Ministry of higher education and scientific research

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The artificial pacemakers and their uses in modern medicine

A project submitted to the council of College of Medicine / University of Diyala in Partial fulfillment of the Requirements for the Degree of bachelor

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بسم الله الرحمن الرحيم

(وَبِالْحَقِّ أَنْزَلْنَاهُ وَبِالْحَقِّ نَزَلَ وَمَآ أَرْسَلْنَاكَ إِلاَّ مُبَشِّرًا وَنَذِيرًا* وَقُرْآنًا فَرَقْنَاهُ لِتَقْرَأَهُ عَلَى النَّاسِ عَلَى مُكْثٍ وَنَزَّلْنَاهُ تَنْزِيلاً* قُلْ آمِنُواْ بِهِ أَوْ لاَ تُؤْمِنُواْ إِنَّ الَّذِينَ أُوتُواْ الْعِلْمَ مِن قَبْلِهِ إِذَا يُتْلَى عَلَيْهِمْ يَخِرُّونَ لِلأذْقَانِ سُجَّدًا* وَيَقُولُونَ سُبْحَانَ رَبِّنَآ إِن كَانَ وَعْدُ رَبِّنَا لَمَفْعُولاً* وَيَخِرُّونَ للأَذْقَانِ يَبْكُونَ وَيَزِيدُهُمْ خُشُوعًا)

سوره الاسراء (105-109)

الاهداء

إلى صاحب السيرة العطرة، والفكر المُستنير؛

فلقد كان له الفضل الأوَّل في بلوغي التعليم العالي

(والدي الحبيب)، أطال الله في عُمره.

إلى من وضعتني على طريق الحياة، وجعلتني رابط الجأش،

وراعتني حتى صرت كبيرًا

(أمي الغالية)، حفظها الله من كل سوء.

إلى إخوتي؛ من كان لهم بالغ الأثر في كثير من العقبات والصعاب.

إلى جميع أساتذتي الكرام؛ ممن لم يتوانوا في مد يد العون لي

اهدي لكم مشروعي البسيط ومن الله التوفيق.

الشكر والتقدير

بسم الله الرحمن الرحيم، والحمد لله رب العالمين الذي وفقنا وأعاننا على إنهاء هذا البحث والخروج به بهذه الصورة المتكاملة، فبالأمس القريب بدأنا مسيرتنا التعليمية ونحن نتحسس الطريق برهبة وارتباك، فرأينا أن (الطب) هدفًا ساميًا وحبًا وغاية تستحق السير لأجلها، وإن بحثنا يحمل في طياته طموح شباب يحلمون أن تكون أمتهم العربية كالشامة بين الأمم.

وانطلاقًا من مبدأ أنه لا يشكر الله من لا يشكر الناس، فإنني اتوجه بالشكر الجزيل للأستاذة الدكتورة (سعاد مصلح الدين عبد المجيد) الذي رافقتني في مسيرتي لإنجاز هذا البحث وكانت لها بصمات واضحة من خلال توجيهاتها وانتقاداتها البناءة والدعم الأكاديمي.

كما اشكر عائلتي التي صبرت وتحملت معي ورفدتني بالكثير من الدعم على جميع الأصعدة، واشكر الأصدقاء والأحباب وكل من قدم لي الدعم المادي أو المعنوي، وأخيرًا نتوجه بشكر خاص للأستاذ (إسماعيل إبراهيم لطيف) عميد الكلية المحترم لمساهمته الفعالة في تسهيل المشروع راجيا من الله التوفيق و السداد للجميع..

Contents

Abstract

The heart is very vital organ located in the central chest region. It's function is to pump blood in the arteries and receive it again through the veins. it blood supply originated from the aortic arch through the complex of the coronary arteries. The electric stimulation of the heart carried out by modified myocytes forming a framework called "The conduction system of the heart" which is consist of SA node, AV node, bundle of His and purkinji fibers. In certain situations, there may be disorders in stimulation or conduction lead to loss of the normal rhythm of the heart. The pacemakers is a electric devices used to do the function of the conduction system by giving regulary intervaled electric pulse to the myocardium. It has been over 60 years since the first pacemaker and the therapy had a considerable developments in the late years. There are many types of the devices according to patient's needs. Nearly, all the available devices consist of the same parts, the pulse generator, the leads and the programmer. They are indicated for the patients who suffer from sinus disease, dysrhythmias, conduction diseases and recently for defibrillation and contraindicated for some patients like the asymptomatic 2nd degree heart block. Infection, thrombosis and errors of sense are the main complications of the therapy.

The objectives

To define the pacemakers, demonstrate their background, physics, indications and complication.

Keywords: conduction system, pacemakers, arrhythmia.

Introduction

The heart is a midline, valvular, muscular pump that is coneshaped and the size of a fist. In adults, it weighs 300 grams and lies in the middle mediastinum of the thorax. The inferior (diaphragmatic) surface sits on the central tendon of the diaphragm, whereas the base faces posteriorly and lies immediately anterior to the oesophagus and (posterior to that) the descending aorta. The base comprises mainly the left atrium. The left surface (left ventricle) and right surface (right atrium) are each related laterally to a lung and a phrenic nerve in the fibrous pericardium. (1)

The anterior surface of the heart lies behind the sternum and the costal cartilages. The constituent parts of the anterior and inferior surfaces are dictated largely by the position of the interventricular septum. Although essentially a midline structure, one-third of the heart lies to the right of the midline and two-thirds to the left. The interventricular septum bulges to the right because the wall of the left ventricle is much thicker (10 mm) than that of the right ventricle (3-5 mm). It consists of four chambers, left and right atria, left and right ventricles. The ventricles is much thicker than the atria and the left ventricle is the thickest of all. (2)

Blood supply of the heart

The heart is supplies by a complex of arteries called the coronary arteries. They originated from the aortic arch just before the bifurcation. (3) They are four arteries:

- Right coronary artery: supplies mainly the left atrium, right atrium, SA node (60%), AV node and small branch to the Right ventricle.

- Left coronary artery: supplies the sinoatrial node (40%).
- Circumflex artery: supplies the posterioinferior surface of the heart and the interventircular septum and the ventricles.
- Anterior interventricular artery: supplies the septa and the ventricles.

Physiology of the heart

The main function of the heart is to pump blood to the body and receive it again in continuous circulation. To achieve this function, the heart has two pumps: right and left pump.

The left pump (left side of the heart) helps move blood through the systemic circulation and the right pump (right side of the heart) helps move blood through the pulmonary circulation. The ventricles with their thick wall contracts and pump the blood to the both systemic and pulmonary circulations. [(4)] The contractions is controlled and maintained by specific modified myocytes called the conduction system of the heart.

The cardiac conduction system

The conduction system of the heart composed of: sinoatrial (SA) node, atrioventricular (AV) node, AV bundle, and Purkinje system.

The sinoatrial node (SA node)

The normal cardiac impulse that initiates mechanical contraction of the heart arises in the SA node (or pacemaker), located just below the atrial epicardium at its junction with the superior vena cava**.** Specialized pacemaker cells in the node possess an *intrinsic rhythm.* This means that without any stimulation by nerve impulses from the brain and cord, they themselves initiate impulses at regular intervals. Even if pacemaker cells are removed from the body and placed in a nutrient solution, completely

separated from all nervous and hormonal control, **they will continue to beat.** In an intact living heart, of course, nervous and hormonal regulation does occur and the SA node generates a pace accordingly. [5]

Thus, the SA node initiates each heartbeat and sets its pace, it is the heart's own natural *pacemaker*. Under the influence of autonomic and endocrine control, the SA node will normally "discharge," or "fire," at an intrinsic rhythmical rate of 70 to 75 beats per minute under resting conditions.

The atrioventricular node (AVN)

A complex structure that performs a variety of functions in the heart. The AVN is primarily an electrical gatekeeper between the atria and ventricles and introduces a delay between atrial and ventricular excitation, allowing for efficient ventricular filling.

The atrioventricular bundle (bundle of His)

Is a continuation of the specialised tissue of the AV node, and serves to transmit the electrical impulse from the AV node to the Purkinje fibres of the ventricles.

Purkinje fibers

They are specialized conducting fibers composed of electrically excitable cells. They are larger than cardiomyocytes with fewer myofibrils and many mitochondria. They conduct cardiac action potentials more quickly and efficiently than any other cells in the heart (6).

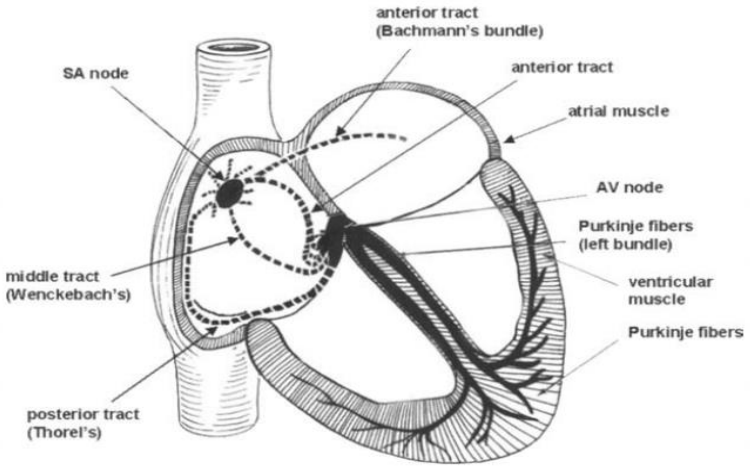

Figure 1. The cardiac conduction system

The pacemakers

Pacemakers are adjustable artificial electrical pulse generators, frequently emitting a pulse with a duration between 0.5 and 25 milliseconds with an output of 0.1 to 15 volts, at a frequency up to 300 times per minute. The cardiologist or pacemaker technologist will be able to interrogate and control the pacing rate, the pulse width, and the voltage, whether the device is temporary or permanent. Pacemakers are typically categorized as external or internal. The external variety is almost always placed for temporary stabilization of the patient or to facilitate some type of surgical procedure. The implantable type is usually permanent and often, significantly more complex than the temporary, external variety. [(7)]

Historical background

The true beginning of the concept of a pacemaker began over 200 years ago. In the late 1700s, Luigi Galvani discovered that he could cause contraction of a frog heart simply by passing an electrical current through the heart. This concept was further realized nearly 100 years later with the first successful resuscitation of a child by Guilliame de Boulogne utilizing

electricity. He was able to accomplish this by introducing an electrical current to the patient's chest with a return electrode on the leg after a drowning. After this feat, many successful resuscitations were reported, leading to the term "artificial cardiac pacemaker" by Dr. Hyman in 1932. (8)

Cardiac pacing, or electrical stimulation to alter or produce cardiac mechanical activity, started in the 1930s with Hyman's "artificial pacemaker," which used a hand crank to generate an electric current that drove a DC generator, which sent electrical impulses to the patient's right atrium via an intercostal needle electrode. Hyman faced professional criticism, lawsuits, and allegations of making "an infernal machine that interferes with the will of God" at the time, and his machine was never manufactured. (9)

After WWII, public opinion shifted, and bold pioneers made significant progress. Battery-powered, transistorized, “wearable” pacemakers replaced large, external, alternating current–powered pacemakers tethered to an extension cord. C. Walton Lillehei, a cardiac surgeon at the University of Minnesota, and his friend Earl Bakken, a hospital equipment engineer, are credited with the invention of pacing. They create a battery-operated system to avoid the failures of the past. Bakken modified a circuit for an electronic metronome he'd seen ten years ago, changing the two-transistor circuit so that the electrical signals would rhythm the heart instead of powering a speaker. The device was immensely successful and they name it the “Pacemaker”. (10)

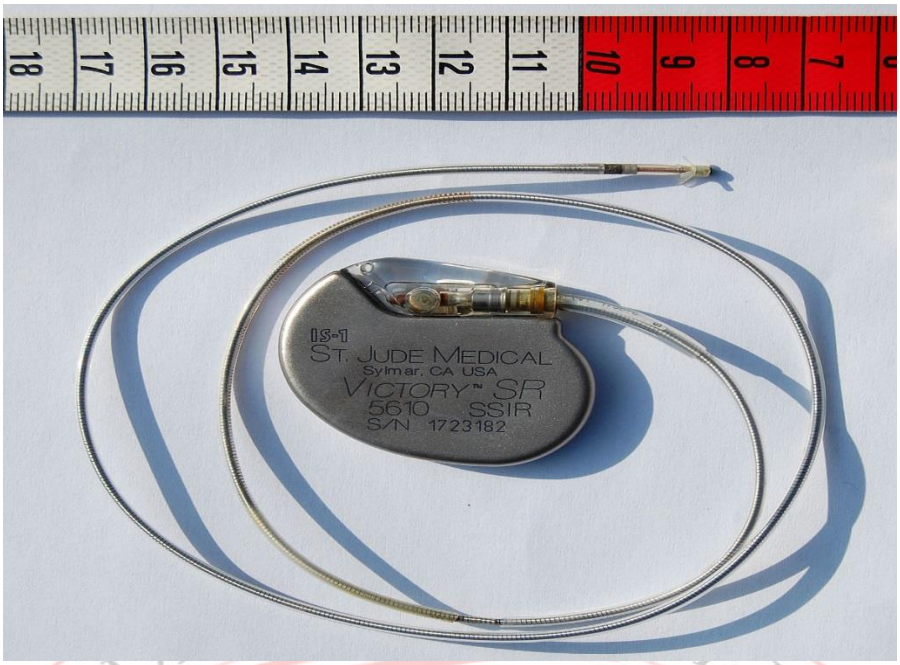

Figure 2. Artificial cardiac pacemaker

Basic principles

Normal cardiac activity begins in the sinus node, where cells with intrinsic automaticity act as pacemaker cells. Electrical wave fronts then spread across the atria to the atrioventricular (AV) node, which they pass through to enter the His-Purkinje system to rapidly spread to and depolarize the ventricles. When intrinsic cardiac automaticity or conduction integrity fails, the electrical excitability of cardiac tissue allows a small, external electrical stimulus to drive myocytes to threshold, leading to depolarization of neighboring myocytes through energy-consuming biological processes and the consequent propagation of an electrical wave front, with near-simultaneous muscular contraction via excitation-contraction coupling. Pacemakers provide this stimulus. (11)

A pacemaking system consists of an impulse generator and lead or leads to carry the electrical impulse to the patient's heart. Leads can be unipolar, bipolar or multipolar. Generators with bipolar leads can be programmed to the unipolar mode for pacing, sensing, or both. (12)

The pacemakers' technique and types

There are three main types of pacemaker devices [13] :

1. Implantable pulse generators with endocardial or myocardial electrodes
2. External, miniaturized, patient portable, battery-powered, pulse generators with exteriorized electrodes for temporary transvenous endocardial or transthoracic myocardial pacing
3. Console battery or AC-powered cardioverters or monitors with high-current external transcutaneous or low-current endocardial or myocardial circuits for temporary pacing in asynchronous or demand modes, with manual or triggered initiation of pacing

The pacing system consists of the pacemaker (or pulse generator) and a lead or leads that connect to the pacemaker. This is all located inside the other important part of the pacing system, the patient. There is a desk based programmer to communicate with the device. [14]

Pacemaker (pulse generator)

This is like a mini computer. It contains a tiny 2.5-volt lithium-iodine battery capable of long battery longevity. It also contains the complex circuit capable of performing functions from delivering the pacing impulse, sensing the intracardiac signal to storing, filtering and analyzing intracardiac signals. This is all hermetically sealed in a hard titanium based case. Pulse generators now weigh only about 20 g and are ~20 cc in size.

Pacing leads

These are predominately transvenous and consist of an insulated wire (silicone or polyurethane covering) that conveys electrical signals between the heart and back to the pacemaker. It connects to the pacemaker by a port

and connects to the heart by a fixation mechanism. This is either a tine or screw mechanism.

Programmer

This is a desk based computer system able to interact with the pacemaker by telemetry function. The more recent devices are wireless enabled. This enables the physician to check lead function and battery longevity, make programming changes, and evaluate large amounts of data detected by an in built holter system in the pacemaker.

Recent advances in pacemaker technology led to development of biventricular pacing, with electrodes placed in the right atrium and both ventricles. When needed, this can further improve physiological function by coordinating ventricular contraction. (15)

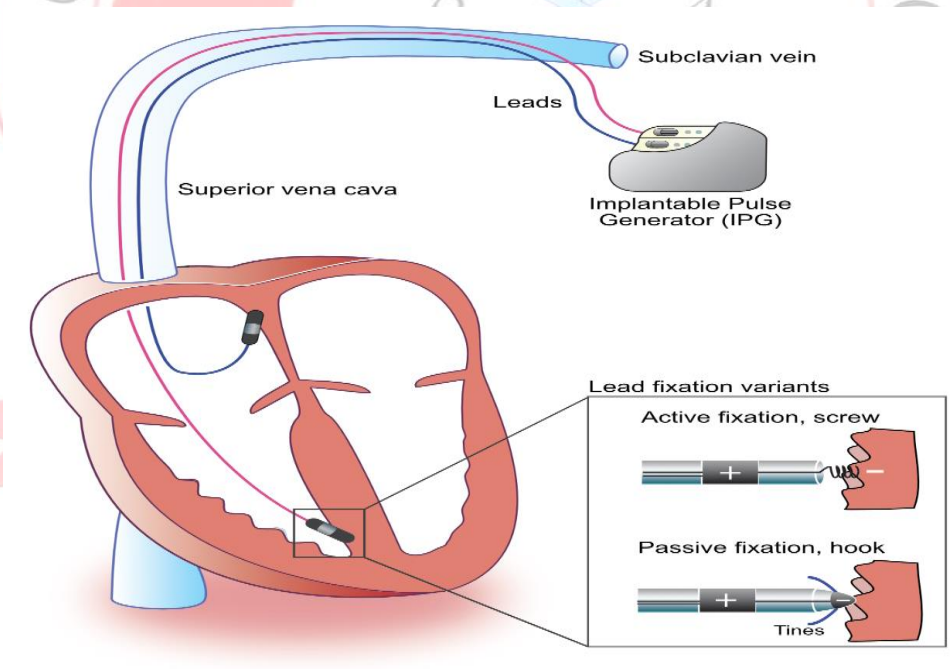

Figure 3. Components of the pacemakers

Indications of the pacemakers

Regular reasons for implantation are bradyarrhytmia, including several conditions, such as, symptomatic sinus bradycardia, second and third-

degree AV block and sick sinus syndrome. In these conditions, the slowed heart rate reduces heart outflow and decreases oxygen supply to vital organs. Hence, symptoms of weakness, fatigue, shortness of breath, confusion, loss of consciousness and heart failure are observed. Since the 1990s, pacemakers are prescribed in other conditions, including cardiomyopathy, CHF, atrial fibrillation and tachyarhythmias. [16]

Implantation

The pacemaker is implanted subcutaneously during a simple procedure, lasting between 1–2 hours. The procedure may be performed in the electrophysiology (EP) lab under local anaesthesia. During the procedure, one or two electrodes are inserted, under translumination, through a central vein directly into the right ventricle and/or atrium. After the electrode is located and fixed with the heart muscle, the pacemaker is located under the skin and starts operating independently After the procedure, the patient may notice a slight swelling around the implantation area and a small (5–10 cm) scar. One day after implantation is completed, patients are provided with general instructions and vital information concerning life with a pacemaker and they are free to return home. [17]

Contraindications to pacemaking therapy

Like in any procedure, the insertion of pacemaker insertion should be chosen wisely for a particular patient. There are situations in which pacemaker insertion is not beneficial or is not enough data to support its use [18]

- Sinus bradycardia without significant symptoms; asymptomatic first-degree AV block
- AV block that is expected to resolve and unlikely to recur example drug toxicity, Lyme disease, or transient increase in vagal tone

- Asymptomatic second-degree Mobitz, type-I block
- Asymptomatic prolonged RR interval with atrial fibrillation or other causes of transient ventricular pauses
- Asymptomatic bradycardia during the sleep
- Right bundle branch block with left axis deviation without syncope or other symptoms compatible with intermittent AV block
- Long QT syndrome or Torsade de pointes due to reversible causes
- In the presence of an accessory pathway that has the capacity for rapid anterograde conduction.

Complications

Like any medical therapy, the pacemakers have some complication. (18-19)

- **Infection**: incidence is 0.8---5.7%4 Staphylococcus aureus (early infections) and S. epidermidis (late infections) are the most common organisms involved.
- **Thrombosis**: usually subclinical (Pulmonary embolism incidence is 0.6---3.5%).
- **Pacing problems:** like, Failure to capture. The occurrence of the stimulus output, which, when delivered outside the refractory period of atrial or ventricular tissue, is not followed by a P wave or QRS complex. This could be due to elevation of stimulation threshold, which in turn could be due to metabolic disturbances, drugs (mostly anti arrythmics), acute myocardial infarction, pacing lead defects (fractures, insulation break), lead maturation, dislodgement or perforation.
- **Sensing problems**: Oversensing of unwanted signals event.
- **Rapid paced ventricular rates:** Atrial tachyarrhythmias: Sinus tachycardia, atrial tachycardia, atrial flutter and ventricular pacing can resemble an electronic AV block, and cardiac output can suddenly decrease.

- Other complications include hematoma formation, pericardial effusion or tamponade, pneumothorax, coronary sinus dissection, or perforation.

Conclusion

The pacemakers therapy was considered a breakthrough in the history of medicine. They developed and designed to treat patients with cardiac rhythm abnormalities and disorders. Their use nowadays is common among the cardiology community and it has estimated that more the one million pacemaker are implanted annually in USA. They are simple, accessible and effective tools which can make the life of a lot of patients get better.

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