Also the battery, the programmable microprocessor with associated memory and circuitry and finally any other sensors that may be in the device.

Alternatives

ICD (Implantable Cardioverter Defibrillator)

The ICD is a device similar to the pacemaker that is able to use electrical pulses to control arrhythmias. It can detect arrhythmias and then deliver low level pulses. If this fails to normalize the heartbeat, or if it detects a more severe type of arrhythmia that could lead to cardiac arrest, it can deliver high power shocks to control it.[5] These high power shocks are effective but can be quite painful. This device can be programmed by the physician for each patient, and can collect data from the patient. The battery can last up to 7 years.[6]

Antiarrhythmic Drugs

These are drugs that normalize arrhythmias by affecting the way in which electrical signals pass through the heart. In many cases, they work by controlling the electrical signal as it passes through the AV node, which it does as it travels to the ventricles. They can suppress abnormal firings from the heart’s natural pacemaker.[7] These drugs however can act as proarrhythmics and can actually cause dangerous arrhythmias to occur. In this way, they can be less effective than other drugs. These drugs must be taken daily and indefinitely.[8]

Beta Blockers

Beta blockers are drugs that can normalize arrhythmias by blocking epinephrine binding sites on cells in the heart. Epinephrine is a chemical released by the body that causes the heart to speed up, and for certain people, it can cause arrhythmias. Beta blockers prevent these arrhythmias. Compared to the other drugs discussed, beta blockers can be

much cheaper, and are just as effective at treating arrhythmia. These drugs often slow down the heart rate, which can help treat the arrhythmias, but can also be dangerous for some patients. Beta blockers must be taken everyday.[9]

Calcium Channel Blockers

Calcium channel blockers are drugs that block the calcium ion channels of cell. The flow of calcium ions generates the action potential that causes muscles to contract, including the heart. By blocking some of these channels, these drugs can help normalize a heartbeat and prevent dangerous arrhythmias. Calcium channel blockers must be taken every day.[10]

Concept Selection Matrix

In the concept selection matrix, we chose effectiveness and risk of complications involved as the highest weighted criteria. Effectiveness is related to how effectively the device treats arrhythmias, and its reliability. Risk of complications is related to how invasive each treatment and what risk of side effects each treatment comes with. Next highest is lifespan because this corresponds to subsequent surgeries and costs. Next, is cost because this relates to how accessible the treatment is. Then comes versatility, data collection, and ease of use. Versatility relates to the ability of the treatment to treat multiple problems associated with arrhythmias.

Data collection relates to the ability of the device to collect data about the patient relating to arrhythmias, since this information is critical for physicians in deciding on future treatment for the patient. Ease of use is how the treatment affects the day-to-day life and activities for the patient. We chose the pacemaker as the standard in the matrix since it is a very established and common treatment for arrhythmia. The ICD came out on top in our analysis due to its ability to act as a pacemaker and a defibrillator, as well as its effectiveness and lower risk of complications.

	Weight	Pacemaker	ICD (Implantable cardioverter device)	Antiarrhythmic drugs	Beta blockers	Calcium channel blockers
Effectiveness	**18**	3	4	2	3	3
Complications	**18**	3	4	3	2	2
Versatility	7	3	4	2	2	2
Data collection	7	3	3	1	1	1
Life span	15	3	2	5	5	5
Cost	10	3	2	4	5	4
Ease of use	7	3	3	2	2	2
Total	100	246	264	240	250	240

Figure 2: Concept selection matrix showing how the ICD scored above the pacemaker as our device of choice according to these weighted parameters.

Key Challenges

Among the many angles of analyzing pacemakers, the key challenges of pacemaker function are of high importance. One key challenge is decreased or absent pacemaker function (failure to output). This occurs when a pacing spike (signal seen in an electrocardiogram (EKG) reading stimulated by pacemaker electrical activity) is absent albeit pacing is expected. This can be caused by electromagnetic interference, oversensing, battery failure, or lead (wire that connects the battery to the heart) fracture.[12]

Another challenge is oversensing in which the pacer missenses pacemaker electrical activity and inhibits pacemaker function. This is caused by muscular activity (of the diaphragm or pectoralis muscles), electromagnetic interference, or lead insulation (covering over the lead for safe transmission of electrical signal to the heart) breakage.[12]

The next challenge is pacemaker syndrome in which poor timing of atrial and ventricular contractions (atrioventricular dyssynchrony) lowers cardiac output, and can ultimately lead to heart failure. Symptoms of this iatrogenic (caused by medical treatment) include dizziness, fatigue, and a drop in systolic blood pressure that is normally above 20 mmHg (patient is in critical condition at this point) while

the natural SA node rhythm is replaced by the paced rhythm.[13]

Finally, a practical concern is how the pacemaker affects a discharged patient's lifestyle. A post-surgery patient must avoid interacting closely or for an extended time period with devices that have detectable magnetic fields. These devices can be anything from cellphones and mp3 players to electric generators. Some medical procedures utilizing magnetic fields can also inhibit pacemaker activity such as magnetic resonance imaging and shock-wave lithotripsy. Initially, patients may be unaware that their pacemaker activity is being disrupted and they operate in their everyday lives. But given a long exposure time and close proximity to magnetic fields, the patient will feel a sudden halt in pacemaker activity.[11]

Ethical Issues

Of the many ethical issues regarding pacemakers, we shall be discussing one in particular which is that of euthanasia. Since a vast majority of the patients who need a pacemaker are seniors, many pacemaker recipients have decreased longevity. Patients who may be in vegetative states or who are barely responsive may have their deaths postponed if they have a pacemaker implanted. Then, the question of interest is whether by turning off the pacemaker you are fulfilling a wish or assisting in a suicide.

The consensus on deactivating cardiac devices is not universal, and there is a seemingly interminable disagreement. One patient's son, Zellner, describes the process that his mother went through before she passed away. She had the implantation at age of 99, and by age 101, she was unresponsive and nearly lifeless. His mother was pacemaker-dependent, meaning that if the device was turned off, she would likely die quickly. She did not have her pacemaker turned off and Zellner blames that his mother's slow death process was on the pacemaker.[14] The controversial aspect of this example is whether a patient like Zellner's mother deserves to die and end suffering or prolong life until that patient naturally fades out when that patient is incapable of making their own decisions. In the future, this is an issue that needs both a practical and "morally palatable" solution.

Conclusions

Arrhythmias are a very serious issue for many people around the world, and the treatment of them is extremely important as they can lead to death in many cases. There are several treatments for arrhythmias, but in our analysis, we determined that the ICD is the

best device due to its effectiveness, its lower risk for complications, and its versatility. However, this may not be the best device for many people. It is an issue that requires treatment on a patient-to-patient basis. The future for the treatment of arrhythmias is bright as the technology continues to improve, battery life increases, and the risk of complications is lowered.

Works Cited

1 - "Types of Arrhythmias." National Heart, Lung, and Blood Institute. Department of Health and Human Services, Jul 2011. 15 November 2014.

2 - "A Brief History of Cardiac Pacing." *PMC*. National Institute of Health, Apr 2006. 14 November 2014.

3 - "Generation of action potentials" - Wikipedia Web. 9 Dec. 2014.

4 - "Sinoatrial node action potentials" - cvphisiology.com Web. 9 Dec. 2014.

5 -"What is an Implantable Cardioverter Defibrillator?" National Heart, Lung, and Blood Institute. Department of Health and Human Services, Nov 2011. 11 November 2014.

6 - Dimarco, John. "Implantable Cardioverter Defibrillator." The New England Journal of Medicine. (2003): Online.

7 - "Medications for Arrhythmia." American Heart Association, Feb 2014. 13 November 2014.

8 - "Antiarrhythmic Drug Therapy." Circulation. American Heart Association, May 2009. 12 November 2014.

9 - "Beta Blockers." Circulation. American Heart Association, Jan 2006. 12 November 2014.

10 - "Calcium Channel Blockers." Patient. Nov 2013. 14 November 2014.

11 - "How Will a Pacemaker Affect My Lifestyle?" - NHLBI, NIH. n.p., n.d. Web. 9 Dec. 2014.

12 - "Pacemaker Syndrome and Pacemaker Complications | Doctor | Patient.co.uk." - Patient.co.uk. n.p., n.d. Web. 9 Dec. 2014.

13 - "Pacemaker Malfunction - Life in the fast lane ECG Library." LITF. n.p., n.d. Web. 9 Dec. 2014.

14 - "Ethical Considerations of Patients with Pacemakers." Curbside Consultation. American Family Physician, Aug 2008. 15 November 2014

Appendix I - Minutes

[Wed Dec 10]

Present: Navrit, Daniel, Aditya
[End of project]

Agenda

- Do ethical issues...
- Finish formatting
- Proof read the paper
- Harmonise citations

Minutes

- Worked on ethical issues section
- Read through and proofread the sections
- Formatted into the two column paper
- Finished numbering citations

Sun Dec 7 (12/07)

Present: Navrit, Daniel, Aditya, Edward
Action Items for Wed 10 14:00 (2pm)

- Cut down function content in the introduction [Navrit]
- Add selection matrix and explanation [Daniel]
    - Clean up selection matrix [Navrit & Daniel]
- Cut down on Key challenges [Aditya] - focus on asterisk content
- Ethical issues - declare all of the issues then only discuss the euthanasia problem [Ed & Jed]
- Conclusion [Daniel]

- **Each person needs to have their content done by WED 10 2PM**
    - including citations etc

- Confirm formatting issues and any other concerns before the meeting [Aditya & Daniel]
- Thursday 11 last minute editing if necessary

Agenda

- Make sure we have requirements in the project specification done
- Final delegation of sections of those components from above
- Discuss formatting of the paper
- Discuss which figures we want in the final paper

- What needs to be cut down in the final paper

Minutes

- Discussed what was covered in the paper
- Discussed who would cover the final elements
- Decided upon the figures to be included
- Discussed which sections were of proper length and which ones needed to be changed

---

Thurs Nov 20 (11/20)

Present: Everyone

Agenda

- Go through and finalise presentation

Wed Nov 19 (11/19) 10-11:30am

Present: Daniel, Navrit, Aditya

Action Items for Thurs Nov 20

- Personally rehearse parts, yourself. Keep to 2-3 minutes per person
- Finish up presentation

Agenda

- Finish slides
- Discuss and rehearse presentation

Minutes

- Discussed presentation etc
- Developed presentation

Sun Nov 16 (11/16) 4-5pm

Present: Daniel, Ed, Jed, Aditya

Action Items for [11/19]

- Powerpoint slides from each person must be done in the Google Slides file
- All details must be researched
- Each member must know what important points they will hit in the presentation and come prepared being able to effectively practice with the groups

Agenda

- Finalize research gathering
- Finalize aspects of the presentation

- Highlight key points for each topic

Minutes

- Discussed the final progress on researching, and discussed what minor details still needed to be researched
- Finalized what part each member will play in the presentation
- Discussed what important points from the research should be talked about in the presentation

---

Wed Nov 12 (11/12) 10-12am

Present:

10-11 Navrit, Daniel, Aditya (20 min late)

Meetings (as before)

Places - Moffitt downstairs

- Wed 12 Nov 10:00-11:00
- Next week (Nov 17-23)
  - Sun Nov 16
  - Mon 17 Nov 15:00-17:00
  - Tues 18 Nov 13:00-14:00 (If necessary)

Action Items for Sun Nov 16

(Navrit will not be present)

- Further presentation coverage - start slides
- Research - wrap up information gathering
- Ed and Jed need to cover the ethical issues section at least

Agenda

- Check research progress
- Begin to discuss presentation
- Concept selection matrix
- Pick out highlights of current research - sift through current content

Minutes

- Determined the important points of what has been researched so far and what still needs to be researched more
- Almost finished concept selection matrix
- Highlighted what should be covered in the presentation and solidified who is presenting what

Presentation - who is covering what

Introduction - Ed
Function - Navrit
Alternatives - Daniel

Key Challenges - Aditya
Ethical Issues - Ed/Jed
Conclusions - Jed

Sun Nov 9 (11/9)

Present: Aditya, Navrit, Daniel

Meetings

Places TBA

- Wed 12 Nov 10:00-11:00
- Next week (Nov 17-23)
  - Sun Nov 16
  - Mon 17 Nov 15:00-17:00
  - Tues 18 Nov 13:00-14:00 (If necessary)

Action Items for Wed Nov 12

1. Each person will research their respective bullet point
2. Be prepared to have researched their topics enough to discuss their topics
3. Add research to Google Doc (Brogade Research Items)

Agenda

- Discuss who is covering what parts of the paper and who will research which sections

Minutes

- Discussed elements as listed below:

Paper Structure

- Introduction *[LATER]*
  - Problem and device explanation
- Function ***[NAVRIT]****[DANIEL]*
  - What the device does
  - How it works
  - How it fixes the problem
- Alternatives ***[DANIEL]****[NAVRIT]*
  - Drugs
  - Brand comparison
  - **Selection matrix**
- Key Challenges ***[ADITYA]***
  - Battery
  - Over sensing - due to higher muscle activity
  - Re-positioning
  - See others later
- Practical concerns (efficacy testing, the regulatory process, etc.) *[JED][ED]*

    - Invasive surgery
    - See others later
- Ethical Issues *[JED][ED]*
    - Invasive surgery
    - See others later
- Conclusions *[LATER]*
    - Restate problem with selection matrix from earlier
    - Is it a good solution
    - Future developments, R&D solutions (eg. Pu powered)
- Works Cited [-]
- Appendix I [-]
    - Agendas and minutes from weekly group meetings
- Appendix II [-]
    - Copy of the personal goals statement for each team member detailing what that student wants to get out of the project experience
    - Brief (250 words or fewer) statement from each team member discussing what steps that member took during the project to meet those goals
    - Signed project contract

Sun Nov 2 (11/2)

Presentation date: Thurs 20 Nov

Action Items

- Agree on at least weekly meetings to work on the final project
- Choose a device and problem that it solves
    - Run it by Terry Johnson **ASAP**
- Take minutes, outline of meeting, outcome of meeting and things to do for the next meeting for the Appendix section. Records of attendance will be kept also.

DEVICE: PACEMAKER
PROBLEM: TREATING ARRHYTHMIA

Appendix II

Navrit Bal

Personal Goal Statement

What I want to learn from the project

I would like to see how PNAS style paper writing works, different methods for efficient collaboration on a scientific research project. How the device works is a major point that I want to take away from this project. Researching skills for biomedical devices specifically, I have been previously exposed to other types of scientific research so I would like to see how the commercial aspect affects the research side. I have never used the the MLA format for citation before, so I would like to see how that works. I have never had to identify any ethical issues (with biomedical devices specifically) before, so that is an aspect that I look forward to. Going through the process to get to the selection matrix method to make a complicated engineering decision. I would like to see how the whole process of a biomedical device fits together, in detail. If it comes to it, I may end up project managing and organizing others to some extent – I have not yet done this with a group of 5, only smaller groups up until now.

What steps I took in order to meet those goals

I have found the 2008 official PNAS Latex template which I am replicating in other software. We are using Google Docs for collaborative work. I have covered the function part and am comfortable with details about how the device works and what it's meant to do. Using Google Scholar has been very useful for finding various papers. There is lots of guidance available online about MLA formatting. As for most of these devices, ethical issues are not the most obvious issues - we first highlighted the euthanasia aspect with our device. We went through the concept selection screening and processing stages to come out with a decision based on our parameters and weightings. The revising of this matrix was also a valuable stage in the decision and final conclusion. I have been keeping up with how the whole process and project fits together This is my first group (more than 2) project and has given a personal example of how groups work for a particular project. As this is a Bioengineering project, it showed me how engineering projects can be handled and how they can progress.

Aditya Aiyer

Personal Goal Statement

From this project, I hope to learn how to negotiate and effectively collaborate with group members, and gain as much teamwork and presentation skills as possible. Second, I hope to learn the art of making my voice heard, and learning to communicate ideas as well as to receive suggestions. Third, I want to learn how to take constructive criticism from my peers positively, and to give relevant helpful feedback to others as well. Mainly, I want to learn how to play different roles in a group so that I am comfortable and familiar with them for future engineering projects, which may have a demanding agenda and group members with differences of opinion. In terms of roles, I would like to be the one in my group who gives ideas and leads the group to success. Regardless of what device our group chooses, I would like to be the one who gives a fresh perspective to the problems of a device, for example. In a nutshell, I want to play the leader, the negotiator, and idea creator because I want to broaden my skills and go out of my comfort zone, not just get used to the idea that my ideas are the only ones that matter.

What steps I took in order to meet those goals

From this project, I gave constructive criticism to all of my group members, and also received and incorporated their helpful feedback into the parts of the project I was responsible for. I definitely played the negotiator role in all of the meetings that our group had and I did bring new ideas to the table as and when our group sat down for our brainstorming session, especially when we needed to choose our device. I thought that we should consider a pacemaker and glucometer as our devices, and ultimately, at one meeting, boiled down the other options to realize that the pacemaker was our best device option by far. I also learned how to be a team player because I really experienced the concept that we sink or swim as a team. When I did research for the key challenges part of our project, I made sure that I was thorough and read all relevant sites until I found what I needed. Sure enough our group got all the information needed and we presented very well, considering our group was the second to present. Although two members in our group did not participate or contribute very much, we still pulled ourselves together and made everything work out well. I am very hopeful that these skills I acquired will take me far in the future.

Daniel Grubb

Personal Goal Statement

I have several goals for myself over the course of the final project. I would like to improve my skills of working in groups, specifically working on taking on multiple roles over the course of the project. I intend to help lead the group at certain times, but I want to work on also stepping back and taking a non-leadership role, as in the past I have tended to try to be the leader in most group projects I have been a part of. In addition to improving my group working skills, I also want to refine my researching skills. I want to do my research for this project primarily through journal articles and published research instead of through mostly websites. I want to improve my ability to pull important information out of journal articles efficiently. I hope to find the process of putting together a large project in a group rewarding and helpful to me in the future.

What steps I took in order to meet those goals

I took multiple steps over the course of the project to achieve my goals. I attempted to improve my group working skills and I tried to take on multiple roles during the project. I tried to do this by taking a step back during certain times during meetings to let others take on a leadership roles. I did take on a leadership role when I thought it would be beneficial to the group, especially with inconsistent participation by certain members. Also, when I was doing research for the project, I tried to use journal articles as a primary source of information by searching through Google Scholar and other databases. Overall, I found this project to be rewarding, and I believe the skills I gained from it will help me in the future.

Edward Wu

Personal goals statement

Through the final project, I would like to work on my team work skills; as trivial as this sounds, thus far in my life, group projects have lead me to trust nobody. Not only do I have to do most of the work, most of my former partners did not appreciate the work that I did.

So far, I have experienced a whole new world of teamwork by attending the meetings, and I am excited to work and find out more about how much more teamwork skills our Brogade group can accomplish.

I would also like to learn about more Statistical analysis. Our group project involves the pacemaker device, and the treatment of Arrhythmia. Although it is good to know the theory behind the treatments, I also want to pay attention to how well the theory translates with the real world; not all theory performs perfectly in the real world and I would like to know about how different techniques can translate into more effective treatment for everybody.

I also would like to learn how to use Excel and spreadsheets better in general. I do not know a lot of the formulas in excel and using computers to solve the trivial questions, and I want to know how to process data a lot more efficiently.

What steps I took in order to meet those goals

Through this paper I have learned how to work out time slots with the group and make sure that this paper can have progress at all times instead of the group procrastinating until the end. Through this paper I have also learned the importance of teamwork and the consequences that follow when the group is not cooperating well. To the aspect of researching, I have learned to use sources outside of plain Google searches, and learn how to use scholar searches and cite medical journals. Although we still received guidance on the paper, this was certainly a step towards more professional scientific publishings.

BioE 10 project contract

Contract for BioE 10 Final Project

We, the undersigned, have agreed to work together on a final research project. Each of us understands that we are jointly responsible for the final product as a whole, and though we may split the work up amongst ourselves, all of us will be expected to comprehend and be able to explain any part of the final product.

Each of us understands that we will personally be responsible to put in approximately 4-6 hours of work per week into the final project. If any of us are unable to do so due to **unforeseen** and **extraordinary** circumstances, we know that it is *our* responsibility to inform the instructor *as soon as possible* so that alternate arrangements can be made. We understand that the instructor reserves the right to assign different grades to various members of the group if the workload is not distributed and carried out evenly.

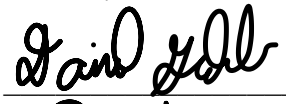
Each of us promise to adhere to the Berkeley Code of Student Conduct (http://students.berkeley.edu/uga/conduct.asp) and understand that plagiarism of any kind will not be tolerated.

Brief description of project:

Pacemaker for arrhythmia

Name (printed): NAVRIT BAL Signature: 

Name (printed): ADITYA AIYER Signature: 

Name (printed): DANIEL GRUBB Signature: 

Name (printed): EDWARD WU Signature: