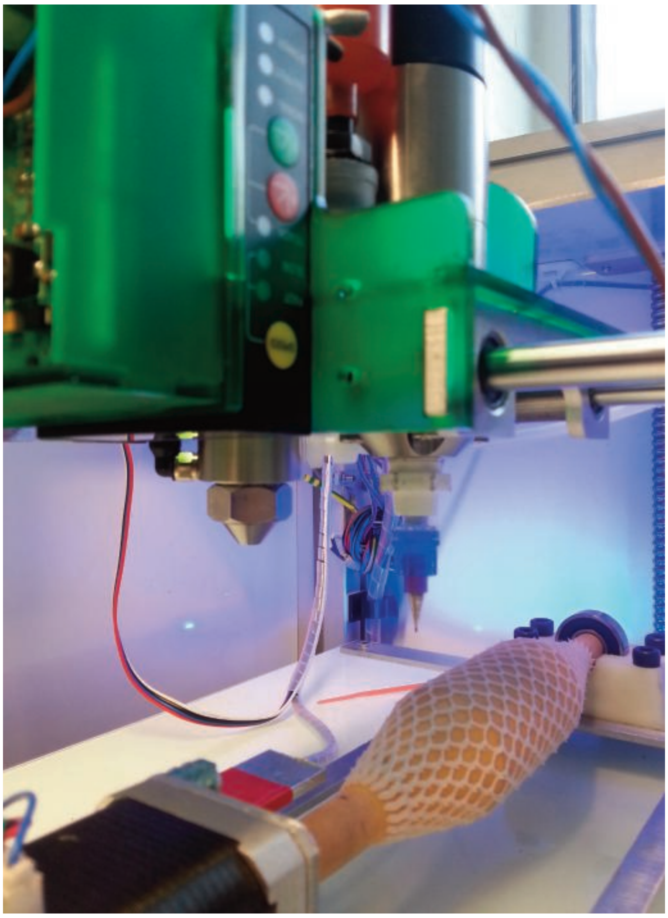
Smart start for the heart

A smart pump being worked on by a university team could provide a breakthrough in treatment for patients with chronic heart problems.

Tim Fryer reports



Around 160,000 people in the EU require heart transplants every year. About 600 actually get them, leaving the other 99.5% needing an alternative. While it is still many years off, a team at Nottingham Trent University is working on such an alternative that could also have applications in other parts of the body.

At the moment, the smart pump project goes under the description of cardiac assist smart aortic graft and it performs a different function to a pacemaker. Whilst a pacemaker regulates the timing of heart beats by stimulating the heart muscles directly with a low voltage, this device will function in a similar manner to the 'aortic balloon pump'.

Its function is to physically force oxygenated blood residing in the aorta (the main artery) against the cardiac muscle during its diastolic (relaxing) phase. Termed counterpulsation, this has the effect of increasing oxygen supply to the myocardium (heart muscle), which increases tissue health and therefore efficiency.

A secondary benefit is increasing aortic pressure during systole (the heart contraction), specifically reducing 'afterload' – the stress developed in the left ventricle wall during contraction.

Rather than use a pneumatic system to counterpulsate the blood, as used in the aortic balloon pump, the Nottingham team's system uses dielectric elastomers. It is a system requiring advanced materials, an innovative manufacturing technique and some clever electronics.

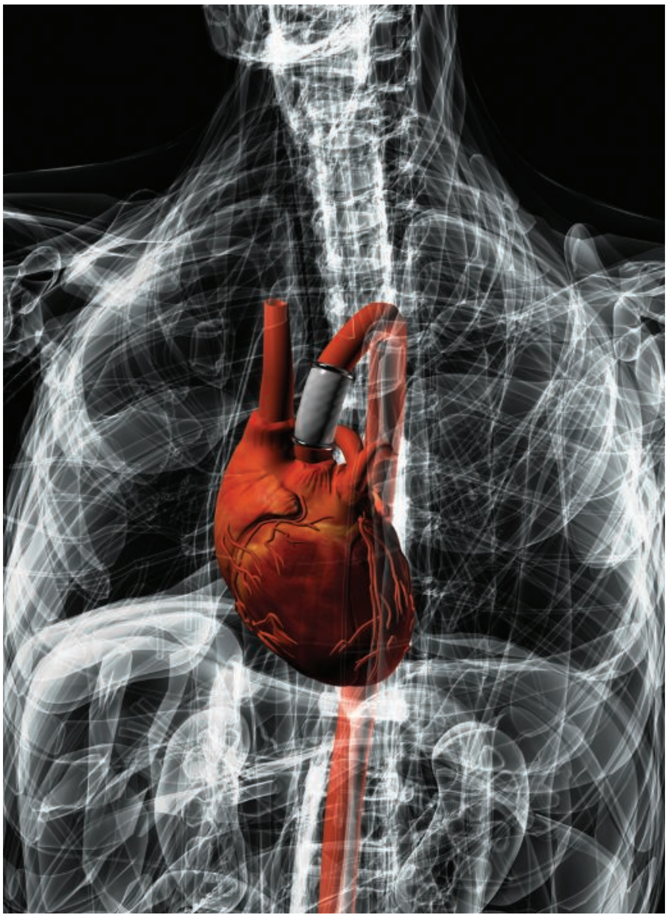
The advanced material in question is a silicone which expands when a voltage is applied to it. As it is formed into a woven tube, this expansion and contraction effectively makes it act as a pump that would beat out of phase with the diseased heart, as described above.

In order to achieve the right properties in the materials, the team has come up with a novel way of manufacturing them. Fergal Coulter, PhD researcher, has adapted a 3D printer for the purpose. "Because we are trying to make these tubular stretched muscles, we needed to design a 3D printer that could create balloon like structures, then inflate them and scan their size so I can print on top of them. I have been referring to it as a form of 4D printing because the substrate itself changes size during the course of the printing. As it is inflating and deflating, there is an extra dimension of change."

To achieve this, Coulter took a 3D printer, kept the XYZ gantry and ripped out everything else, then added a fourth rotating axis, an inflation system and a 3D scanner. The idea is to create a 20μm thick layer of low viscosity silicone, stretching it pneumatically and then printing on it. Coulter explained: "The reason for doing that is that the

Printing onto inflated smart material – the 4D printing process – has been one of the Nottingham team's innovations

Fergal Coulter with the elastomer being used in the research and (top right) how the device would fit into the aorta.



silicone's electrical properties improve, breakdown voltage increases, the dielectric properties of the silicone increase through strain. Then, on top of that, by adding mechanical strain into the system, it is akin to a bow and arrow – the overall muscle has more potential energy available to it."

Control circuitry will consist primarily of an implanted electrocardiogram (ECG) to monitor the heartbeat via a microcontroller, a proportional DC-DC voltage transformer to energise the Dielectric Elastomer Actuator (DEA), and a transcutaneous rechargeable battery.

These are current and commercially available medical technologies, with some already being used for other implantable devices. The power source has been used for such things as deep brain stimulation and pacemakers, but these don't generate sufficient power at the moment, so one consideration for the design team is to reduce the device's power budget.

Powering the device by energy harvesting has been discounted as it would be counter productive, according to Coulter. "The thing about trying to harvest energy from the heart itself is that it is already diseased, so it is weak. Trying to take any energy out of it when it is already struggling to do its job seems potentially a bit dangerous." The team expects advances in through skin induction charging will provide the battery recharging solution.

However, the main challenge within the electronics research is related to the refinement of the Maxwell's pressure on the actuator membranes. It will require a sensor to be built into the device to provide continuous positional data as part of the feedback loop. The solution to this could lie within the inherent properties of the device.

Coulter said: "When you strain the actuators mechanically, you create a capacitance. This whole thing is a multilayer actuator and so having one of the layers, normally the outer one, as a passive sensor, tells us what state the device is in, how it is performing and we can keep it in a closed loop."

Fit to size

One of the perceived advantages is that it will be an implanted solution. It may not be permanent, but it should allow freedom from the tubes and bedside treatment associated with the alternatives. This means the device should not be much bigger than the natural ascending aorta that it is grafted in place of – a diameter of 25mm is typical, but not standard. "One of the issues with some of the artificial hearts that are available at the moment," said Coulter, "is that, for smaller women in particular, there is just not room in their chests to fit them without doing damage to their lungs and so on. We are interested in making a bespoke device for each patient."

The intention is to use the output from a CT or MRI scan to program the 4D scanner directly to create a mandrel that is exactly the right size for the patient. This will be the initial substrate on which the actuator layers are created.

Coulter conceded that creating the smart heart pump was the star prize in terms of the end goal and of attracting further funding for the research. However, with clinical trials taking many years and even the bio-compatibility of the materials yet to be established in some cases, a prototype, let alone an end product, is still a long way off. It may well be that there is lower hanging fruit that can be plucked along the way.

There are, as the prime example, 50 sorts of sphincter in the body – a sphincter being a circular muscle that essentially acts as a valve. Coulter commented: "The large sphincters in particular only need to open and close occasionally, it is not as 'mission critical' as the heart. So the device, in my mind, is going to see use as a sphincter or perhaps as a peristaltic device for the oesophagus. It is going to come to fruition there before the heart because it is a far simpler movement replicating the peristalsis or just opening and closing a valve."