

Artificial Pacemakers

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Technology has surrounded our lifestyle and that fact is more than apparent in the field of medicine. The fictional concept of the Bionic Man came alive in television in 1974 but the idea of artificial technology being used in the human body goes back much further than that. Just about every specialized field of medicine uses some type of artificial technology. In cardiology that technology may be artificial heart valves or stents made of exotic metals but we are going to focus on the artificial pacemaker.

In this article our objective will be to

- Explore the history of pacemaker science.
- Examine the components of the pacemaker and their function.
- Review the different types of pacemakers and the conditions that they treat.
- Learn the way that the pacemaker treats these conditions.
- Study the problems that pacemakers may have and EMS role in treating them.

History of the Pacemaker

Wikipedia defines the pacemaker as a medical device designed to regulate the beating of the heart. The Artificial Pacemaker replaces or assists the natural pacemaker which stimulates the heart to beat with an electrical impulse originating from the Sinus Atrial Node. The first pacemakers were made of two parts. The pulse generator sends an electric impulse out to the heart and the leads carry the impulse and deliver it to the heart.

The science behind electrical therapy goes back hundreds of years to the 1600's. Early scientist studied static electricity and its affect in biology. They applied static electricity into the muscles of dead animals and executed criminals and observed the muscles as they contracted in response.

In 1786 Italian scientist Luigi Galvani while studying the anatomy of frogs discovered that by applying a metal scalpel to the nerves of a freshly killed frog he could cause the muscles to contract and the legs to flex. While exploring some of his theories he attached brass hooks to the spine of a dead frog and then hung the frog from an iron rail during a lighting storm. He observed that the legs would twitch in response to the lighting and concluded that animals receive electricity from the environment and store it in a “nerveoelectrical fluid”. He called his theory “animal electricity”.

Galvani is most famous for his invention the “Galvanometer”. The galvanometer measures electricity as



it flows through tissue and is essentially the first EKG monitor.

A few years later in 1792 the inventor of the battery Alessandro Volta set out to disprove Galvani's theory. He believed that the electricity was created by the metals that were used in experiment and not the environment. He compared his theory to the battery he invented which used a pile of dissimilar metal plates separated by paperboard soaked in saline. He named his invention the 'Voltaic pile'

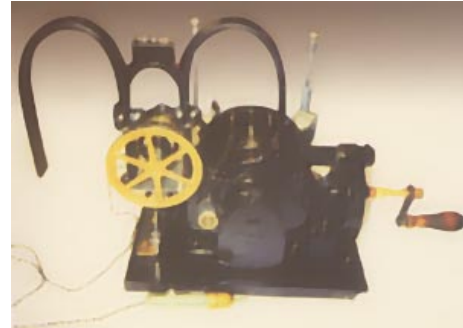


In 1838 a Professor of Physics at the University of Pisa in Italy named Carlo Matteucci took great interest in the work of Luigi Galvani. Using the Galvanometer he discovers that an electric current accompanies each heartbeat. He also proves that nerves carry an electric current to the muscles causing contraction. He proves this by building a device that uses a frog's leg with all but one muscle removed and the nerve that connects to that muscle. Using a small amount of electricity from a voltaic pile that is applied to the nerve he causes the muscle to contract. The electrical impulse is measured using a galvanometer. The experiment proved that electricity travels using nerves as a pathway and cause muscular contractions.

All these discoveries did not go unnoticed by the world of medicine. A Russian physiologist named Y.M. Chagovets and a Russian physician named N.E Vedensky were studying the influence that electrical impulses have on the heart and were identifying some heart conditions that could benefit from some of the discoveries being made.

Many doctors and scientist were looking for ways to apply their new found knowledge about electricity. Ventricular fibrillation was discovered but it was recognized as a result of applying electricity rather than as a medical condition that could be treated with electricity. Crude devices were created using a “Voltaic pile” to stimulate the heart into beating after cardiac arrest. Their success however is greatly debated.

The first device that is documented to be effective was created in 1926. Dr. Albert Hyman created an electro-mechanical instrument which many believe may be the first



successful pacemaker. The device was patented in 1931 and was first used in Sydney Australia. The hand operated machine used a transthoracic needle that was inserted into the chest and then into the heart. Within a year the device had been used 43 times with 14 successful outcomes.

1926 to 1950 was a time when great steps were taken in world of the galvanometer but few in the pacemaker. The simple device that was created in 1786 had been perfected into an instrument that could read and record the hearts electrical actions. Many of the dysrhythmia’s that



we know today were discovered during this time. The pacemaker made its big change in 1950 when a Canadian electrical engineer named John Hopps paired with Dr. Wilfred Bigelow to create a pacemaker that could be used for long periods and treat many of the new dysrhythmia’s that had been discovered. The new

pacemaker was a great advancement but still had some shortcomings. The device that sat on a tabletop was large and heavy. The vacuum tube technology that was available at the time of development was unreliable. The externally placed electrode patches sent electric impulses into the patient resulting in a great deal of pain for the patient. The device worked, but its life would be short because new technology that would change the world of electronics had just arrived.

Electrical engineers working in the Bell Telephone laboratories December 16, 1947 changed not just the world of electronics, but the lifestyle of people world wide. William Shockley, John Bardeen, and Walter



Brattain had created the first successful point-contact transistor. This electrical component replaced the vacuum tubes that were used in early electronics. The transistor was first seen by the public as a novelty that allowed for smaller radios to be made. But in a few short years the transistor found itself making many previously unimaginable inventions possible. Considered to be the greatest invention in modern history, it wins its creators a Nobel Prize in Physics in 1948.

The Transistor makes a big impact in the medical field as well. The component allows all things electronic to be smaller, lighter and more reliable.

Dr. Paul Zoll a cardiologist from Boston led the way in modern electronics with a pacemaker that he created in 1951. The pacemaker used modern transistors but still was

large, heavy and relied on AC power. Despite these shortfalls the Zoll pacemaker remained a standard for pacing patients for several years.



The next advancement came from electrical engineer and part-time TV repairman Earl Bakken. In 1957 he developed a smaller pacemaker that could be worn around the neck allowing the patient to move as far as the extension cord would let them. This new pacemaker was also less painful than those before because the leads were surgically attached to the outside of the myocardium. The “Bakken Pacemaker” was well received by the medical community and by the public but Earl Bakken was not satisfied. While the device was much smaller than its predecessors it was still too heavy for many pediatric patients. Earl Bakken also realized the need for a battery powered pacemaker after several patients died during a power failure.

While researching for a solution Bakken came across a 1956 issue of “Popular Electronics”. In it he found an article about how small amounts of electricity could be amplified so that sound could be projected to groups through loudspeakers. Pacemakers had always been powered by a 110 volt AC circuit but Bakken thought of a way that power from a battery could be amplified so that it could simulate the human heart. Bakken had to start from scratch. He created a miniature mercury battery that supplied 9.4 volts and miniaturized his pacemaker until it was 4 inches square



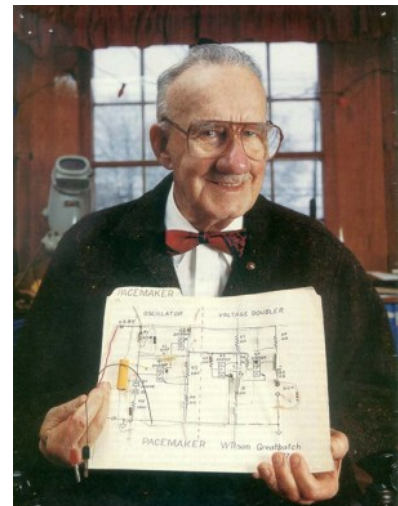
and only ½ inch thick. Made of aluminum this pacemaker was light enough to be carried around the neck of even the weakest child. The pacemaker was put into clinical use within 4 weeks. Earl Bakken co-founded the company Medtronic and continued to improve his pacemaker and batteries.



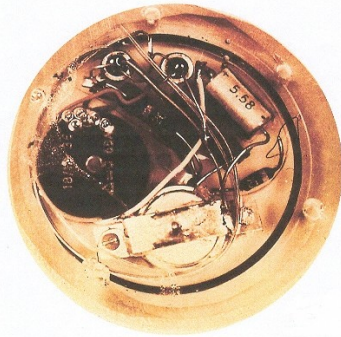
Up until now all pacemakers had external pulse generators. With the size of pacemakers and the short battery life, the idea of implanting a pacemaker into a patient was unthinkable. In 1958 Wilson Greatbatch

changed that thought process. Greatbatch was an electrical engineer who was trying to create an implantable device that would monitor and record pulse rates. Instead he created a device that would generate an electrical impulse. Greatbatch was a deeply religious man who believed that this accidental creation was “Divine Intervention” and set out to find someone who could put his device to use. He found Dr. William Chardack and Dr. Andrew Gage of the Buffalo Veterans Hospital. They perfected the device and implanted it into a dog for testing.

After two years of animal testing the pacemaker was implanted into a 77 year old man who suffered from complete heart block. The patient went on to live two more years before he died of unrelated causes. Greatbatch felt like the biggest limitation of his pacemaker was the battery life. His battery would last 24 months before it needed to be

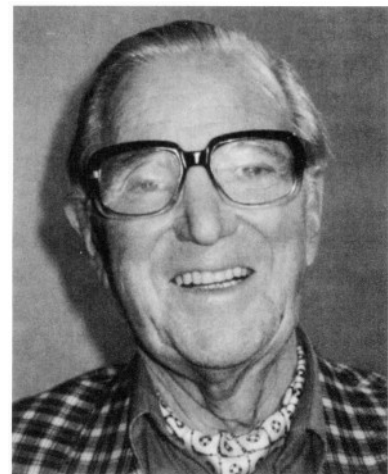


replaced. Wilson Greatbatch joined up with Medtronic and battery pioneer Earl Bakken and focused on creating a better battery. Greatbatch and Bakken created and perfected the Lithium Iodine battery that is still used to power pacemakers today. Greatbatch left Medtronic and created his own company Wilson Greatbatch Ltd. which concentrates on creating batteries to power pacemakers. Earl Bakken and Medtronic turned their attention to perfecting and marketing the “Greatbatch Pacemaker”

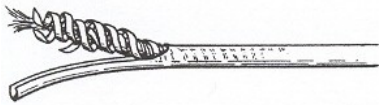


In Sweden a team of Doctors were also working on an implantable pacemaker. Dr. Ake Senning and engineer Rune Elmqvist made history when they implanted the first pacemaker into a human but that was not always their plan.

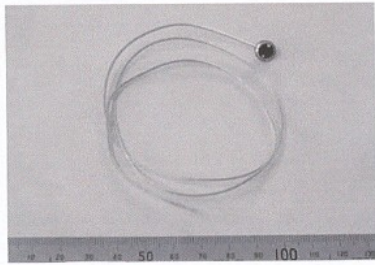
On October 6 1958 the scientists were approached by Else Marie Larsson. Mrs. Larsson’s husband was dying of Stokes-Adams syndrome and had to be resuscitated several times a day by an external pacemaker. When Mrs. Larsson heard that a permanent implantable pacemaker was being developed in Stockholm she immediately went to see the developers. Senning and Elmqvist repeatedly told Mrs. Larsson that animal testing would be needed before it could be used in a human but she would not accept their answer. Finally after several visits with Mrs. Larson the scientists were convinced to use her husband Arne Larsson as their test subject. October 8 1958 the first implantable pacemaker was placed in Arne Larsson. The pacemaker that was placed in Larsson was accidentally dropped and possibly



damaged just prior to being implanted. Since a replacement was not available it was still implanted. The pacemaker functioned for 8 hours before failing. A second pacemaker was placed the next day and lasted a week but a broken lead caused its failure. The team continued to work to create a successful device and as a result Arne Larsson lived to be 86 years old dying in December 28 2001 of cancer. In his lifetime he received 5 different lead systems and 22 pulse generators of 11 different models. He

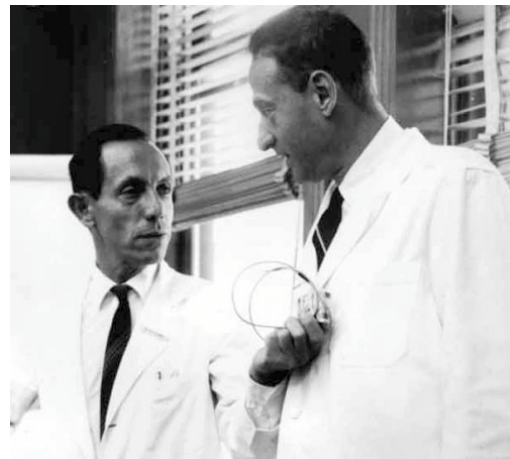


outlived both of the doctors that saved his life.



Leads proved to be point of failure in many of the pacemakers that were being developed in the 1950's. Recognizing the need for a better lead Elma Schonander and the Telecom Company Ericcson focused on the job of creating a lead that could withstand thousands of flex cycles. In 1959 the "Elma Lead" was created. The Elma lead was made of 4 thin bands of stainless steel that was wound around a polyester braid and then insulated with soft polyethylene. The new lead could withstand an estimated 184 million flex cycles and last at least 6 years.

The following decades saw few changes in the basic design of the pacemaker. The market prospects were perceived to be poor because the pacemaker was considered a device that could only be afforded by a few wealthy individuals who were in all around poor health and usually died before they could become profitable customers. Pioneers such as Paul Zoll, Earl



Bakken, and Wilson Greatbatch found themselves nurturing the industry through the company's they founded like Electrodyne, Medtronic and Wilson Greatbatch Ltd. In spite of the lack of interest the pacemaker and its power source still managed to make some advancement.

In the mid 1960's transvenous leads that could be easily placed inside the heart through the subclavian vein replaced epicardial leads that required a thoracotomy so that the lead could be placed on the outside of the heart.

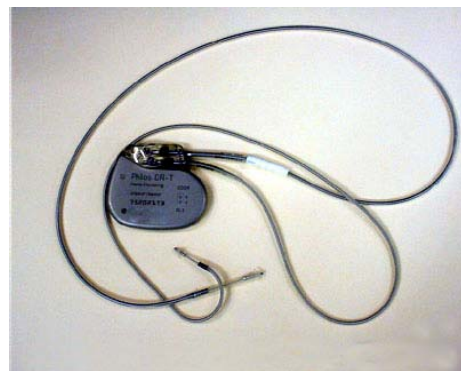
Also in the mid 1960s the demand pacer made its first



appearance. Prior to the demand pacers creation all pacemakers fired at a preset rate regardless of the hearts native rhythm. The power source was also an item that many tried to improve on.

Rechargeable batteries were experimented with a great deal. Medtronic attempted to make a pacemaker that was recharged by winding it with a crank but it was not reliable and did not see any public use. An external AC charging systems that connected through a port in the skin was tried, but they

were complicated and confusing for the older patients who used them. In 1972 a nuclear powered pacemaker was even created that had a lifespan that was expected to be 20 years but the extensive regulatory paperwork limited its



regulatory paperwork limited its use. In the late 1970s large advancement was made when the dual chamber pacemaker was developed. The dual chamber pacemaker made the pacemaker a device that would help patients with heart failure. The concept that a

pacemaker could improve the quality of life for a patient suffering from a variety cardiac conditions changed the role of a pacemaker from a device for a dying wealthy



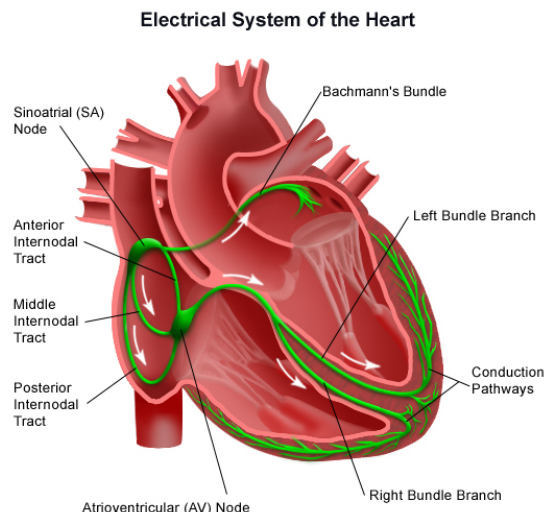
individual to one that could help many people.

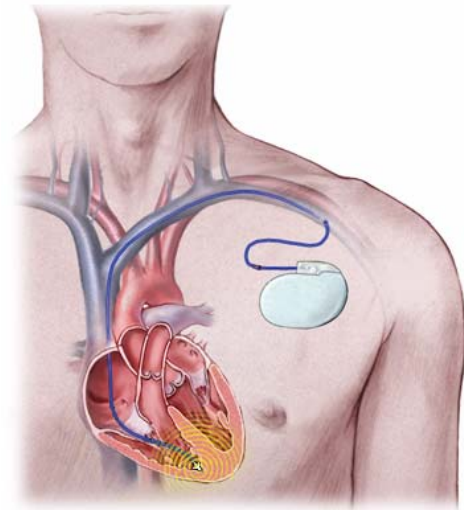
Companies that made pacemakers also found that with the increase in capability came an increase in profit.

With more companies getting involved in development, the pacemaker made even greater advancement. In the 1980's pacemakers were built with sensors that detected increases in the patients activity and increased the pulse rate accordingly. The new technology was called "Rate Responsiveness". In the 1990's microprocessors allowed the pacemaker to perform many different jobs. The pacemakers could store several algorithms to respond to the patients changing needs and collect data about the hearts performance to be reviewed by the patient's cardiologist during routine visits. In the last few years Bi-Ventricular pacing has been introduced and the quality of life for patients suffering from heart failure has been greatly improved.

What do Pacemakers Do

The hearts natural pacemaker generates and delivers an electrical impulse to stimulate a muscle contraction. That impulse comes from the Sinoatrial

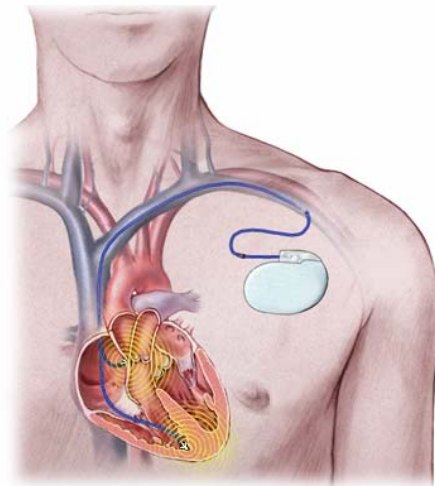




Node. In a healthy heart that impulse will travel from the SA node through the Bundle of His and into the ventricles through the bundle branches. When the natural pacemaker is not working or when pathway used by the impulse is blocked then an artificial pacemaker is needed. A single chamber

pacemaker has one lead that delivers an impulse to the right atrium or the right ventricle. The lead also carries information back to pacemaker. Modern pacemakers are able to “listen” to the hearts native rhythm and only fire when needed. These pacemakers are called demand pacemakers. A single chamber pacemaker placed in the atrium can be used to treat atrial arrhythmia or treat a condition were the SA node does not fire properly called Sick Sinus Syndrome. A single chamber pacemaker placed in the ventricle can aid in pumping blood to the lungs and treat rate problems.

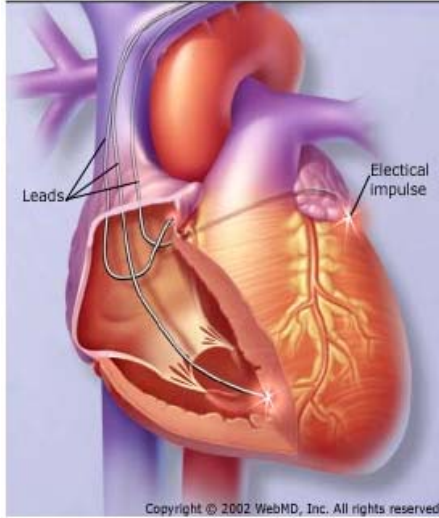
Dual chamber pacemakers have two leads. The tip of one is placed in the right atrium and the tip of the other is placed in the right ventricle. The information processor located in the pulse generator is able to monitor and deliver impulses to both of the chambers independently. The pacemaker



is especially beneficial when it is able to coordinate the timing between the two chambers improving blood flow through the heart.

Organizing the contractions of each chamber to improve the operation of the heart is called “Cardiac Resynchronization Therapy” or CRT. CRT is becoming the ideal treatment for patients suffering from heart failure.

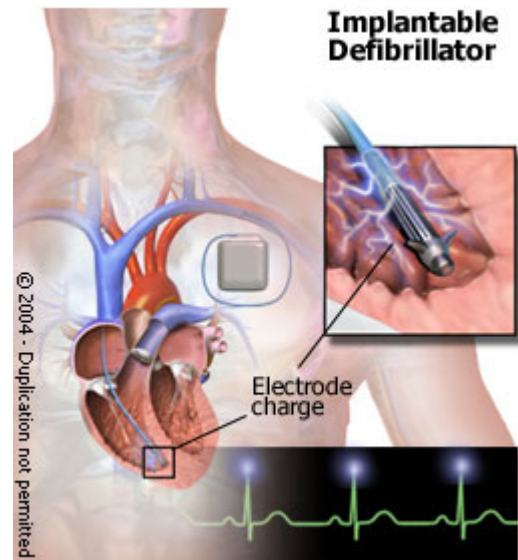
Biventricular Pacemaker



In recent years Biventricular pacemakers have been created and are maximizing the benefits of CRT. This device has three leads that are placed in the right atrium, right ventricle and left ventricle. These pacemakers can move blood through the heart and lungs efficiently and prevent pulmonary edema in patients that have CHF.

Since the size of the pacemaker has become smaller and its capabilities have increased it has become possible for the pacemaker to do more. Pacemakers are now being built with an internal cardioverter/defibrillator, or ICD installed in the pacemaker generator. ICD's may also be installed separately without a pacemaker.

An ICD is slightly larger than a pacemaker but otherwise looks the same. The ICD is designed to monitor the heart's EKG rhythm and deliver a shock when it senses a dangerous tachycardia or fibrillation.





The monitoring ability of the artificial pacemaker has also made some changes over the years. Pacemakers that have large amounts of memory may monitor and store the hearts EKG. During routine doctors visits this information

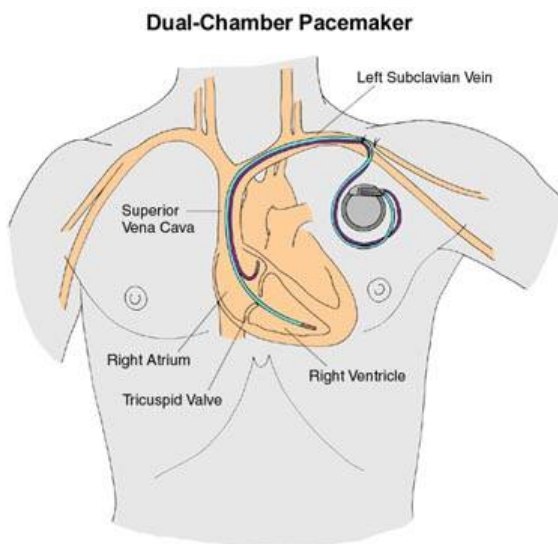
can be retrieved and reviewed to evaluate the performance of the heart and the pacemaker. The pacemaker can also monitor the activity of the rest of the body too.

Pacemakers that include a feature called “Adaptive Rate Pacing” can sense increased activity in the patient and respond by increasing the rate. Increasing the rate also increases blood flow to the muscles, making activities such as fast walking or climbing stairs. After the pacemaker senses that the activity has stopped it will return to its normal limits.

How are pacemakers implanted

Pacemaker placement today is simple, compared to placement forty years when a thoracotomy was required. Today pacemaker placement is a minor surgical procedure that can be preformed in a hospitals cath or electrophysiology lab. The procedure does not require direct contact with the heart and sometimes the patient is released the same day. The





procedure is done under mild sedation with a local anesthetic. A 2 inch incision is made parallel to and just below the collarbone, usually on the left side. The pacer wires are introduced into the left subclavian vein and threaded into the heart chambers under fluoroscope

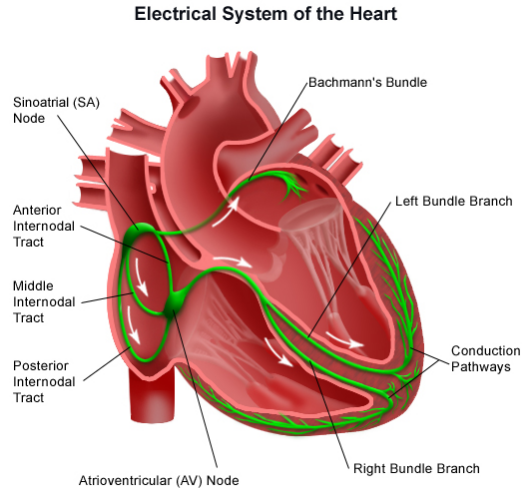
guidance. The ultrathin pacemaker wires are passed through the heart valves where they will harmlessly find a place to stay. At the end of the wires the electrode attaches to the heart wall using a claw like device. On the other end the wires are secured to the pulse generator and the pulse generator is tucked into a pocket made in the subcutaneous fat of the chest wall.

After placing the pacemaker the patient will receive an ID card that will identify the type of device they have. The performance and status of the pacemaker should be checked during routine cardiology visits. The pacemaker is checked by placing a device on the skin over the pacemaker. Information stored in the pacemaker's memory is also retrieved this way. When it is time to replace the pulse generator an incision is made in the same place as before. The old generator is removed and the new one is inserted in its place. If the existing leads do not need to be replaced then they will be attached to the new generator.

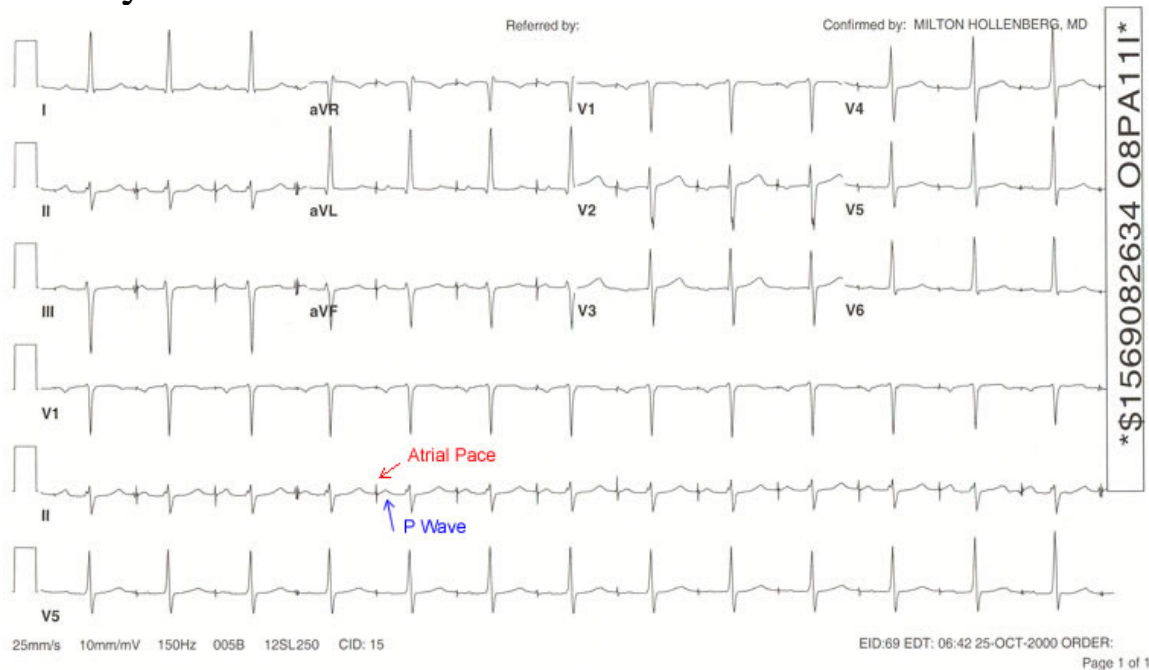


Pacemaker Problems

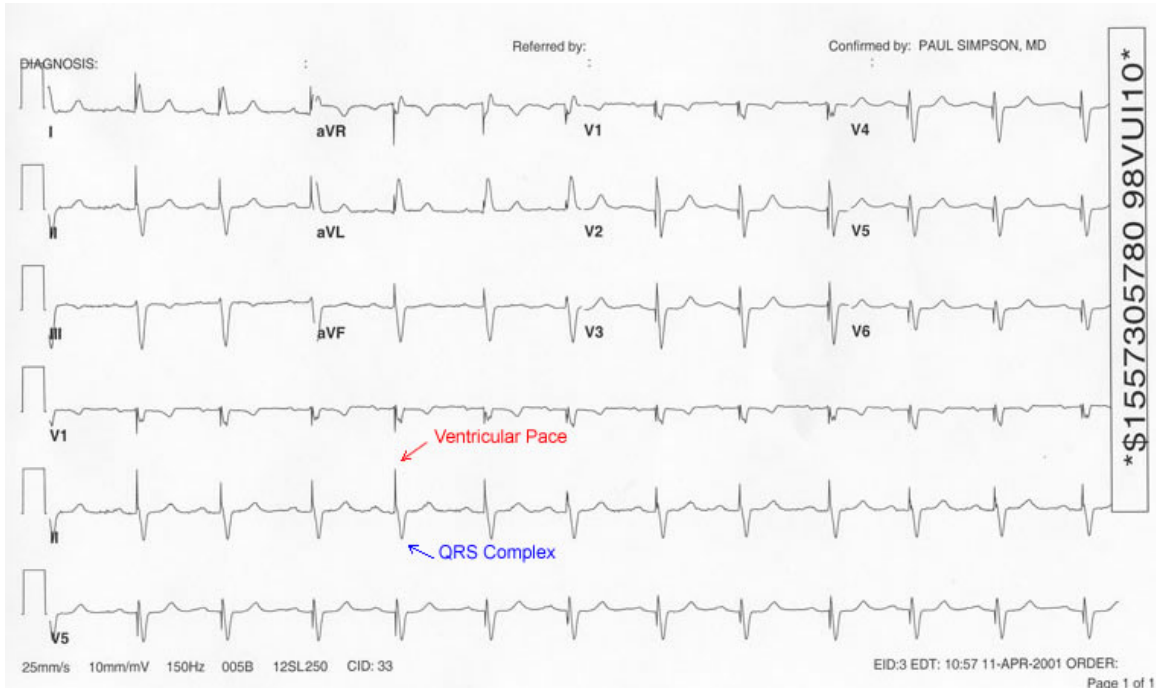
In most cases the only problem that EMS will see with a pacemaker is in the way it interferes with our EKG's. The pacemaker can change the way an EKG looks and often times will make it look like another rhythm. Finding the pacemaker spike is critical in identifying a paced rhythm however that can oftentimes be difficult.



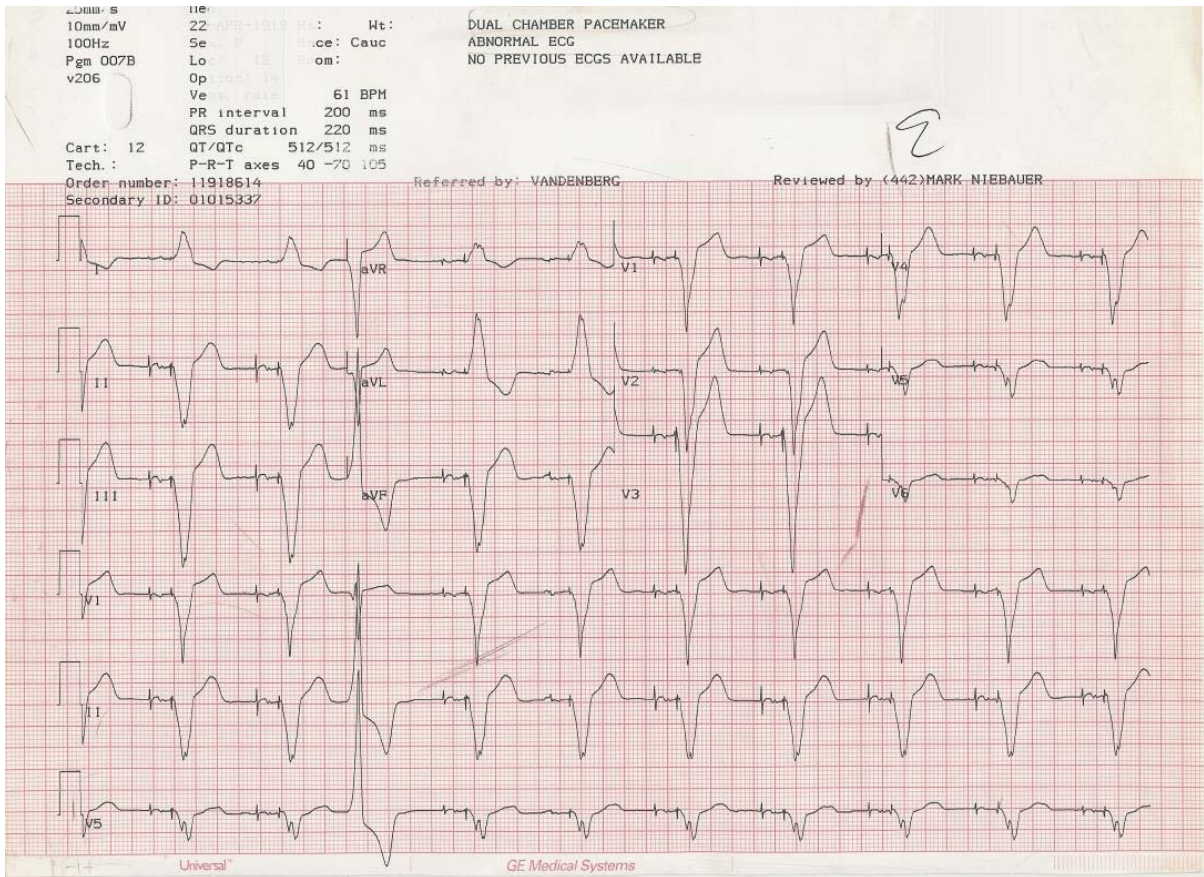
The location of the pacemaker spike can identify what type of pacemaker the patient has. With a single chamber pacemaker that is placed in the right atrium the pacer spike will be seen just ahead of the P wave. Since the impulse does not originate from the SA node the PRI may appear longer than normal. Assuming the electrical pathway is healthy the rest of the EKG should look normal.



If the electrical pathway is blocked then a single chamber pacemaker may be placed in the right ventricle or a dual chamber pacer may be used to synchronize the contractions. If a single chamber pacemaker is used in the right ventricle then the pacemaker spike will be just before the QRS complex on the patients EKG. The P wave may or may not be present.



When both chambers are being paced with a dual chamber pacemaker then two pacer spikes can be seen. The first spike will be seen just before the P wave. The P wave will often be cut off by the second pacer spike that stimulates the contraction of the ventricles. Since the impulse does not originate from the normal pathway the QRS complex may be wide and look similar to a ventricular tachycardia. It is for this reason that EKG's should be carefully examined before deciding on a treatment path.



Problems with the pacemaker and ICD's themselves may be caused by powerful electromagnetic fields (EMF) or electromagnetic interference (EMI). EMF and EMI can be created by MRI's, large speaker systems, CB and HAM radios and high voltage power lines. EMF and EMI can interfere with the pacemakers normal operations and in some cases even reprogram the pacemaker. EMF and EMI's affect on pacemakers and ICD's is well known, and changes have been made in the devices and most household appliances to fix the problems. Still some problems persist. Most of these problems are seen with powerful electrical equipment such as cordless power tools, welders and power generators. Small items have also been found to create problems most commonly the cell phone. It is found in most cases the cell phone is being carried in a shirt pocket near the pacemaker when the problem occurs. It is



recommended that cell phones be kept at least 12 inches away from the pacemaker. One surprising new problem has arrived with new video game technology. Nintendo's new game system Wii with its

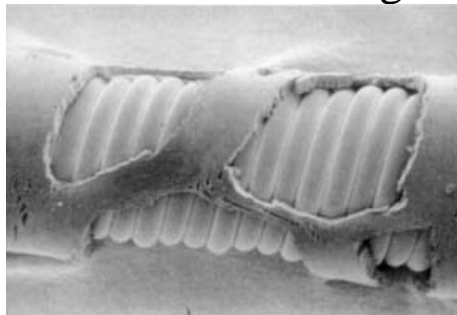
unique cordless controllers has been blamed for many injuries and a lot of damage. It may also affect pacemakers and ICD's along with other wireless game controllers.

Problems with pacemakers alone are unlikely to lead to a 911 call but the symptoms the patient may feel as a result of the failure in most cases will. In the case of ICD's the most common malfunction is inappropriate cardioversion. The problem will be very evident to the patient as they will receive painful shocks without any warning.

Oversensing

Oversensing occurs when a pacemaker incorrectly senses non-cardiac electrical activity as cardiac activity. This may cause the pacemaker or ICD to fire when it is not necessary. Oversensing can be caused by

- Muscular activity. Especially activity in the diaphragm or pectoral muscles.
- EMI or EMF
- Lead insulation breakage



Failure to output

Failure to output occurs when pacing or cardioversion is indicated but the device does not send out an impulse or fire. Failure to output can be caused by many things one cause may be phenomenon called crosstalk. Crosstalk occurs when an electrode in one chamber senses the contraction of another chamber and does not sense the need to fire. Other reasons for failure to output may be caused by



- Battery failure
- Lead fracture
- Lead insulation breakage
- Poor lead connection at the generator

Failure to capture

Failure to capture occurs when a pacemaker spike is noted on the EKG but is not followed by a contraction.

Failure to capture may be caused by

- Lead fracture
- Lead insulation breakage
- Lead dislodgement
- Elevated pacer threshold
- Poor lead connection at the generator

Failure to capture may also be caused by an AMI that has left the cardiac muscle that the pacemaker is anchored in dead or non-functional. Since the pacemaker may limit the usefulness of the 12 lead EKG, AMI should be high on the index of suspicion. Metabolic abnormalities such as hyperkalemia, acidosis and alkalosis can also cause a failure to capture as well as certain drug interactions. Treatment by EMS should be focused on the medical

causes of the failure. This is especially true when an AMI is suspected.

ICD problems are similar to those seen in pacemakers with a few exceptions.

Inappropriate Cardioversion

Inappropriate cardioversion is the most dramatic failure that a patient with an ICD will see. It may be caused by

- Misreading A-Fibb with rapid ventricular response or other supraventricular dysrhythmia as V-Tach.
- Lead fracture
- Insulation breakage
- Electrocautery
- EMI



New filters have been put in place on new ICD's to improve the recognition of atrial and supraventricular dysrhythmia. Electrocautery on the other hand is still a problem. The surgical tool that uses electricity to cut and cauterize tissue

produces a large amount of EMI that will cause the ICD to fire. It is important that a patient with an ICD tells their physician about the ICD before such a tool is used.

Ineffective Cardioversion

Some times an ICD fires but rhythm does not respond. This is referred to as ineffective cardioversion. Ineffective cardioversion may be caused by

- Inadequate energy output.
- Rise in the defibrillation threshold due to antiarrhythmic medication such as Amiodarone.
- AMI at the lead site.
- Lead fracture or dislodgement.
- Insulation Breakage.

Many ICD's have limits that are set by the manufacturer of the device. The limit is preprogrammed into the ICD and will only allow a certain number of therapeutic shocks to be delivered. The limit is set per event and will not reset until a new rhythm is read by the ICD.

Both ICD's and pacemaker's battery powered and batteries can fail. Battery development has come a long way since the pacemakers was first created. The lithium-iodine cell batteries are still the primary battery used. The batteries will last an average of 5 years. During routine visits to the patient's cardiologist the battery will be checked. If the battery is getting low it will start to give off warning signals months prior to the batteries failing. It is important that the patient keeps appointments so that the pacemaker generator can be replaced in time.

Pacemakers and ICD's are commonly scene in the pre-hospital field and we should be knowledgeable about them. Problems with these devices are outside the scope of EMS treatment protocols but the underlying cause of the problems or the problem the device is trying to treat is not. We should be open minded and suspicious so that we can identify and treat these events.



Credits

1. Pacing systems
Guidant products
www.guidant.com
2. Artificial Pacemaker
Wikipedia
www.wikipedia.org
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Defibrillator
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www.medschool.ucsf.edu
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8. A brief history of cardiac pacing.
Cardiology Dept. St. Luke's Hospital
www.impaedcard.com