International Journal of Science Academic Research
Vol. 03, Issue 12, pp.4775-4778, December, 2022
Available online at http://www.scienceijsar.com

ISSN: 2582-6425

Research Article

BIOCOMPATIBLE, SOFT MATERIALS FOR STRETCHABLE AND EPICARDIAL PATCH ENABLING DIAGNOSIS OF HEART DISEASE

Doyeon Kwon, *Jong Wook Lee and Sunny Kim

Brighton College Abu Dhabi, UAE

Received 10th October 2022; **Accepted** 16th November 2022; **Published online** 12th December 2022

Abstract

One of the most significant public health concerns is heart failure, with a mortality rate greater than most cancers. Myocardial disease may cause heart failure, and it often comes with the impairment of the electrical conduction system and function of myocardium. Compared to conventional materials, novel advanced materials have been developed for providing the conformable covering and softness of bio-implantable epicardial patch with epicardium surfaces. However, it is still challenging in material research to achieve both conformability and biocompatibility, which is important to detect signals from heart. Unlike conventional wearable and implantable bioelectronics that consist of metal and/or inorganic materials, biological tissues are hydrophilic, ion rich, and fluidic. This difference in chemical properties limits the long-term biocompatibility and performance of bioelectronic system. In this research, we address the importance of early diagnosis of heart disease from bio-implantable system and introduce the candidate materials for components of biocompatible, conformable epicardial sensing/pacing system. The proper combinations of materials could provide a new pathway towards the reconstruction of the soft diagnosis system in the future.

Keywords: Biocompatible, Heart disease.

INTRODUCTION

Implantable epicardial devices are essential for screening, observing, and treating diseases related to heart and blood vessels. When in contact with the epicardium, a typical epicardial bioelectronic device analyzes the electrical and physical properties of the heart, including electrocardiograms (ECGs), mechanical contraction and expansion behaviors, and pathophysiological data (Ramasamy *et al.,* 2018; Rashkovskaet *et al.,* 2020). Moreover, the electrical stimulator integrated with sensor platform can also provide treatment by applying electrical pulses. In conventional bio implantable system for epicardium, it is still challenging to realize accurate and reliable properties because the systems are fabricated in rigid form, which induce large strain to our organs. In this respect, the ideal bioelectronic device should have a softness and flexibility similar to actual cardiac tissues with various sensing functions (Song *et al.,* 2021). Therefore, the device should be made of materials that have similar properties to the heart tissues in order to interact with the outer layer of the heart (epicardium) and change shape according to the heartbeat. It should offer spatiotemporal mapping of the cardiac conduction characteristics and other physical features. Deformable epicardial bioelectronics has been created as a result of developments in materials, mechanical structure designs, and bioelectronic technologies. A key technique in the development of soft epicardial devices has been the structural engineering of stiff materials to produce mechanical softness (Figure 1). For instance, rigid materials have been used in epicardial patches with open-mesh structural designs that give overall mechanical stretchability and deformability, allowing them to deform with the heart (Xu *et al.,* 2020). Thin-film flexible electronics based on ultrathin silicon on a polymer film have also been used to spatially map electrophysiological activities.

However, connecting these materials to cardiomyocytes is challenging: flexible silicon electronics for cardiac mapping cannot be deformed while the heart is beating simultaneously and mesh-structured cardiac devices based on inherently hard materials can overstrain cardiomyocytes. Likewise, soft bioelectronics methods often employ rigid, non-elastic materials that provide a hard-soft interface with living tissues. Utilizing materials that are naturally soft is an alternative strategy. A cardiac wrap has been created using soft conductive composites of silver nanowires (AgNWs)/ styrene-butadiene-styrene in order to maintain diastolic relaxation, physically supporting the heart and increasing cardiac contractility by electrical stimulation. But a cardiac wrap that relies only on a continuous conductive material is unable to do the spatiotemporal mapping (Park *et al.,* 2016).

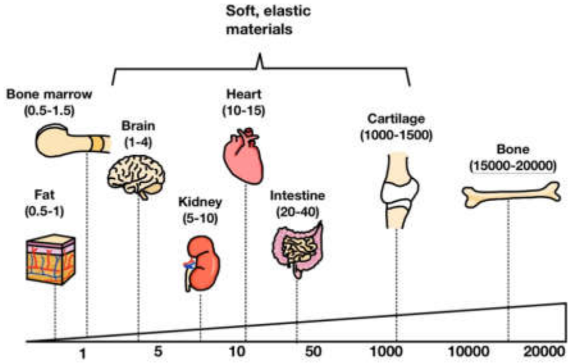

Figure 1. Modulus of organs

A new kind of technology, termed "stretchable/flexible bioelectronics", provide a new way to solve these problems. Stretchable/flexible electronic systems are lightweight, soft, which could provide intimate contact with muscles and minimize the stress applied on surfaces of biological tissues. Recently, the development of soft materials and processing

---

Corresponding Author:** ***Jong Wook Lee
Brighton College Abu Dhabi, UAE

technology has made it possible to monitor and diagnosis of internal organs for a long time through bio-implantable sensors. (Choi *et al.,* 2019) In this review, we address the importance of early diagnosis bio-implantable cardiac system directly covered on heart, enabling early detection of heart disease. Next, we explain the current limitation of diagnosis and pace-makers and address the promising solution to overcome current challenges with soft, biocompatible materials. Finally, we review the recent applications of soft epicardial patch, which shows successful diagnosis and therapeutic functions for specific heart disease. In the future, the health management of people will be done in real-time with high accuracy by using these new information technologies.

Why is important to early diagnosis?

Cardiovascular disease (CVD) still remains the main cause of death and mortality these days. For this reason, early diagnosis of heart disease is of paramount importance, preventing urgent occasions. An early detection of cardiovascular disease can be the difference between life and death. By checking the signs of CVD in advances, patient have a better chance of catching threats early on. There is major challenge in making early detection and treatment of heart disease. A technology gap – currently, there is no simple to use medical device, which is suitable for the screening of asymptomatic patients, that is able to detect and diagnose a sufficiently broad range of heart diseases. The lack of an appropriate device coupled with the heart's complexity explains why heart disease was always regarded as the domain of cardiology. Our organs, including heart, lung and kidney have very complex structure and irregular surfaces, which hinders the intimate interactions between commercial cardiac devices and biological surfaces. Moreover, they move continuously in our body, for example, our heart changes their volume during repetitive contraction and expansion as they have to pump our blood to entire body. Due to these harsh environments, it is very difficult to make stable interfaces by using commercial bio-implantable devices such as cardiac pacemaker, which is essential part of patients for early detection and treatment. To overcome these obstacles, stretchable bioelectronics have been researched to realize stretchable bio-implantable system, providing mechanical robustness owing to their deformability. To fabricate the soft pace maker, which has functions of commercial pacemaker as well as elasticity and stretch ability, the researchers have to do research in a range from materials, mechanics to biomedical engineering (Hang *et al.,* 2021). In the future, imperceptible soft cardiac pacemaker could provide accurate early diagnosis during the intimate and direct interfaces with heart, enabling immediate response in an emergency occasion.

Soft, Biocompatible materials for epicardial patch

Soft materials are needed to realize the soft cardiac devices including pace maker, sensors and electrical stimulator. Basically, the composite is the intrinsically stretchable materials, which consist of elastic matrix and functional nanomaterials. Although the elastic matrix contributes soft mechanical capabilities to the nanocomposite, the filler materials dominate the electrical and thermal properties of the nanocomposite. Most elastic matrices are insulating, however, well-distributed and highly conductive filler elements of the elastic composite, such as conducting polymers, carbon nanotubes, and metal nanoparticles, can form a percolation network that serves as a charged carrier channel. A highly percolated network of filler materials in the elastic matrix is achieved by using a variety of filler materials, modifying the fillers' dimension (Figure 2) and surface properties, and increasing the number of fillers, and quality of contacts between fillers. This results in high conductivity and stretchability at the same time. The quality and number of connections between filler materials in the elastomeric matrix determine the electrical conductivity as the electrical current travels through the percolation network. In other words, the geometry and distribution of the filler materials within the polymeric matrix as well as the intrinsic conductivity of the filler material determine the conductivity of the nanocomposite. The quality of the percolation network has therefore been assessed using a mathematical concept of the percolation threshold, which suggests the threshold content of the filler material in the network is necessary to develop long-range connectivity. Several fillers are needed in the composite with a high percolation threshold to achieve high electrical conduction.

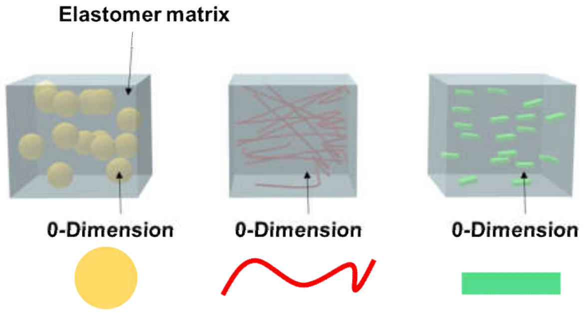

Figure 2. Different dimension fillers in polymer matrix

Controlling the dimension of fillers could be a simple method for adjusting the filler materials. Typically, the dimensions of nanomaterials are divided into four groups: 0D (Zero dimensional), 1D (One dimensional), 2D (Two dimensional), 3D (Three dimensional) materials. Using filler materials with a high aspect ratio can improve conductivity because electrical conduction through a filler moiety increases while conduction from contacts between filler moieties is reduced at the same time. The overall conductance rises because the resistance of a filler moiety itself is significantly smaller than the contact resistance between filler moieties. Since resistance is inversely proportional to thickness, conductance can be increased further by adding more layers of high aspect-ratio fillers. In addition, surface chemistry is crucial in the dispersion of fillers in the polymeric matrix. Due to physical or chemical interactions such as van der Waals force, electrostatic force, and hydrophilicity, nanometer-sized filler materials frequently agglomerate. Due to the high resistance between the aggregates, such aggregation reduces the nanocomposite's electrical conductivity. When building their percolation network, filler materials should be homogeneously dispersed. The percolation threshold can be further lowered locally through microscale phase separation, which will enhance electrical conductivity. A variety of approaches, such as ligand exchange, solvent exchange, and hydrophilicity control techniques, have been employed in order to precisely regulate the dispersion of filler materials in the elastomeric media. Contact resistance across filler materials in the percolation network of fillers is essential for determining the overall resistance of the nanocomposite. Therefore, it's crucial to increase both the quantity and quality of contacts. The simplest technique to enhance the number of effective contacts between fillers is to add more fillers to the composite. Overloading the fillers, however, raises the cost of manufacture, and reduces mechanical softness. Alternately, changes to the filler's shape, such as those to its aspect ratio, curvature, and branches, might also improve the fillers' actual contact with one another. Another typical strategy is to enhance the quality of connections by welding or by employing conducting polymers. In the case of cardiac devices, the conductive material is very important in terms of detection and stimulation on the surfaces of myocardium, which is operated by an electrical conduction system.

Electrical and thermal conductivity in metal nanoparticles is extraordinary. Metal is rigid and heavy in its bulk condition, making it unsuitable for soft bioelectronics, yet metal nanoparticles are flexible and light. Therefore, they can create soft and conductive nanocomposites when combined with elastic media. These metal-based nanostructured materials can be categorized as 0D, 1D, or 2D nanomaterials, which include nanoparticles, nanowires, and nanosheets, respectively. Compared to 1D or 2D nanomaterials, 0D nanomaterials have a larger percolation threshold. As a result, 1D or 2D nanomaterials have been employed more frequently in conductive nanocomposites than 0D nanomaterials, although there have been a few. However, 0D nanomaterials have been utilized in conjunction with 1D or 2D nanomaterials because they can improve the quality of the contact in the percolated network of those materials. Building the conductive percolation network with 0D metal nanoparticles is rather challenging. Therefore, to increase their electrical conductivity without compromising the mechanical properties of the original nanocomposites, 0D metal nanoparticles are frequently added to the nanocomposites with other 1D or 2D nanomaterials. Still, there are a number of researches describing nanocomposite materials that contain metal nanoparticles. For instance, PU and gold nanoparticles were used to create a stretchy conductor by Kim and colleagues (8). Layer-by-layer (LBL) deposition and vacuum-assisted flocculation were used to combine citrate-stabilized 13 nm-sized gold nanoparticles (AuNPs) into PU matrix (VAF). The filler percentage in both AuNP/PU nanocomposites was the same (21.7 vol%). The mechanical and electrical characteristics of the nanocomposite were examined using five films for each (LBL and VAF, respectively). The conductivities of the LBL film and VAF film, respectively, were 11,000 S/cm and 1800 S/cm (without strain). The highest stretchability for the LBL and VAF films, however, was 115% and 486%, respectively. Under 60% strain, the LBL film and VAF film's conductivity decreased to 3500 S/cm and 210 S/cm, respectively, while under 110% strain, it decreased to 2400 S/cm and 94 S/cm. The VAF film has a conductivity of 35 S/cm and could be stretched to 480% of its original length. Each nanocomposite's strain-induced arrangement of AuNPs was examined using the TEM and SEM pictures. Under tensile strain in the LBL film, AuNPs displayed high mobility in the PU matrix, rearranging along the stretching direction. Because the LBL film had more effective conducting channels than the VAF film did, it had better overall electric properties.

Applications for diagnosis and therapeutic stimulation

The heart consists of four chambers: right atrium, left atrium, right ventricle, and left ventricle. The oxygenated blood from the lungs enters the left atrium through the pulmonary vein and is forced through the bicuspid valve during atrial systole. The left ventricle then pumps the blood through the aorta to various organs in the body, hence it has the thickest muscular wall. If the left ventricular muscles lose the ability to contract normally, less oxygenated blood is pumped through the body leading to stiffening of the left ventricular walls (HFrEF). HFpEF reduces the ability of the walls to relax, resulting in less oxygenated blood being pumped to different organs in the body. It could cause damage or death of some muscles, which are vital to our life. The build-up of plaque (or stroma) in the coronary artery, which consists of chemicals such as cholesterol, interferes with the blood flow, reducing the oxygen supply to the body tissues. This damages the myocardium, making it less elastic, leading to less contraction of the heart walls. This can be seen in the electrocardiogram by the increase in the QRS time. Failure to detect the partial blockage of the coronary artery can ultimately lead to myocardium infarction. The conventional method of diagnosis is artery pulse detection, where the wrist patch detects the sounds of valves. However, this is not perfectly accurate and may result in misdiagnosis. To overcome this low accuracy system, the conventional treatment method is to implant a left ventricular assist device (LVAD), a mechanical pump, on the left ventricle. The pump is attached to drivelines, which connect the pump to the controller. Because the controller is implanted in the skin on the patient’s stomach, it presents several obstacles and inconveniences, affecting the quality of their life. To provide the imperceptible property, the electromechanical cardioplasty employs soft epicardial mesh attached directly onto the epicardium of the heart with no external devices implanted in the patient, thus improving their quality of life.

Conclusion

Conventional medical devices, especially an electrocardiogram (ECG) have been used to check the current status of patient and prevent additional shock. However, the system has challenge to detect cardiac disease earlier due to relative low accuracy. Heart disease should be treated in golden time, which is below 5 minutes. In this respect, early detection of heart disease and direct treatment is vital in medical system. To detect the accurate signal from the heart for diagnosis, direct interaction with intimate contact is promising solution and it could be realized by soft cardiac devices. By using the soft conductive materials, low modulus and deformability of materials relax the external stress applied to cardiac devices during repetitive expansion and contraction of ventricles. From this approach, bio-implantable cardiac devices could have a further step to next generation epicardial patch.

Acknowledgement

I would like to thank Sunny Kim for his guidance, encouragement during process of this review, and J.W. Lee for edits of writing throughout the writing.

REFERENCES

Choi, C. *et al.* 2019. ‘Wearable and Implantable Soft Bioelectronics Using Two-Dimensional Materials’, *Accounts of Chemical Research,* 52(1), 73-81.

Hang, C. *et al.* (2021), ‘A Soft and Absorbable Temporary Epicardial Pacing Wire’, Advanced Materials, 33(36).

Kim, Y. *et al.* 2013. ‘Stretchable nanoparticle conductors with self-organised conductive pathways’, Nature, 500, 59-63.

Park, J. *et al.* 2016. ‘Electromechanical cardioplasty using a wrapped elasto-conductive epicardial mesh’, *Science Translational Medicine*, 8(344), 344ra86.

Ramasamy S. *et al.* 2018. Wearable sensors for ECG measurement: a review, *Sensor Review,* 38, 412-419

Rashkovska A. *et al.* (2020) Medical-Grade ECG Sensor for Long-Term Monitoring, *sensors*20, 1695

Song X. *et al.* 2021. A tunable self-healing ionic hydrogel with microscopic homogeneous conductivity as a cardiac patch for myocardial infarction repair, *Biomaterials,* 273, 120811

Xu L. *et al.* 2020. Perspectives on smart stents with sensors: From conventional permanent to novel bioabsorbable smart stent technologies, *Nature communication,* 5, 3329.

****