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Technological Advancements Applied to Cardiac Care

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Biomedical Engineering Student at Wentworth Institute of Technology Expected Year of Graduation: 2020 Area of Interest: Emerging Trends in Biomedical Engineering

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Abstract:

According to a report from the American Heart Association, over 92 million US adults have at least one type of cardiovascular disease (CVD). Technological advancements in biomedical engineering have been adopted in cardiac care to assist in CVD therapy for better outcomes. The objective of this paper is to review major applications of technological advances in cardiac care including robot-assisted heart surgery, implantable cardiac technologies, and heart valve replacement, as well as to highlight the associated benefits. Technological advances applied in cardiac health care can provide doctors with the ability to improve patient care and ease of access, thus proving to be beneficial to all the stakeholders in the healthcare delivery spectrum.

Keywords:

Technology in Cardiac Care, Robot-Assisted Cardiac Surgery, Cardiovascular Implants

Introduction:

The heart is a major internal organ upon which many of the body's systems rely on. While it is in the best interest of every person t to be in a good state of cardiac health, it is not the case, since millions of people around the world suffer various cardiac problems. Modern technology and health care have created several innovations to help those in need.

Cardiac Disease is the number one cause of death in the United States, killing over 614,000 people in 2014.[1] Major innovations, such as robotic assistance in cardiac care, implantable cardiovascular technology, and heart valve fabrication and replacement attempt to greatly reduce the problem of cardiovascular diseases and increase the health and wellness of patients.

The objective of this research paper is to explore solutions to cardiac diseases and other heart-related illnesses and highlight the benefits. This paper covers specific topics such as robot-assisted heart surgery, implantable cardiovascular technology, and heart valve fabrication and replacement.

Robotic Assistance in Cardiac Surgery:

A major innovation that has changed the way that doctors operate on the heart is robotic cardiac surgery. Robotic cardiac surgery is heart surgery done through very small incisions in the chest. With the use of small instruments and robot-controlled tools, surgeons can perform heart surgery in a method that is less invasive than open-heart surgery.[2] This surgery is most commonly used to repair or replace stiff or leaky heart valves, remove a tumor in the heart, or treat other congenital heart conditions.[2] The reason this method of operation has become successful is because it is faster, more precise, and safer for the patient when compared to an alternate method such as traditional open-heart surgery.

By using the data from the various tests and diagnostics, doctors can establish an ideal method to treat many cardiac complications. Robot-assisted cardiac surgery can often be used in procedures such as mitral valve repair and replacement surgery, tricuspid valve repair and replacement surgery, combined mitral and tricuspid valve repair and replacement surgery, ablations of atrial fibrillation, atrial septal defect repair, patent foramen ovale repair, the removal of cardiac tumors, and lead placement.[3] While surgery may not be a doctor's first choice, as lifestyle changes and medication are both preferred options when viable, certain situations will require advanced surgical procedures to solve the problem.

After isolating the region of tissue and assessing the results using tests and diagnostics, the surgeon will decide to perform surgery. After the anesthesiologist sedates the patient, the surgeon will make several small incisions on the side of the patient's body below the armpit near the right chest. These incisions may vary from procedure to procedure. However, regardless of the operation, they allow small robotic instruments and cameras inside the patient's body in a minimally invasive way. The surgeon then uses the camera and small robotic devices to operate inside of the patient. Once the procedure is completed the surgeon removes the tools from the patient, and the incisions are closed. A representative configuration of robot-assisted surgery is seen in **Figure 1**.

Figure 1. *A typical operation room set up during robot assisted cardiac surgery. The surgeon (left) controls the robotic arms (middle) that operate on the patient. The surgeon's assistants (right) often help the surgeon perform the operation on the patient.*

Following the operation, the patient is moved to a recovery area so that he or she may be monitored as the body heals following the operation.[2] After a relatively short stay in the hospital, approximately 50 percent of the recovery time of conventional open-heart surgery, the patient is discharged after their status is stabilized. After a few weeks, most patients can resume normal activities postoperatively.[2]

Robot-assisted surgery offers many advantages when compared to other forms of open cardiac surgery. Patients who undergo robot-assisted cardiac surgery see a faster return to normal activities.[4] Rather than waiting several weeks to heal, patients can return to work or other activities within about two to three weeks.[4] This is mainly because patients who undergo robot-assisted cardiac surgery reduce their hospitalization times by as much as 50 percent when compared to other open procedures.[4] Furthermore, the exchange of splitting the breastbone with several smaller incisions means that the body goes through less trauma, and is, therefore, able to more effectively heal itself.[4] Keeping the breastbone intact reduces the chance of post-surgical complications and infection.[4]

The patient can also see a quicker resolution of pain.[4] Decreased damage to tissue and muscle results in pain that does not last as long as pain following a sternal incision.[4] Common analgesics may be sufficient to manage pain after hospital discharge.[4] Furthermore, there is minimal blood loss and a lowered need for blood transfusion.[4] This is very important as blood loss can be a very important factor in any surgery, especially operations dealing with the heart and circulatory system. When compared to different forms of open-heart surgery, robot-assisted cardiac surgery produces very little scar tissue. Rather than a long chest scar, the procedure only leaves a few tiny scars or one short 2-inch scar.[4] This is beneficial to the cardiac patients as they are not burdened by an unappealing scar down the center of their chest.

Robot-assisted cardiac surgery allows doctors to more quickly, safely, and efficiently operate on the patient's heart. This is not only beneficial to the individual patient, but all patients since the decreased operation and recovery time allow more patients to receive treatment. However, robot-assisted surgery should not be limited to cardiac care alone. This technology could be expanded to fit the needs of a wide variety of surgeries. Many open form surgeries could see a transition to robot-assisted surgeries. Hopefully, as more advancements in science and technology are made, robot-assisted surgeries will become the standard practice, allowing the patient's a safer and faster operation. Furthermore, robot-assisted surgeries could just be the stepping stone to a much more advanced form of surgery. With technological innovation and advancement, new forms of surgeries may be produced that are safer and more efficient than robot-assisted cardiac surgery. For the time being, however, the innovations that are present must be used to the best of their abilities to provide the best care of the patients.

Robot-assisted cardiac surgery is a major innovation that has helped many people who require cardiac operations. Its promising role in cardiac care will help further its development as a substantial procedure in various forms of cardiac health science.

Implantable Cardiovascular Technology:

Another innovation that has changed cardiac care is the development and improvement of implantable cardiovascular technology. New cardiovascular device therapies for atrial fibrillation (AF) and heart failure (HF) are rapidly evolving with the use of innovative materials and new technologies.[5] While there is a wide range of developments in cardiac technology, implantable technology is one of the most successful fields and is being adopted by other fields of research rather quickly.[5] This technology enhances patient care by providing an enhanced, long-term solution to those in need of cardiac care or assistance.[5] Implantable cardiovascular technologies are innovative that can be implanted and interact with the human body. While there are many types of implantable cardiovascular technologies, the most successful and influential solutions are the leadless pacemaker, the Implantable Cardioverter Defibrillator (ICD), and the Ventricular Assist Device (VAD).

Pacemakers are small devices that are placed in the chest or abdomen of a patient to help control abnormal heart rhythms as shown in **Figure 2**.[6] The device uses low-energy electrical pulses to prompt the heart to beat at a normal rate.[6] Pacemakers are used to treat arrhythmias and other cardiac disorders that influence the heart's rhythm.[6] During an arrhythmia, the heart can beat too fast, too slow, or with an irregular rhythm.[6] These devices are especially helpful because they provide a solution to the heart arrhythmias preventing further cardiac problems such as heart failure or stroke.

Figure 2. *A size comparison between a €1 coin and the Nanostim pacemaker.*

Normally, pacemakers require wired connections, or leads, to certain areas of the heart to maintain its rhythm. However, the development of leadless pacemakers establishes a less invasive and harmful design while achieving the same pacing results as a standard pacemaker. A standard pacemaker requires your doctor to create a surgical pocket to implant the pacemaker.[7] Leads are then attached to the pacemaker and run to your heart, where they pace the heart.[7] Leadless pacemakers securely placed inside the patient's heart, sending small electrical pulses when needed to prompt the heart to beat normally.[7] The pacemaker requires no surgical pocket, produces little to no scarring, and requires no leads.[7] The pacemaker battery life is equivalent to that of similar standard single chamber pacemakers.[7]

This innovation greatly increases patient satisfaction due to the small size of the device, roughly 10 percent the size of a conventional pacemaker, and lack of a surgical pocket, coupled with the exclusion of leads, improves patient comfort and can reduce complications, including device pocket-related infection and lead failure.[8] Furthermore, the device eliminates the visible lump or scar at the conventional pacemaker's implant site and reduces the patient's activity restrictions following the implantation.[8]

Implantable Cardioverter Defibrillators, ICDs, share some similarities with pacemakers. ICDs are battery-powered devices that are placed under the skin to keeps track of the patient's heart rate.[9] Thin wires connect the ICD to the patient's heart.[9] If an abnormal heart rhythm is detected the device will deliver an electric shock to restore a normal heartbeat.[9] ICDs have been very useful in preventing sudden death in patients with known, sustained ventricular tachycardia or fibrillation.[9] Studies have shown that they may have a role in preventing cardiac arrest in high-risk patients who haven't had, but are at risk for, life-threatening ventricular arrhythmias.[9]

Another type of implantable cardiovascular device is a Left Ventricular Assist Device (LVAD). An LVAD is a type of mechanical circulatory support device (MCSD) that is implanted in patients who have experienced heart failure to support the weakened organ.[10] By assisting the ventricle, the major pumping chamber of the heart, LVADs ensure that the heart can distribute blood throughout the body.[10]

When the LVAD is surgically implanted, one end is attached to the left ventricle, the chamber of the heart that delivers blood to the lungs and therefore to the body, and the other end is attached to the aorta, the body's main artery.[11] Blood flows from the ventricle into the pump which passively fills.[11] When the internal sensors indicate, the device is full, the blood is ejected out of the device and into the aorta.[11] Along with the internal mechanical parts, there is a tube, called a driveline, that passes from the device through the skin to an external battery.[11] This not only allows the LVAD to receive battery power but allows for the use of rechargeable batteries.

These devices are especially helpful because they not only provide short-term capabilities but also cater to long-term cardiac needs. LVADs are commonly used in bridge-to-transplant procedures as well as destination therapies.[10] In a bridge-to-transplant procedure, the LVAD provides temporary assistance for the weakened ventricle until a donor's heart becomes available for transplant.[10] This type of procedure is best used for short-term assistance. In a destination therapy, the LVAD is used as an alternative to a heart transplant, providing long-term support to the patient.[10]

It is important to note that while these products do offer very significant cardiac health benefits, they do create a few risks for the patient. A major potential risk when using pacemakers and ventricular assist devices (VADs) is magnetic fields. Because the normal function of the devices relies on internal magnets, any sort of external magnetic interference can impact the device's performance. Being in the presence of strong magnets or in the presences of magnet fields for an extended period can negatively impact the performance of the devices, resulting in damages to the cardiac device. It is recommended that those who use these devices stay away from magnetic fields and strong magnets to stay safe.

Implantable cardiovascular technology is a major innovation that has helped many people who require cardiac assistance. Its role in cardiac care will help further its development as a viable replacement for various forms of cardiac diseases.

Heart Valve Fabrication and Replacement:

The third innovation in cardiac health care is heart valve fabrication and replacement. Heart valves act as one-way valves for blood in the heart. As the heart contracts and relaxes, the heart valves open and close to ensure the correct flow of blood in the heart. Heart valves are extremely important as they ensure the correct volume and pressure of blood is being released with each contraction of the heart.

Heart valve disease occurs if one or more of the heart's four valves: the tricuspid, pulmonary, mitral, and aortic valves do not work well, or function poorly.[12] It is typically caused by heart conditions and disorders, age-related changes, rheumatic fever or infections.[12] There are two main types of heart valve disease: regurgitation and stenosis.[13] Regurgitation occurs when the valve(s) do not completely close, causing the blood to flow backward instead of forwards through the valve.[13] Stenosis occurs when the valve(s) opening becomes narrowed or does not properly form, inhibiting the flow of blood out of the ventricle or atria causing the heart to pump the blood with added force to move the blood through the stiff (stenotic) valve(s).[13]

Heart valve replacement surgery is often used to fix heart valve disease. The objective of the operation is to remove the damaged or faulty heart valve and replace it with a working valve. While there are various types of heart valve replacement surgery, the most common types of valve replacement surgeries are tissue or bio-prosthetic, donor, and mechanical valve replacement surgery. Each type of replacement surgery comes with its own benefits and drawbacks. Each type of heart valve replacement surgery works to better the patient's cardiac health.

Recent developments in 3D bioprinting technology have expanded the options for human-based heart valve replacement. 3D bioprinting makes it possible to design biological tissues from scratch that contain many of the natural geometry, stiffness, and biological cues that are needed for full function.[14] By using STEM cells from the patient and a 3D skeleton of the desired organ, doctors can bioprint a functional organ. Furthermore, the chance that the body will reject the organ is greatly decreased since the organ is made from the patient's own cells. This is extremely significant as one of the biggest roadblocks to any replacement surgery is the rejection of the implant. Many patients will wait a long time for an organ that they need, assuming the organ they receive will be accepted by the body. 3D bioprinting has the potential to change replacement surgeries and operations by increasing organ availability and decreasing the body's rejection of the organ.

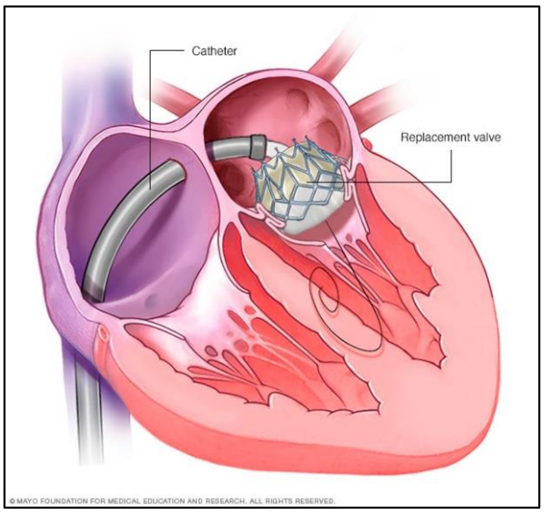

Figure 3. *An example of how the TAVR method replaces a heart valve.*

Most heart valve replacement surgeries require the surgeon to open the patient's chest to fix the faulty valve.[15] However, there are some minimally invasive methods in which the damaged valve is replaced through a small incision near the sternum or under your right chest muscle.[15] Prior to the operation, anesthesia will be given to the patients so that they will be unconscious during the operation. Many heart valve replacement procedures require the use of a cardiopulmonary bypass (CB) machine to keep the patient's lungs breathing and heart beating.[15] This ensures the circulation of blood during the procedure. During the procedure, the surgeon will remove the damaged valve, and then sew the new valve into place. Following the procedure, all incisions are closed.[15] The patient is then moved to the intensive care unit (ICU) so that they may be monitored to ensure there are no complications following surgery.[15]

One of the most popular minimally invasive heart valve replacement options is a trans-catheter aortic valve replacement (TAVR). TAVR is a method of repairing the heart valve without removing the old, damaged valve.[16] Instead, a stent is placed into the valve and opened allowing space for the new heart valve.[16] A sample of the TAVR procedure is shown in **Figure 3**. The TAVR delivers a fully collapsible replacement valve to the valve site through a catheter.[16] Once the new valve is expanded, it pushes the old valve leaflets out of the way and the tissue in the replacement valve takes over the task of regulating blood flow.[16] This minimally invasive procedure removes the need to open the chest, a practice that is becoming more common as minimally invasive surgeries and operations become standard practice.

Future Works:

One specific technology that has the potential to revolutionize medical devices, especially in the cardiac field, is inductive, or "wireless," charging. Inductive charging allows energy to be transferred between two objects using an electromagnetic field. Devices such as pacemakers, ICDs, and LVADs all have potential to use inductive charging to improve the day-to-day lives of patients by removing the external components of said devices, along with the internal-to-external device connections. This not only would revolutionize the way these devices are implanted into the body, but also post-surgery patient care.

While inductive charging has the potential to be beneficial to patients, there are some complications that may arise. Firstly, devices such as LVADs, which use a magnetic field to operate, could have functional complications from the magnetic field of inductive charging. Furthermore, it would be beneficial to research the effects of long-lasting exposure to electromagnetic fields before implementing this technology. On the other hand, inductive charging could make devices such as the LVAD more effective, allowing the electromagnetic field to not only run the device but also keep it charged.

Inductive charging has the potential to improve patient care and comfort. By further developing the technology, inductive charging has the potential to gain greater acceptability in cardiac technological innovations.

Conclusion:

While there are many cardiac diseases that one can develop, there are equally as many technological advancements that can be applied to treatments in the cardiac healthcare field. These innovations can provide doctors with the ability to improve patient care and ease of access. Major innovations such as robot-assisted heart surgery, implantable cardiac technologies, and heart valve replacement not only have the power to enhance patient care and treatment but also have the potential to completely reshape the direction of the field.

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