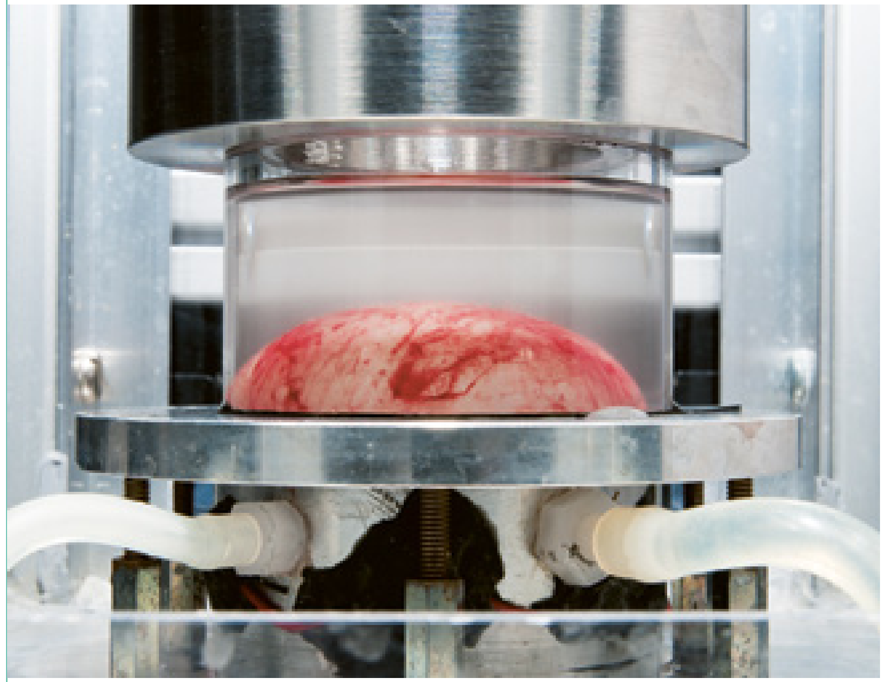
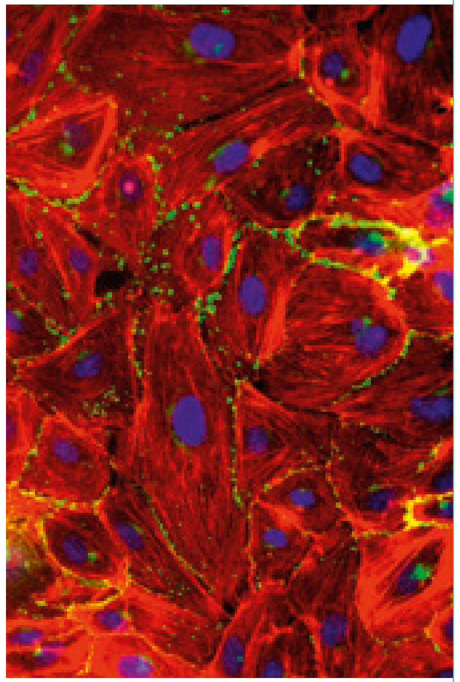


Researchers use this device to study the mechanical properties of different tissue types.



In laboratory tests, they have managed to cultivate a complete layer of endothelial cells on a substrate under extreme mechanical stress.

PROGRESS ON ALL LEVELS

More and more people are living with an artificial heart, but today's devices have serious drawbacks. ETH researchers are now working with doctors to develop alternatives.

TEXT Felix Würsten

Image: M. Maurer; L. Bernardi and B. Bachmann

In 1982 in Salt Lake City, American heart surgeon Robert Jarvik implanted the world's first permanent artificial heart into a patient. While it is true that Barney Clark, a retired dentist, survived for "just" 112 days, this operation nonetheless heralded a new era in heart surgery. Ever since, artificial hearts like the one given to Clark have been implanted not only as an interim measure, but increasingly as a longer-term solution for keeping patients alive.

Figures from the German Heart Institute Berlin, which runs the world's biggest mechanical circulatory support programme, indicate just how much demand there is for these life-saving devices: to date, the institute has implanted over 2,500 cardiac support systems. Demand is likely to grow even higher in coming years, since more and more patients are suffering from heart failure – not least because of increasing life expectancy – while the number of donor hearts is plateauing.

Close cooperation with doctors

The problem with this development is that today's artificial hearts exhibit a number of major weaknesses. One of them is the frequency of severe complications, which arise from the blood clots that tend to form inside the artificial hearts and subsequently cause a stroke. Another is that, since these devices are electrically powered, they need a connection to a battery – and the entry site into the body through which the connector cable passes is a haven for dangerous infections.

Five years ago, this unsatisfactory state of affairs led ETH – together with the University Hospital Zurich and Zurich University, its partners in the Zurich University Medicine initiative – to launch the Zurich Heart project. The idea was to pool the broad medical and technical expertise at hand in Zurich and use it to refine the existing technologies. According to Edoardo Mazza, a Professor at the ETH Institute for Mechanical Systems and Co-Director of Zurich Heart, since then the people working on the project have developed a truly functional community. "Our work tackles a variety of problems," Mazza says, "and we can all benefit from each other's knowledge." Indeed, a whole series of chairs at both universities is now involved. Between them they have 28 doctoral students and a total of 75 scientists working on various sub-projects.

"Zurich offers an ideal environment for this sort of undertaking," explains Volkmar Falk, Medical Director of the German Heart Institute Berlin. It was Falk who initiated the project back when he was Director of Cardiovascular Surgery at University Hospital Zurich. When he took up his role at the institute in Germany, he managed to bring a major new partner on board: after all, the doctors at the Berlin institute have a long history of clinical experience in the field of mechanical circulatory support. For Dimos Poulikakos, ETH Professor for Thermodynamics and the project's other co-director, the opportunity to work closely with the Berlin-based specialists and learn from them is an exciting one: "Doctors think in terms of solutions, just like we engineers do, which explains why we get on so well. Their feedback helps us to set the right development priorities."

Better components, new ideas

One major objective for Zurich Heart is to optimise individual components in a way that leads to fewer complications while improving system performance at the same time. For instance, ETH engineers are developing a

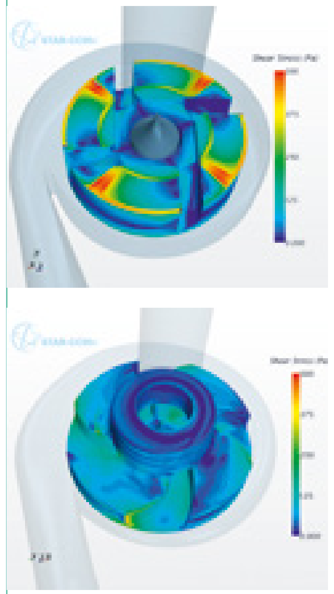
›

System modifications:
Dimos Poulikakos
Professor of Thermodynamics at ETH's Department of Mechanical and Process Engineering. In the Zurich Heart project, he is in charge of system modifications, with a focus on improving the current support systems.

Alternative systems:
Edoardo Mazza
Professor of Mechanics at ETH Zurich's Department of Mechanical and Process Engineering. He runs the alternative systems section of the Zurich Heart project, which includes work on how to employ new materials systems in artificial hearts.

Clinical integration:
Volkmar Falk
Full Professor at the Department of Cardiothoracic and Vascular Surgery at Charité in Berlin and Medical Director of the German Heart Institute Berlin. As the former Director of Cardiovascular Surgery at University Hospital Zurich, in the Zurich Heart project he is responsible for clinical integration of the newly developed systems.

Image: Giulia Marthaler (2); Volkmar Falk



Lower stress thanks to new geometry: In today's pumps, the blood is exposed to high mechanical stresses (see the upper picture, which shows areas with high shearing forces in red). An improved design markedly reduces these stresses (lower picture).

new kind of control unit to improve today's passive control systems. If they are successful, the new control unit will ensure that artificial hearts no longer pump blood at a largely constant rate; instead, the volume pumped will be automatically adjusted to the body's needs, within certain limits. Initial short-term testing over several hours in an acute animal model showed that this approach holds much promise. The next step is to conduct long-term pre-clinical studies with the novel controllers for several weeks.

The engineers have also improved the heart pump's design. With the help of simulations, they were able to design a pump with a high degree of hydraulic efficiency that also causes less damage to red blood cells. This blood trauma is a grave problem for patients, as it impacts how effectively their blood transports oxygen around their bodies.

There is good news on the power supply front, too: ETH engineers are developing an efficient wireless system for supplying the artificial pump with electricity. Their system is built on the principle of electrical induction – similar to wireless mobile phone chargers. The challenge is to avoid excessive heating of body tissue. In an experiment, they were able to transmit 30 watts of power while keeping electrical losses so small that the tissue temperature rose no more than 1.5 degrees.

Improvements to existing technology are of course just one part of the project. Another part sees engineers and scientists pursuing wholly new approaches that might well lead to completely novel designs. For instance, they are experimenting with highly deformable materials that could be used to make a “soft” pump that more closely resembles the native organ. Of pivotal concern here is how such materials perform over the longer term if they are required to constantly change shape.

Endothelial cells are the key

Whether they are seeking to improve existing components or develop new concepts, researchers' work often throws up questions that touch on basic research. One central question is how to prevent blood from coming into contact with foreign materials, since this in particular gives rise to complications. The interior of natural blood vessels is lined with a layer of endothelial cells, which regulate the passage of materials in and out of the bloodstream. Now the researchers from ETH and UZH are working together with colleagues at EMPA (the Swiss Federal Laboratories for Materials Science and Technology) to cultivate autologous endothelial cells on a flexible substrate and bind this new tissue to the artificial materials.

Scientists are now in a position to generate an artificial layer of endothelial cells of this kind in a matter of hours. Moreover, they have developed a special bioreactor that they can use to emulate the conditions within the human body. The reactor enables them to realistically test cell adhesion on synthetic materials in the laboratory and determine whether the cell layer is capable of withstanding the high mechanical loads in new pump systems. Not least, this laboratory set-up gives the scientists hope that they will be able to reduce the amount of animal testing.

Comprehensive testing

Despite the excellent progress that so many Zurich Heart sub-projects have already made, it will still be some time before these new technologies can be employed in everyday medicine. For one thing, new materials must undergo thorough testing to prove their suitability for clinical use; for another, scientists need to conduct animal tests of longer duration in order to gather long-term data on how well the devices function over time within the circulation. What's more, the new sensors and algorithms used to control the pumps must pass innumerable tests, as do the components responsible for the wireless transmission of power and data. Like the pumps themselves, these components must demonstrate that they will operate with absolute reliability in practice and will never cause the cardiac support system to break down, since this would result in acute danger for the patient. “And then, of course, quite apart from meeting the onerous regulatory requirements for medical device approval for use in humans, it's essential we secure financing for the technology transfer,” Falk adds, “because translation is expensive.” ○

Image: Stefan Boës; Lena Wiegmann, UZH

BRAIN TO ROBOT: “MOVE, PLEASE”

Using the power of thought to control a robot that helps to move a paralysed hand: a project from the ETH Rehabilitation Engineering Laboratory could fundamentally change the therapy and daily lives of stroke patients.

TEXT Roland Baumann

One in six people will suffer a stroke in their lifetime. In Switzerland alone, stroke affects 16,000 people every year. Two thirds of those affected suffer from paralysis of the arm. Intensive training can – depending on the extent of damage to the brain – help patients regain a certain degree of control over their arms and hands. This may take the form of classic physio- and occupational therapy, or it may also involve robots.

Roger Gassert, Professor of Rehabilitation Engineering at ETH Zurich, has developed a number of robotic devices that train hand functions and sees this as a good way to support patient therapy. However, both physio- and robot-assisted therapy are usually limited to one or two training sessions a day; and for patients, travelling to and from therapy can also be time-consuming.

Exoskeletons as exercise robots

“My vision is that instead of performing exercises in an abstract situation at the clinic, patients will be able to integrate them into their daily life at home, supported – depending on the severity of their impairments – by a robot,” Gassert says, presenting an exoskeleton for the hand. He developed the idea for this robotic device together with Professor Jumpei Arata from Kyushu University (Japan) while the latter was working in Gassert's laboratory during a sabbatical in 2010.

“Existing exoskeletons are heavy, and this is a problem for our patients because it renders them unable to lift their hands,” Gassert says, explaining the concept. The patients also have difficulty feeling objects and exerting the right amount of force. “That's why we wanted to develop a model that leaves the palm of the hand more or less free, allowing patients to perform daily activities that support not only motor functions but somatosensory functions as well,” he says. Arata developed a mechanism for the finger featuring three overlapping leaf springs. A motor moves the middle spring, which transmits the force to the different segments of the finger through the other two springs. The fingers thus automatically adapt to the shape of the object the patient wants to grasp.

›

Roger Gassert has been Professor of Rehabilitation Engineering at ETH Zurich since 2008. He studied microengineering at EPFL, where he completed his doctorate in the field of neuroscience robotics. Following research placements in London, Vancouver and Kyoto, he became head of the joint robotics laboratory of EPFL and the University of Tokyo in 2007, before being appointed Assistant Professor at ETH Zurich. In 2014 he was promoted to Associate Professor; his Chair is supported by the ETH Zurich Foundation in collaboration with Hocoma AG.

Image: Giulia Marthaler