

# An electromechanical hug for the failing heart

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Heart failure is a condition describing the failure of the heart to deliver sufficient amounts of blood to meet the oxygen requirements of the body. This is caused by a structural and/or functional cardiac abnormality. While a myocardial infarction (MI), which is caused by the occlusion of a coronary artery supplying blood to the myocardium, is probably the best known and most common cause of heart failure, many other diseases may lead to such an outcome (1).

An acute MI leads to loss of cardiac tissue due to necrosis, which leads to a deterioration of the structural integrity of the heart. Next, scar tissue is formed, followed by the thinning of the myocardium itself (2). To prevent the damage caused to the myocardium and relieve the stress on the thinning tissue, the concept of cardiomyoplasty was introduced. The idea behind it is that by using a physical support around the heart, either composed of the patient's own skeletal muscle or using an artificial wrapping device, the stress can be alleviated, the function of the myocardium can be restored and post-MI remodeling can be further prevented (3).

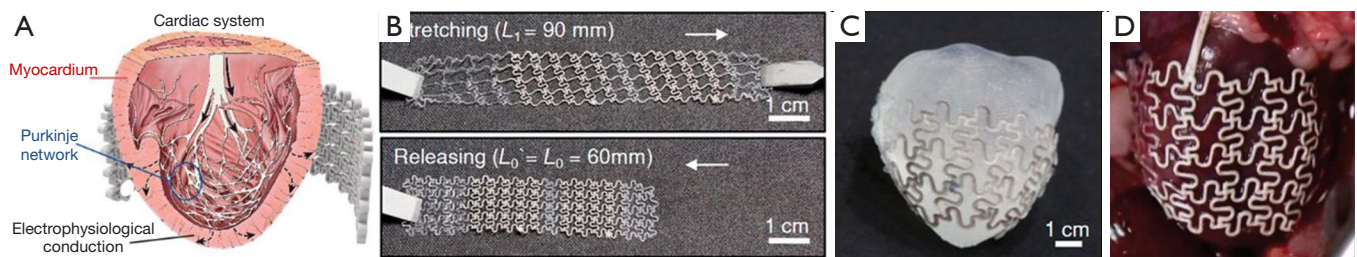
Another symptom commonly exhibited with heart failure is impairment of the heart's native conduction system. Cardiac resynchronization therapy aims at using implantable devices to pace the heart and thus improve conduction and synchronization (1,4-6).

In a recently published article in *Science Translational Medicine*, Park and colleagues introduced an electromechanical mesh with the ability to provide physical support to the heart while providing electrical stimulation to pace the whole ventricle (7). The researchers fabricated a mesh device from styrene-butadiene-styrene (SBS), a biocompatible, rubber-like material that after transplantation on the epicardium

can extend and relax with the heart. Silver nanowires were then integrated within the polymer to create a homogenous, conductive composite (*Figure 1A,B*). The hybrid material was optimized to reach a fine balance between conductivity and elasticity so that the device would have a Young's modulus similar to that of the native epicardium. To reduce the stress on the myocardium the device was designed to be a porous, stretchable mesh. In order to personally fit the device to individual hearts, computed tomography (CT)-based 3D printed heart models were used, and the meshes were designed according to the specific anatomy (*Figure 1C,D*). Furthermore, using the same CT data, the researchers could estimate the mechanical effect of the device on the heart's diastolic expansion rate, and confirm that the mesh structure was superior to a continuous film fabricated from the same composite.

The first goal of the epicardial mesh was to alleviate the stress generated on the myocardium by transferring some of it to the device itself. The researchers demonstrated in an MI model that the device was able to reduce wall stress without adversely affecting the volume and pressure generated by the heart.

As a supplement to the mechanical benefits of the epicardial mesh, electrical stimulation replaced the malfunctioning natural conductive system of the heart and synchronized muscle function. The exposed pads on the epicardial mesh allowed for continuous monitoring and stimulation of cardiac function. By applying a pacing regime the researchers were able to reduce heart cycle duration in the post-MI hearts to a level resembling that of the healthy hearts. The treatment was able to restore synchronous activation throughout all of the segments, as



**Figure 1** Device schematics and applicability. (A) Schematic illustration of the epicardial mesh for electromechanical cardioplasty; (B) demonstration of the elasticity of the epicardial mesh; (C) a photograph of the epicardial mesh encircling the 3D printed heart model; (D) photograph of the epicardial mesh implanted in a control heart [Reprinted with permission (7)].

well as abolish the abnormal electrical activities in the heart, such as tachycardia and ventricular fibrillation. Moreover, pacing through the epicardial mesh improved systolic heart function and contractility through an increase in the generated myocardial strain.

The article presents several important features that could contribute to the field of regenerative medicine in general, and for treating heart failure in particular. The ability of the device to confer structural support to the diseased heart and reduce stress on the cardiac muscle, through the matching mechanical properties is essential in failing hearts. Additionally, through CT imaging and 3D printing the epicardial mesh can be tailored to the specific needs of the patients and their individual heart anatomy.

The data presented in the paper shows great promise for cardiac treatment, however, several issues still need to be addressed. While the ability to stimulate the heart is an important facet of the device, the use of a network composed of a higher number of electrodes instead of two large dipoles presented in this system could prove advantageous to such an approach. This would allow for the activation of the heart muscle in an expansive, sequential manner that is more similar to that of the native cardiac conduction system (8). Another challenge facing the use of such a device is immune rejection. Silver nanoparticles have been shown in the past to induce antimicrobial and also cytotoxic effects depending on their size, method of administration and concentration (9). To address this issue the researchers coated the exposed areas of the mesh with gold which is inert in humans, resulting an improved biocompatibility both *in vitro* and *in vivo* without compromising the conductivity of the device. In addition, the device's potential to treat the infarcted heart was investigated in the short-term. In the future, longer experiments should be performed to evaluate the true

efficacy of the therapy. In terms of an electrophysiological treatment, the device was designed to allow for biventricular stimulation, and the resulting effect proved substantial. However, next generation devices should be designed to address the need for atrioventricular synchronization as well.

In the future, one can easily envision the integration of different technologies into a superior device. For example, the integration of cardiac tissue engineering approaches (10,11) with such epicardial mesh devices could provide tissue regeneration. The electrodes inside the tissue could report both on the function of the heart and on that of the engineered tissue as has recently been demonstrated (12,13). Furthermore, spatiotemporal activation of the tissue can be achieved (13). Finally, through the use of smart electroactive polymers, it would be possible to release drugs and growth factors from within the device to treat the failing heart and provide smooth integration by alleviating immune response (13). With the latest advances in tissue-electronics interfaces, it is now possible to envision how an impediment such as a failing heart could be transformed into a major advancement by converting it into a bionic organ with enhanced capabilities.

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*Comment on:* Park J, Choi S, Janardhan AH, et al. Electromechanical cardioplasty using a wrapped elasto-conductive epicardial mesh. *Sci Transl Med* 2016;8:344ra86.

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