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Application of Sensors, Actuators and devices in Cardiovascular Treatment

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Abstract - This research paper presents a scholastic analysis, including a technological overview of the most recently done research evaluations and technological accomplishment in the treatment and diagnosis of cardiovascular treatment. The main purpose of this paper is to provide future developers and researchers with critical highlight concerning the achievements and efforts related to devices, actuators and sensors which are essential for the treatment, diagnosis, imaging, mapping and monitoring of the cardiovascular treatment. This scholastic analysis ends by showing the segments of significance and potential areas that require further analysis.

Keywords - Imaging, Devices, Sensors, Actuators and Cardiovascular

1. Introduction

The transferring lifestyle has contributed significantly over the past few years to deal with heart illnesses at an exceptional rate. In United States alone, it is projected that more than 500,000 people die every year due to heart-related diseases [1]. Moreover, more than a billion people in the entire globe are affected by hypertension. Nonetheless, it is projected that fundamental life savings in relation to the healthcare expenses can be attained with some precautionary procedures, including monitoring, preventions and diagnosis. The accelerated enhancements in the medical field and technological enhancements for devices, sensors and cardiovascular-connected applications assure certain accomplishments to minimize the risks that come with heart diseases. Technological developments range from the sites of patients and their application to online monitoring aspects.

A critical overview of the enhancement applications required in various stages and areas of the cardiovascular framework treatments clearly shows that the applications which are not inclusive of medications and drugs, include the actuators or sensors or the two. These mentioned applications are typical and regulatory categorized as medical devices. Whether the healthcare devices are catheter actuated strategically to accomplish a mechanical purpose, it is a battery-centered pacemaker which is meant to regulate heartbeats. Moreover, it can be termed as embedded or external pressure sensors which is further described as healthcare devices of various categorizations. In that case, this indicates the significant engagement of actuators and sensors in various stages of heart-connected treatments that range from precautionary and monitoring measures based on diagnostic applications which considers pre-treatments and post-treatments.

Literature investigations of recent analysis and technological advancements show that literature efforts are concentrated in areas such as: treatment, diagnosis, monitoring and image mapping. The research efforts might categorically present a number of approaches to a single issue or problem which is a thesis for researchers to highlight novel methodologies and approaches meant to boost awareness to the problematic heart-related issues. The cardiovascular framework, heart illnesses and the connected problematic diseases are significantly complex and sensitive for some obvious reasons. In that regard, it is essential to conduct a research that will create solid thesis for firm understanding of the cardiovascular framework related issues [2].

This will resultantly develop a comprehensive basis of novel improvements and approaches, to evaluate the research findings, sophisticated technological advancements and to evaluate the various possibilities for novel collaborative partnerships and efforts. The analysis done in this contribution critically evaluates both the critical research efforts, technological trends and advancements [3]. Other than the fact that this is never an exhaustive analysis it might need more space and time compared to the scope of the analysis; it potentially presents some recent efforts that significantly address the demanding problems from the perspective of medical technology. In the scope of this evaluation, the areas are considered as highly significant and future projections are included as well.

There are a lot of analyses that have been carried out over the past few decades to concentrate on medical

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instruments with developed electronic frameworks which might effectively enhance the treatment and diagnosis of cardiac conditions and diseases. Evaluated in novel papers published in the journal of natural and bio-medical engineering, researches have applied matrices, stretchable electronic actuators and sensors, including pressure and temperature sensors to catheter balloon systems to effectively invasive ablations or surgeries for heart arrhythmias. The novel framework that conforms effectively to soft tissues compared to the present devices might perform various functions which include vivo temperature measurements, forced contract, electro-physical parameters and the capacity to customize therapeutic functions, including actual-time feedback. The novel framework might significantly minimize the duration of invasive ablation process and put the doctors and patients to risks that come with x-ray radiation [4]. A lot of minimally invasive surgeries depend on catheters incorporated into the human system via the minor incision meant to conduct diagnostic intervention and therapeutic measurement.

The doctors for instance, utilize the catheter-centered technique to treat and map irregular heartbeats and arrhythmias which is typically as a result of ablating, killing and locating cardiac body tissues that lead to arrhythmias. Although this is mostly applied in surgery, the present catheter-centered technique has some limitations. The rigidity of the current catheter devices implies that it might conform effectively to biologically soft tissues which affect the maximum fidelity map of organs and electrophysiological signal. Present devices contact the minor parts of the human body at a given timeframe hence making it needful to shift the probe around and widen the medical process [5]. The present catheter frameworks have been limited to some functions which might perform the procedures based on the application of physicians that utilized catheters in one ablation process. Moreover, long procedures for instance, to ablate and locate tissues affecting arrhythmias expose the physicians and patients to x-rays since the healthcare practitioners depend on x-rays pictures throughout the process of surgery when leading the catheters.

2. Overview of Imaging and Mapping

The theme of mapping and imaging is of a significant interest in cardiovascular diagnosis due to its direct inclusivity of the diagnosis symptoms, operation of patient's heart and post monitoring or treatments. Moreover, the imaging processes are also included. Based on the evaluation of patient treatment, ages and conditions, various imaging methods are needed to adapt to the varying elements. For this purpose, it is noticed that research developments and efforts take much more space in the field of medicine. Intensified efforts have been done by different research groups to evaluate the present imaging methods and launch the novel ones including modifying and improving the present ones. Among the mostly mentioned imaging methods include the Cardiac Magnetic Resonance (CMR) that are termed as versatile and essential as medical tools in the process of evaluating suspected and known heart issues as a result of the transitional features through modulation pulse sequences and the medical parameters. More importantly, the methodology is termed as a powerful non-invasive diagnostic framework for myocardial anatomy, viability evaluation, perfusion, function and some other coronary arterial illnesses.

A critical issue affecting the utility of CMR is attributed to consequent positional transition and continuous motions which conform to the heartbeat mode and rates in relation to the challenges of synchronizing the timeframe for images. Nonetheless, the enhancement of various CMR methodologies has reduced the impact of the issues through the timings of image acquisition in the cycle of cardiac cycles based on the gating of ECG. Various ECG gating modes have been evaluated to include single shot methodologies, cine methodologies and segmented methodologies. Consequently, various protocols have been structured and applied to effectively quantify the case-dependent CMR intensity. Anatomic imaging protocols are utilized to project initial localization of the cardiac frameworks whereas functional images are utilized in the process of obtaining images based on heart contractions via the cardiac cycles in many forms of orientations based on the application of many cinepulse sequences [6].

Researchers have evaluated the performance of semi-automatic segmentation techniques for functional and anatomical evaluation for the right and left ventricles originating from the cardiac cine of CMR, including the novel quantification method which have been projected to permit accurate and faster assessment of ventricles. Moreover, the characterization of tissues might be retrieved through more pulse sequences via the intrinsic magnetic relaxation timeframe. Apart from the CMR application, fibrosis, myocardial scarring and myocardial perfusion are elements considered as well. CMR is typically utilized to incredibly diagnose and treat the coronary artery illness, heart failure, ventricular thrombus, microvascular obstruction and myocardial edema, including viability assessment. Considering that CMR utilizes the firm magnetic field which is approximately 40,000 times more than the earth's magnetic field and its strength, it is possible to identify the body protons in the body [7]. This is considered in the process of researching effective gating methodologies on both hardware and software dimensions. Various researchers have also evaluated in a more elaborated manner the various gating protocols before launching novel techniques.

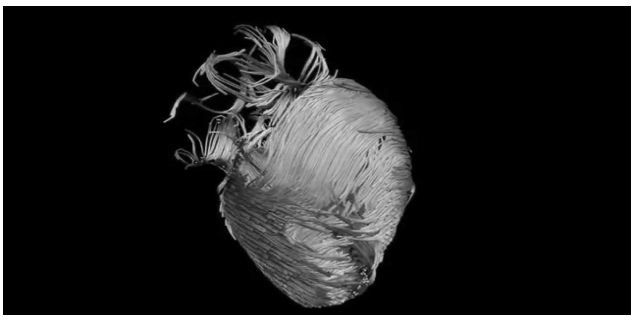

Fig.1 Whole heart coronary MRI angiography

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The catheter represented by Acutus medicals forms a segment and a system structured to build 3D maps and images of the heart electrical activation system based on the application of the ultrasound micro-transmitters and micro-sensors. On both the hardware and software dimensions in the reduction of patients' interface in CMR include advanced patient stages, premature, pregnant and fetus. Researchers have projected novel approaches whereby the ultra-wide band sensors are applied remotely for the ultra-high magnetic resonance ecosystem. The technique has proved that UWB alongside the effective signal processes might boost the image resolution in CMRI [8]. Moreover, the researchers have also formulated the MRI compatible framework to facilitate the scanner gating in the fetus heartbeat for various imaging application which do not have adverse effects.

In the research, the analyses have proven the chances of effectively gating the stages of CMR. Whether we are handling the presumed fine heart or treating the patients based on a specific scanner, the modified ECG and the carbon fiber system might be utilized. Based on the perspective of technological advancement, a lot of advancements are revealed over the past few decades. In many samples, GE medical remedies over the past few decades introduced novel CMR technologies for the MRI scanners alongside the sophisticated software known as viosworks which are meant to simplify MRI scans via automated image sequences to accomplish complete 3D imaging.

Another incredible avenue includes the cardiovascular imaging which represents the 3D mapping of the medical system. A lot of firms like the Acutus medicals and Topera are considered as leaders in the segment based on the present 3D mapping and imaging products. Nonetheless, it has been projected that certain technological areas are still in their early stages and there is more space for advancements. This is mostly for the researchers focused in evaluating the ultrasound-based sensors and actuators [9]. One of the incredibly promising research field in image processing includes the usage of the Fractional Flow Reserve which is considered as a methodology applied in coronary cauterization.

This is meant to evaluate and measure the pressure variation over the coronary arteries and stenosis to effectively evaluate the stenosis impedes and oxygen delivery to the muscles of the heart. FFR might be utilized in the process of developing unnecessary invasive evaluation of heart conditions. Progressive researches have been done to evaluate the FFR application in cardiovascular-connected evaluation of various problems including CAD, ischemia, intracoronary lesion and acute myocardial infraction [10]. The evaluations in this paper have concluded that medical verified FFR practices might become novel non-invasive technique for evaluating the kind of lesions that require revascularization and hence minimizing the patient numbers that refer to coronary angiography.

The existing researches have also projected and evaluated the methodology for utilizing FFR through coronary computed topographies and angiography in detecting ischemia-leading lesions through the inclusion of coronary atherosclerosis illness which is meant to enhance the varied discrimination between ischemia and stenosis. In another research, there are rational evaluations that support the application of guided FFR for maximum routine CAD practice. In the same case, there are researches that have compared FFR findings based on stress testing techniques in evaluating the extent, location and presence of ischemia. The evaluation has evaluated the effective connection between stress and FFR techniques that assure the potential application of FFR techniques are non-invasive. Moreover, the analysis has critically evaluated the viability and affordability of FFR as a fundamental technique of choice in evaluating the functionality and significance of coronary arteries and lesions which can be viewed as a decision-making framework for revascularization terms.

Contrary to that, the present researches have evaluated the issues that face the processing of FFR techniques on a massive scale in the assessment of CAD and projected that a lot of research efforts have to be concentrated in the areas before considering the numerous issues that face the various application of significantly potential techniques. Moreover, recent technological enhancements have considered the chances of applying data from regular CT scans which are meant to evaluate the flow of blood via the 3D computing frameworks meant to evaluate FFR measurements without requiring cauterization [11]. There are technologies projected by Heart-Flow Inc. concerning the initiation of technologies meant to simulate the flow of blood and the pin-pointed arteries connected to FFR problems.

3. Available Sensors in Cardiovascular Nursing

The analysis in cardiovascular-connected nursing concentrates critically in evaluating two parameters as an evaluative element and determining factor of heart-related conditions in various stages. The factors being considered here include temperature and pressure. There are a lot of research efforts that have concentrated on the significance of pressure evaluation and monitoring, including the various pressure sensing methodologies. The fiber optic sensors and piezo resistive are some of the prevailing technologies being used in the evaluation of the mentioned factors [12]. The minor foot prints, light weights, capacity to incorporate the catheters and the guided wires with minimal energy necessity based on relatively minimal costs and long-term capacities are some of the merits of the fiber optic sensors and piezo resistive.

Certainly, the minor dimensions, flexibility and light weights are the optic fibre-centred pressure sensors which make them non-invasive and effective for the vivo instruments in a lot of implantable healthcare applications. The present research efforts have focused on persistent necessity for implantable equipment for patients suffering from heart failure irrespective of their invasive conditions which are connected to their capacity of the implantable devices. This is critical for the provision of actual-time hemodynamic information from a remote location. These devices incorporate left atrial pressure, pulmonary artery, and the right ventricles which include the novel therapeutic

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methods like cardiac contractility modulations and the bar reflex evaluation therapy.

Researchers have also presented novel numerical control techniques meant to optimize the element of interaction between the turbo dynamic ventricles that aid devices for enhancing the circulation of blood. In this aspect, a mathematical framework was structured and utilized in the process of optimization. The findings were therefore validated based on the application of actual blood pump in the hybridized blood-mock framework. In the same research, there were investigations of the application of polyaniline conduct metrics bio-sensors which were used to detect the cardiac biomarkers as a technique for treating and diagnosing cardiovascular illnesses. The linear sensor profiles and the test responses, including the ultra-high sensitivity factor were deeply focused. This was due to the requirements to showcase the significant success of linking bio-materials and signal evaluation as an integrated framework (Fig 2). The identification of cardiac bio-markers has been evaluated based on the application of DNA-centered bio-sensors.

In these research efforts, there is an evaluation of extrinsic Fabry-perot inter-ferrometer based on the application of integrated fiber brag grating as a simultaneous temperature and pressure sensors for volume-encrypted bio-medical application. The efforts showcase the application of sensitive fiber-optic temperature and pressure sensors in relation to the sophisticated software algorithms which is based on all-glass 200 um diameter fiber with a movable diaphragm tip. As a result, this makes it appealing to minimize the handling of sensors for the restricted volumes and areas. Moreover, other significant efforts have been concentrated on the evaluation of sensor capacities to evaluate temperature and pressure parameters which capable of impeding plethysmography for the evaluation and measurement of extra-vascular factors for arteries. As proved significantly by ex/vivo measurements, an implantable design of sensors has been projected for the process of evaluating the cardiac events as seen in Fig 3.

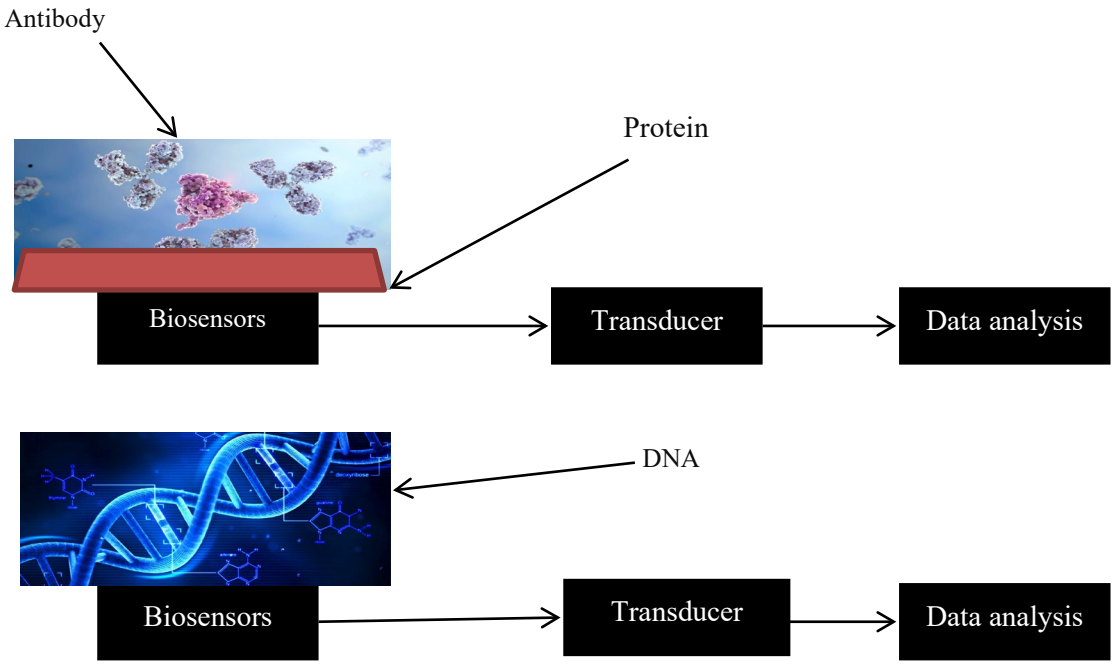

Fig 2: Detection of Proteins using Nanowire Biosensors

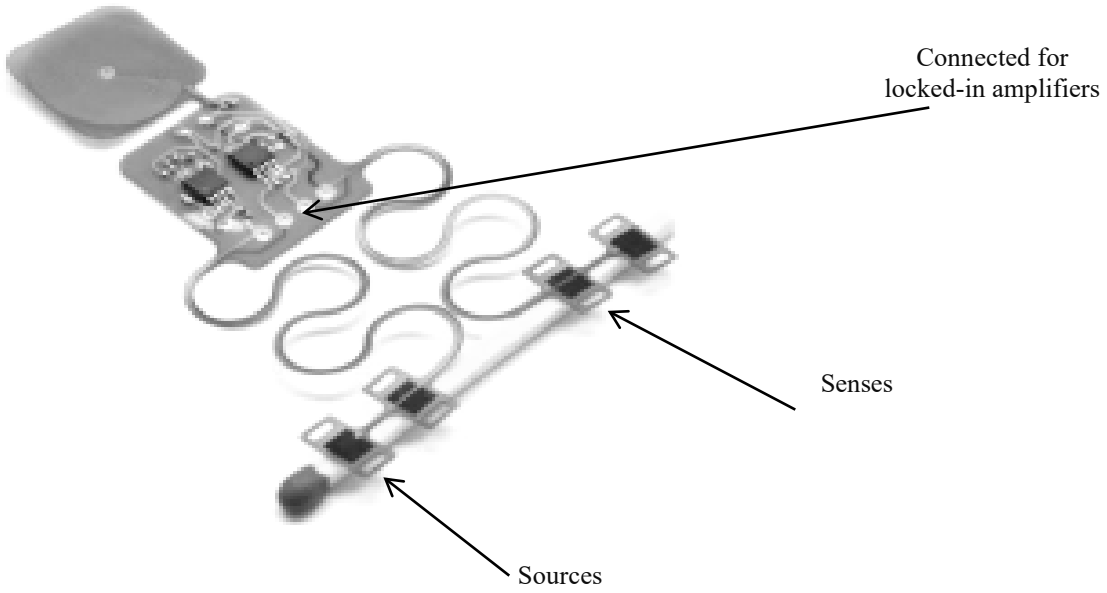

Fig 3: IPG implantable battery-powered sensor

Based on the application of FEM simulation and ex/vivo validation in actual-time evaluation, the projected sensors have proved to correlate with the measurement aspects of blood pressure that suggest that the impeding measurements might be utilized as a reliable evaluation technique with effective resolutions and the state-of-earth signal to noise ratio. The protein levels have been indicated in the treatment of various cardiovascular system illnesses. As shown in Fig 3, IPG implanted battery-powered sensors use polyimide foils with four electrodes included in the arteries which have to be monitored. Based on the merits of utilizing ultrasound methods for categorizing the mechanical features of arteries and diagnosing various pathologies, there are research efforts which have projected novel analytical rigid frameworks in relation to soft-body dynamics in the process of quantifying the elasticity of various arteries. Various frameworks in this process have been evaluated as block matching and various optical flow frameworks have been used to determine the most effective method to be utilized. In this process, a synthetic ultrasound factor was utilized as an optimal framework in the process of simulation.

Whereas these efforts evaluated the implantable sensors, there are some efforts that have projected the designing framework of acoustic sensors that are the basis of ultrasound application. Moreover, tremendous research efforts have been concentrated on biosensors, bio-agents and DNA bio-sensors in the process of evaluating the pressure of arteries and illness evaluation through the process of analyzing the protein content and other essential body fluids. The technological developments are considered parallel with critical research efforts concentrating on minor wireless and implantable powered monitoring devices. There are many examples ranging from iRythm and ZIO-XT Patch technologies that provide progressive cardiac monitoring of the arrhythmia which last for two weeks [13]. Moreover, these systems and technologies assure a long-term monitoring aspect and also apply the implantable wireless sensors in the process of monitoring and evaluating the pressure in the arteries (Fig 4).

Fig 4: The "Cardio MEMS HF System

As shown in Fig 4, the cardio MEMS apply HF frameworks and apply the implantable wireless sensors in the process of monitoring the pressure in the arteries.

4. Devices and Actuators

It is critically certain that the actuators are utilized in cardiovascular diagnosis and treatments which are the end case evaluation of the actual research necessities supported in research efforts in analytical forms: materials, flows and physiology. In that case, the research on the actuators is considerable limited and a number of advancements have been done around this research area. However, a number of research efforts have evaluated the theoretical significance in the evaluation of the projected remedies for a number of devices and actuators such as the ventricular aided devices which are obliged to execute the replacement of functional

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biological muscles and the coronary stents. A number of research efforts have considered this form of technological front in the medical field. Among the most recent samples, it is considered as a leadless pacemaker which incorporate the MedTronics and St-Jude Medicals which are of minimal sizes, minimal power essentials and massive long-term reliability which focus on the most essential features (Fig 5)

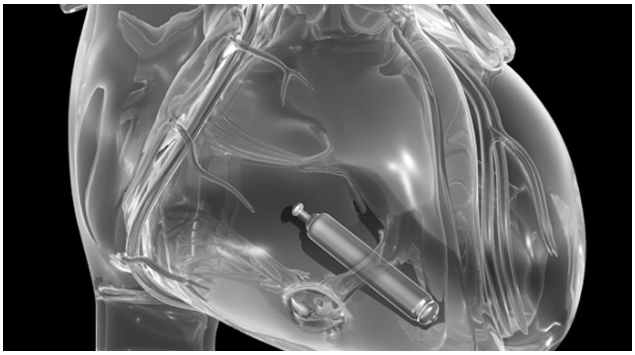

Fig.5 Leadless Pacemakers

Other forms of application concentrate on these actuators as heart implant for CardiAQ new mitral valve replacements from the various Edward Technologies (Fig 6)

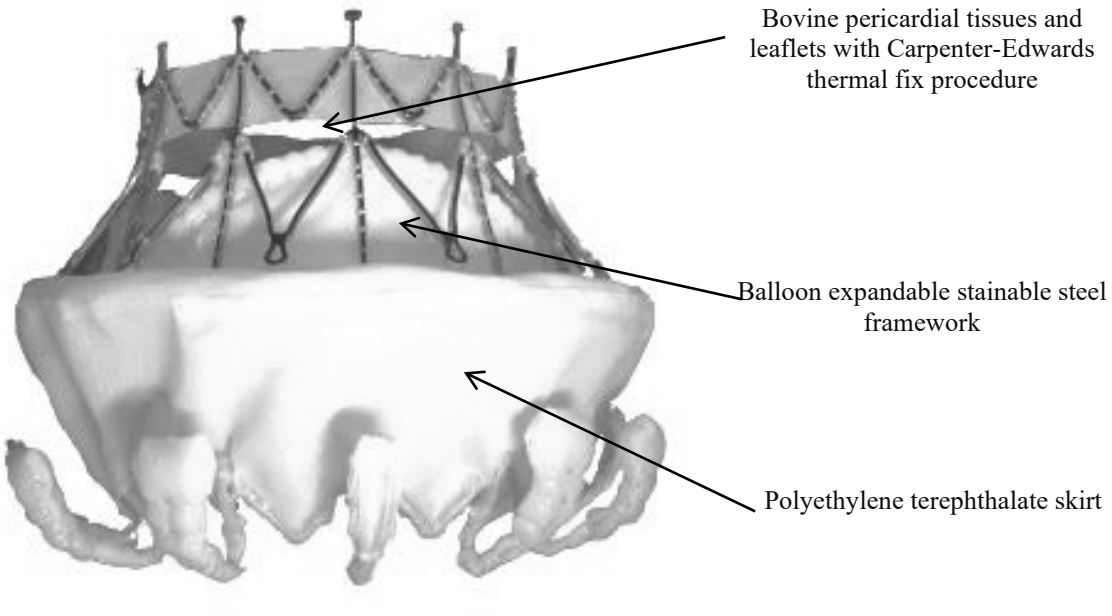

Fig 6: Edward Technologies CardiAQ mitral valve

4.1 Materials in Cardiovascular Frameworks

The research analyses [14] evaluate the considerable efforts allocated for developing and researching novel technologies and materials meant to support novel advancements and mitigate the issues in cardiovascular application. Actually, focus is incredibly on the bio-compatibility of evaluated materials with the human body. Apart from that, there are researches that concentrate on the material classification and characterization from sensor and imaging application whereas there are others that concentrate on the significant surface parts and modification of size controls. One of the essential parts in biomaterial analysis includes the evaluation of polymer materials and their essential application in cardiovascular devices, actuators and sensors. For instance, there are investigations on the application of the electroactive polymers which are meant to replicate the cardiovascular devices which critically incorporate the actuators with the capacity to replicate the biological muscles which have their minor activation energies that range from one to two volts.

In the same case, there are researches in the advancements of miniature pressure ‘catheter sensors’ based on the application of nanomaterials and microsystems which are seen as flexible. In a more elaborated evaluation, the micro fabrication is considered as a matter of sensors originating from the PVDT-centered nanomaterial which incorporate the surface treatment stage and the evaluated developed sensors. The variety of the

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polymeric materials are categorized from the purpose of application of cardiovascular application and devices which include the bio-stable polyurethane, UHMWPE fiber, bio-compatible drug delivery material and the medical grade coat. The mentioned classes are featured based on the light weight, biocompatibility, strength, flexible and the long-term toughness. Concentration on the electroactive polymer in the cardiovascular application is considered as one of the most essential and the parts requiring significant evaluation in relation to the potential effects, characteristics and essential features including affordability.

4.2 Wireless Energy and Actuation of Cardiovascular Devices and Sensors

This is considered as one of the most interesting themes in the field of medicine since it projects from potential issues for effective usage of enhanced application, mostly the implantable ones. The research in this segment concentrates on two critical parts. Firstly, it concentrates on the wireless mobile application in the process of evaluating the critical aim of monitoring the remedies of the gradually evolving lifestyle of patients suffering from heart symptoms and diseases [15]. As evaluated by present research efforts in this theme, enhancements seen in nanotechnology have added to the enhancement of textile-centered wearable devices which are critical for cardiac evaluation and monitoring. Wireless communication systems have advanced over the past few decades and also enhance the viability of devices (Fig 7).

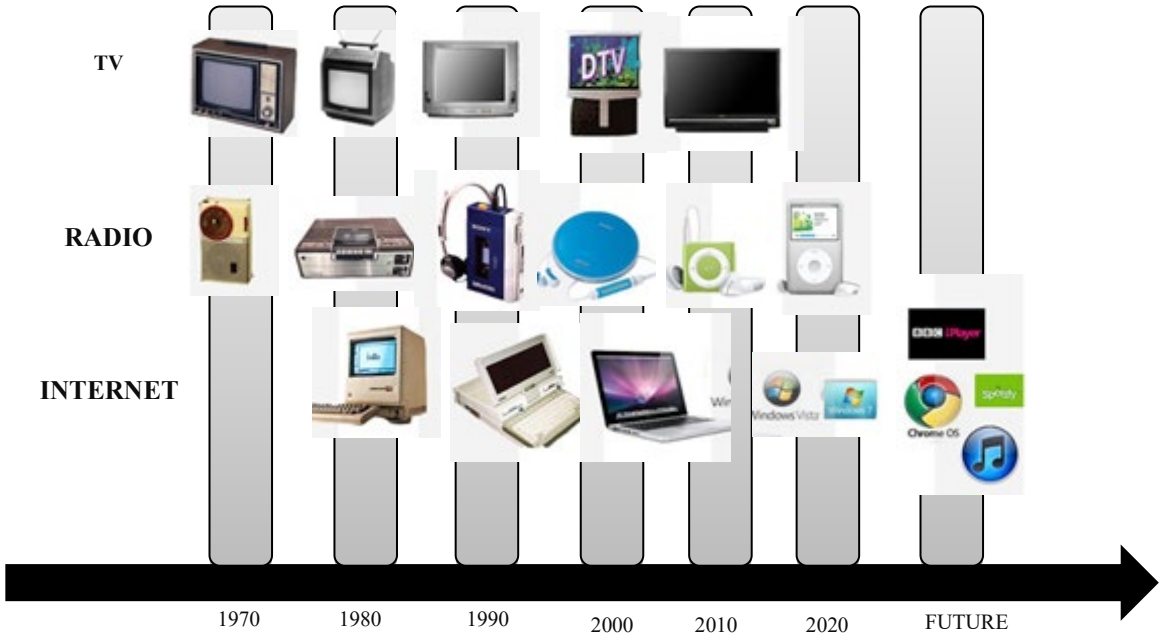

Fig 7: Advancements in wireless communication

There are proposals on novel software applications and the protocol-based reasoning engines for physicians and patients. The architecture is projected based on mobile phones for progressive monitoring and thus communication is possible between critical diagnoses of heart illness patients and physician or clinical based. A similar remedy has also been projected to focus on incorporating kinetic sensors that are included in smartphones. Another fundamental investigation has been done to evaluate the wireless-based implantable atrial defibrillator system which facilitates the aspect of measurement of the intra-cardiac impedance. In this evaluation, it is seen that there are outcomes that significantly recommend further research in the field of wireless communication. According to Fig 7, the enhancements in wireless communication have significantly transformed, hence amounting to the viability of wearable cardiovascular monitoring.

Secondly, the wireless energy transmission is of much significance to the implanted devices and sensors which critically focus on the transcutaneous energy transmission which is meant to be implantable for bio-medical devices. Since it is of a significant relevance, it can effectively transmit energy to the implanted devices in the body. In this part, different techniques have been considered to incorporate genetic, free-ranged resonant and adaptive algorithms. Moreover, the present research efforts have concentrated on the approaches for wireless power transfer to the implantable bio-medical devices with optimum transfer efficacy. The transcutaneous energy transfer techniques such as the adaptive models and the free-range have also been evaluated.

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5. Conclusion and Future Directions

In this paper, we have shed light on the fundamental data and possible areas of interest for developers and researchers with the interest to explore a wide-range of opportunities in the treatment and diagnosis of cardiovascular illnesses. In this research, it is projected that, based on the perspective of the medical practitioners, there is the need to establish instruments that will allow healthcare practitioners to retrieve electrophysiological data and deal with the surgeries in a short-frame with one catheter architecture. The cardiovascular illness is the leading causes of death for patients suffering from heart-related disease. Since this has been seen to advance gradually over the past few decades, there is need for progressive cardiac monitoring which is critically essential for early diagnosis and treatment of the illness. Due to the advanced effects of the illness, stretchable and flexible devices are presently emerged as a fundamental tool that specifically serves the purpose of treatment and diagnosis. Apart from focusing more on monitoring, future researches should focus on intimate contact which is essential for high-precision therapy. Linked with tissue monitoring and engineering, soft bio-electronic have showcased the capacity to effectively repair the damaged cardiac body tissues.

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