Center for Artificial Muscles

Report 2021

Center for Artifical Muscles

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EPFL

“We have just achieved the world’s first ever proof-of-concept by successfully implanting our cardiac device in a live pig”

Prof. Yves Perriard

INTRODUCTION

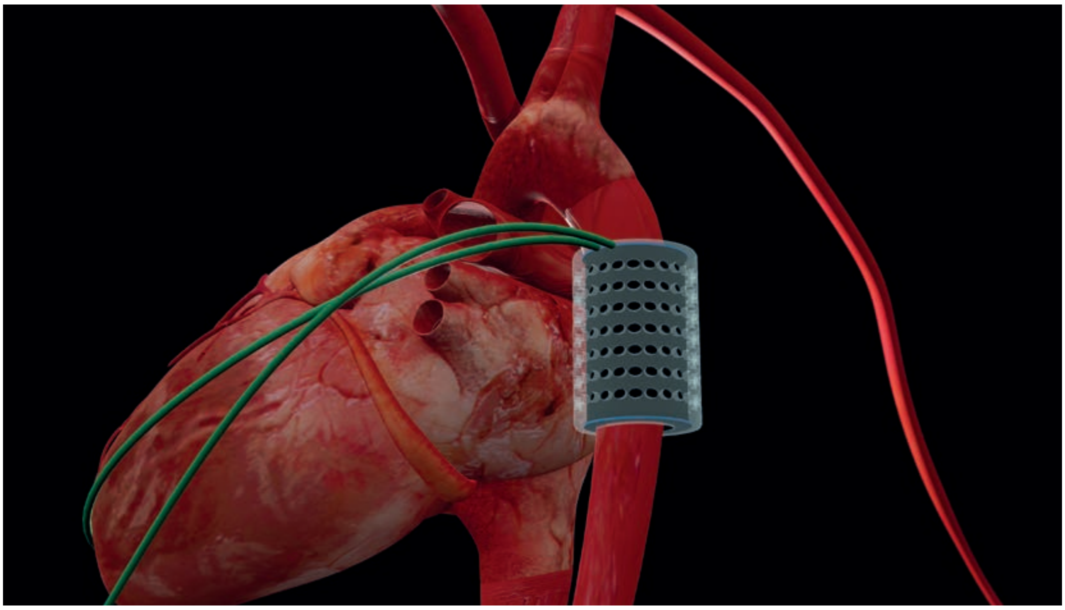
Last April, the Center for Artificial Muscles’ team successfully implanted – *in vivo* - an artificial, tubular muscle that augments the aorta and assists cardiac function in pumping blood, at the InselSpital in Bern. As a result of this significant accomplishment, the Werner Siemens Foundation approved the granting an additional CHF 8 million over 8 years.

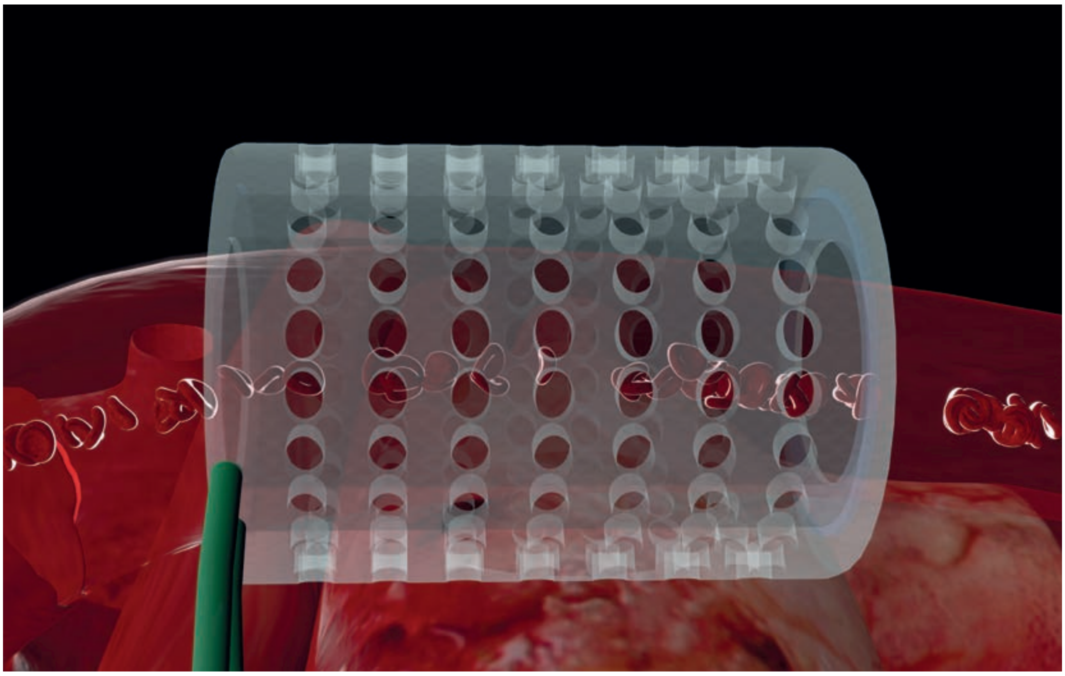
This added funding will go toward the next phases of the project, which includes the development of artificial muscles to address other human disorders such as artificial sphincters - in collaboration with University of Bern - that could resolve urinary incontinence for example, or to restore control of facial expression together with the University of Zurich.

b UNIVERSITÄT BERN

University of Zurich UZH

Center for Artifical Muscles





Team

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Prof. Dominik Obrist,
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University of Bern

Prof. Jürgen Hörer,
Technische Universität München

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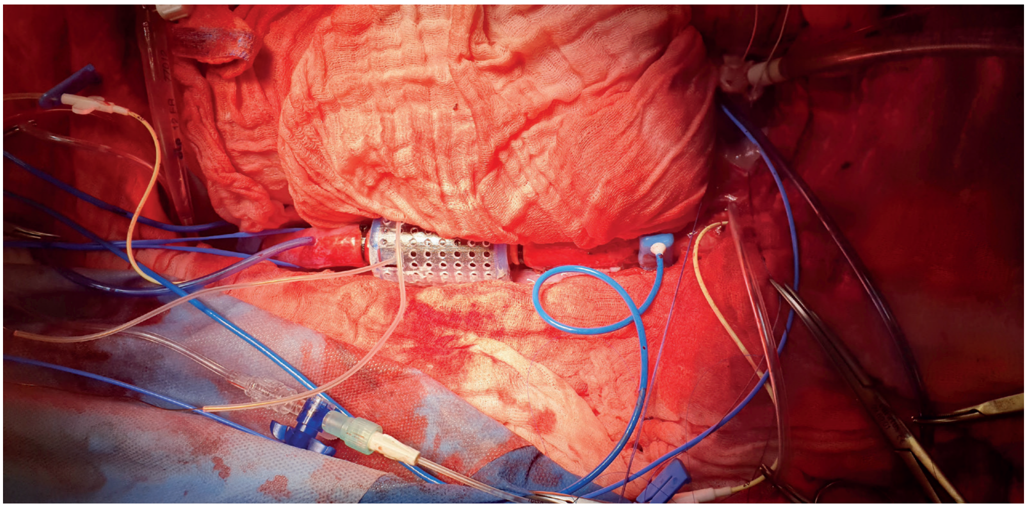
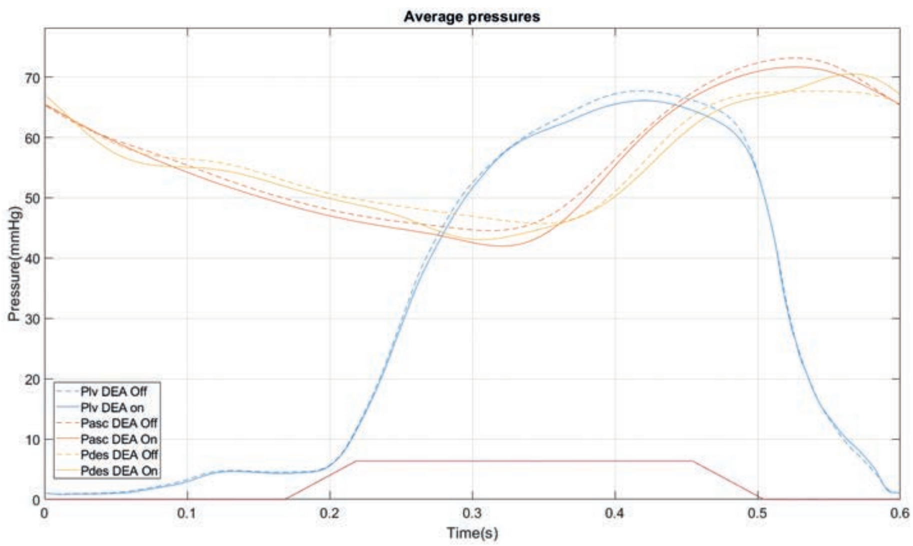
Scientific Highlights

In-vivo experiments

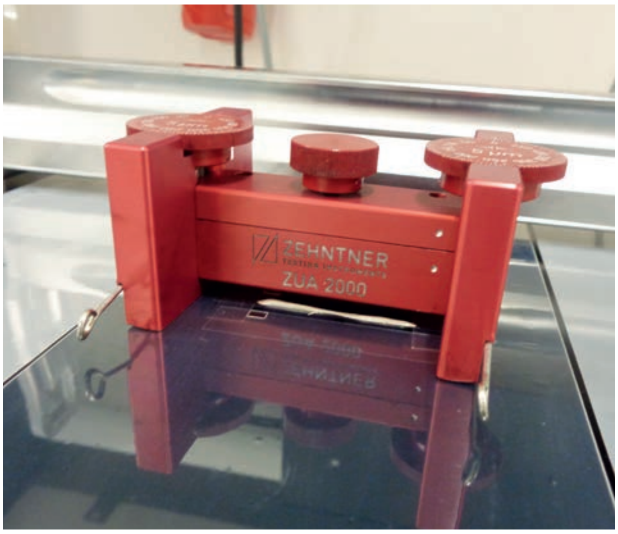
After four years of intensive work, the team successfully implanted the first artificial tubular muscle, *in vivo*, in a pig. The device was placed in the descending aorta and worked for more than 4 hours, with 24 000 pulsations, of which 3200 activated artificially, thereby showing a decrease in the aorta's pressure. The operation was made possible thanks to the close collaboration between 15 people, namely, Paul-Philipp, Maks, Daniela, Andreas, Kay, Luisana, Angela, Mariafrancesca, Hansjörg, Silje, Thomas, Francesco, Armando, Lorenzo and Yoan.

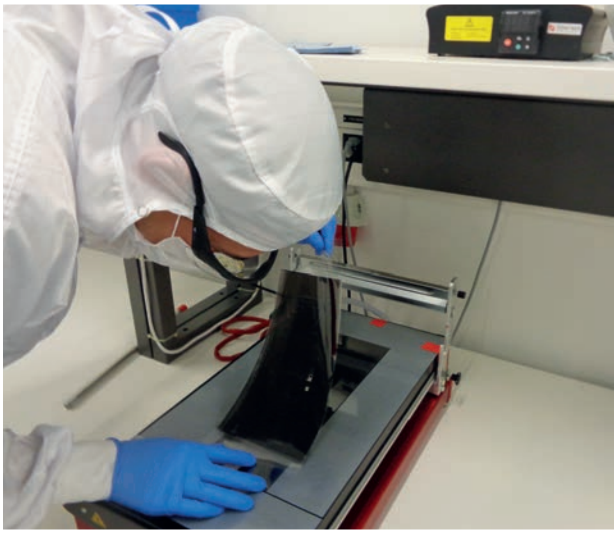




A reliable manufacturing process

On the DEA manufacturing side, there is a desire to continuously improve the quality and performance of the electrodes (i.e. thickness, access resistance, electrical diffusion etc). To do this, it was necessary to review some elements of the fabrication process. In view of the animal trials, we also adapted our implants that were designed for human beings, for pigs. The challenge was to reduce the size of the diameter from 30mm to 20mm, all the while keeping the maximum amount of energy supplied by the device. In parallel, we had to find a way to connect our tube to the aorta. The best compromise was to 3D print a housing with connectors.

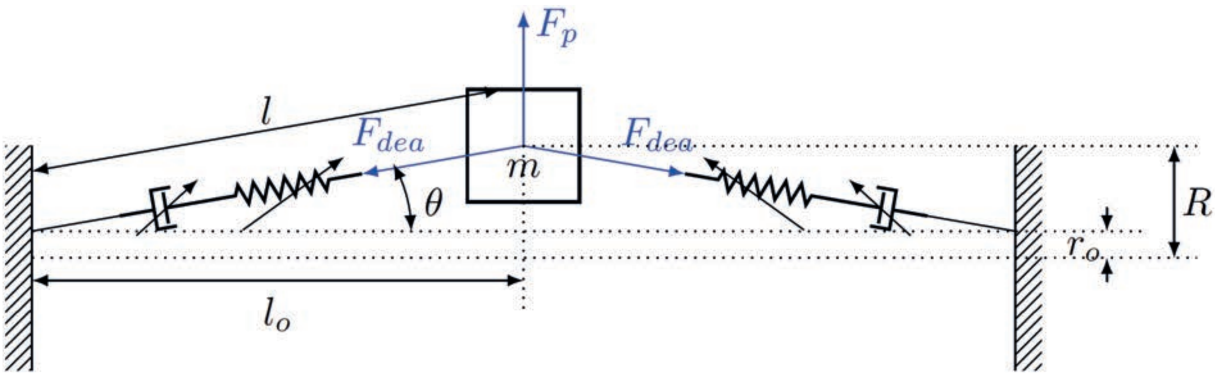




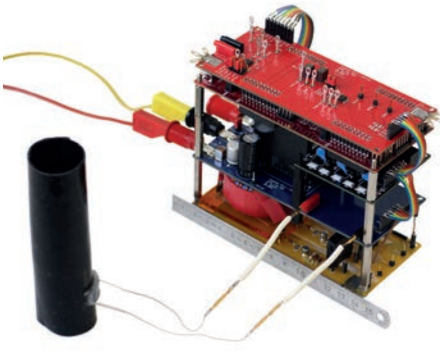
Dynamic Control

The ultimate aspects of the static modelling of the DEA were finished this year. The final modelling allows us to assess the Pressure-Volume characteristics of the actuator very accurately by taking into account the fabrication process and the complex multi-layered structure of the DEA. Furthermore, the modelling can evaluate the influence of the radial limitation around the actuator on its performance and stability. The work performed on this modelling has led to a publication in the journal *Smart Materials and Structures*.

Another approach has been developed this year to evaluate the dynamics of the activation of the DEA. This model is based on the representation of the elastomer by a lumped parameter model and especially the Maxwell-Voigt one that takes into account both the hyperelastic and electrical behaviors as well as the viscosity. As the complexity of the static model is already high, solid hypotheses must be carried forward in order for the model to converge. Thus, we consider the DEA as a beam fixed on both sides and separated in two segments represented by the lumped parameter model. The results obtained with this model already show good correlation with the measurements. Further work will focus on improving the accuracy of the modelling by increasing the number of segments considered, for example, but without excessively increasing its complexity. Indeed, the final goal of this dynamic model is to perform real-time control of the DEA activation to optimize its behavior according to the patient activities and limit the breakdown due to electromechanical instability.



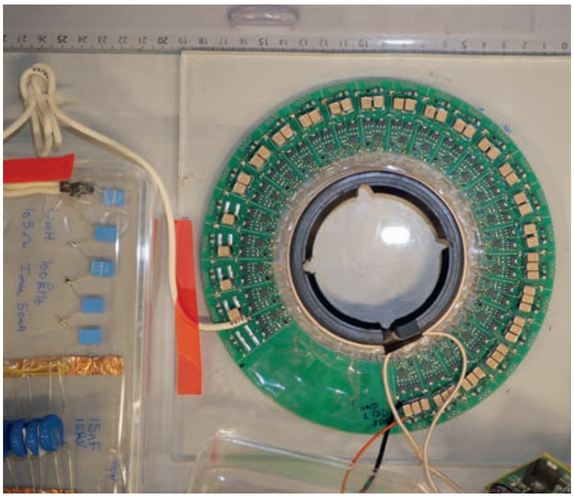
A robust and compact power supply

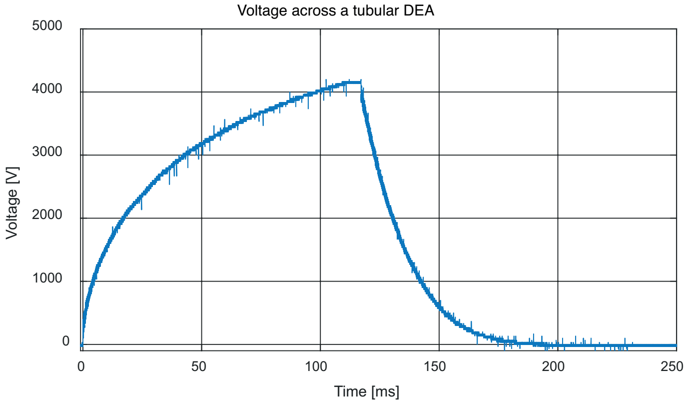


After successfully designing an electronics system (Flyback) capable of supplying more than 8 kV to a planar DEA, improvements were implemented to make it significantly more compact and more practical to use. By stacking PCBs (Printed Circuit Boards), we were able to reduce the footprint while ensuring safe operation, given the high voltages to be manipulated. This power supply also integrates a high impedance probe, which allows for the monitoring of the output voltage and thus can enable an effective control of the pump.

In parallel to the development of the flyback converter, a new topology has been proposed to reach the high voltage required by the DEA. This structure is constituted of 24 capacitive stages and is similar to a Marx generator. The stages, which are connected in parallel, are loaded at 400 V when the DEA is off.
To activate the actuator, they are then put in series to reach voltages as high as 9.5 kV. This solution constitutes a good alternative to the flyback converter to obtain a more planar and easily implantable system. A new miniaturized converter, based on a Cockroft-Walton Converter, has been developed to obtain the intermediate 400 V voltage required to load all the stages of the multi-level converter. It uses the alternative output of the Wireless Power Transfer circuit as its input. Furthermore, this system is made up of capacitances and diodes alone and can thus be easily miniaturized. Future work will focus on the integration and optimization of these converters. For the multi-level converter, the WPT has not yet been optimized and we can expect to reduce the size of the circuit. Moreover, with the development of new PCB fabrication techniques, we can hope for a more compact fabrication with integration of the passive components and dyes directly on the PCB.

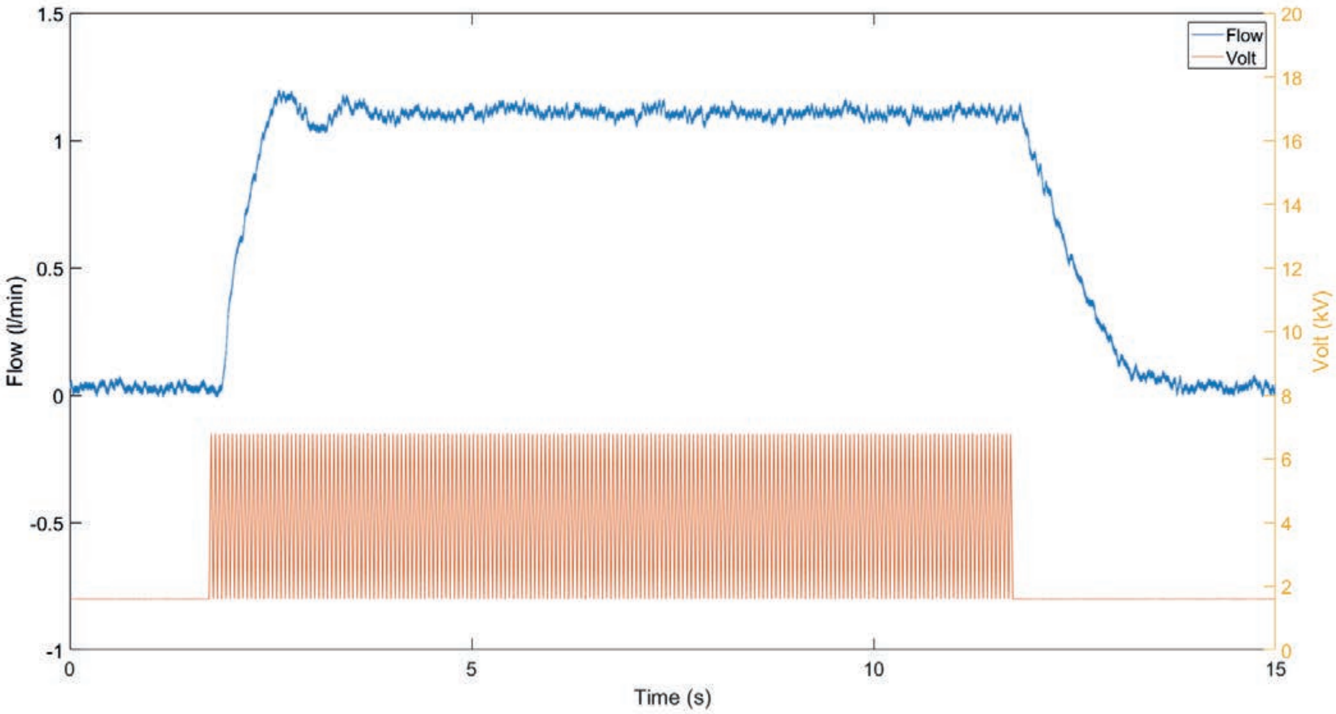
In addition, numerous tests were conducted with the full electronics (Flyback + WPT) connected to tubular DEAs to move towards a more global integration of the system. To-date, voltages of only 4kV have been reached but the system is now ready to go further.





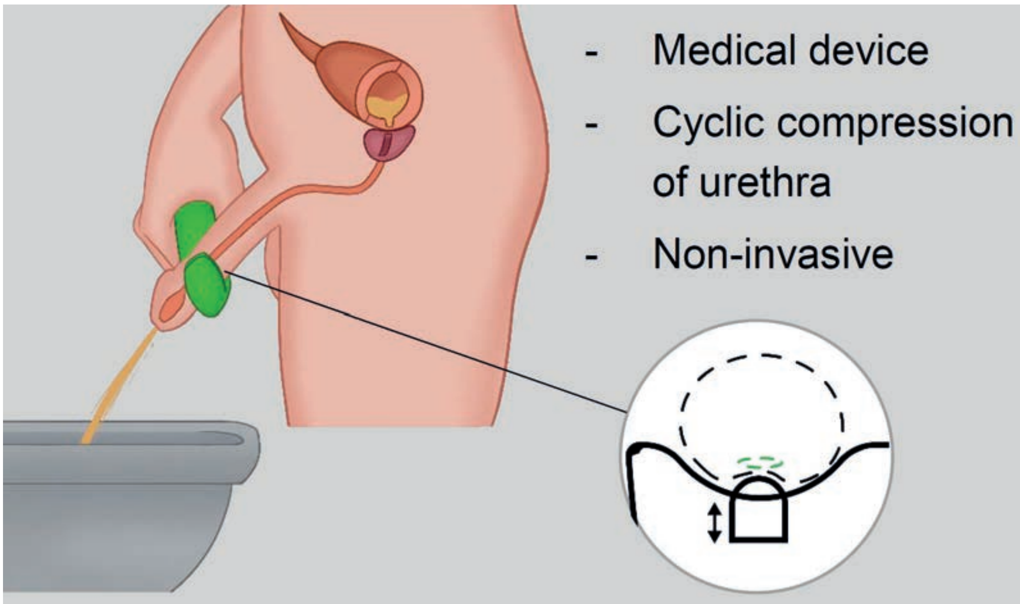
Impedance pump as an additional support mechanism

Impedance pumping technique is mechanism that generates flow in a compliant tube by repeatedly actuating the tube asymmetrically, without employing any internal valves. The pump uses the reflection of the waves at the interface of the two consecutive subsystems with different mechanical properties. Our tubular DEA was tested within the flowloop as "an impedance pump" while keeping the aortic and mitral valves in the system. A mean flowrate of 1.1L.min^{-1} was obtained and this opens up new prospects for cardiac assist devices. Further works must be done to deeply investigate the underlying mechanism to implement such systems in failing Fontan patients presenting a single heart ventricle. This new application takes place in collaboration with the German Heart Center Munich of the Technishe Universität München, with Prof. Dr. Med. Jürgen Hörer. He brings invaluable expertise to our team, allowing us to better identify the medical challenges specific to young patients.



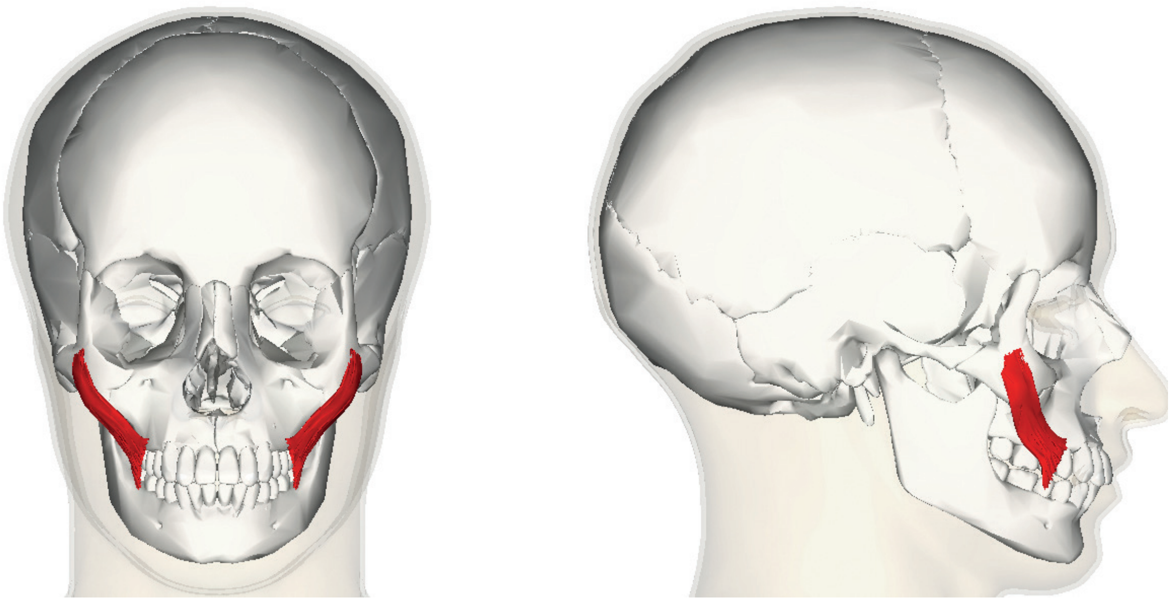
URODEA

URODEA AG was incorporated in June 2021 and signed an exclusive patent license agreement with the University of Bern (the owner of the patent). The non-invasive, bladder-emptying device has been developed for clinical trials. After obtaining approvals from the Cantonal Ethics Committee (KEK) and Swissmedic, the first human clinical study started in July 2021. URODEA is ready for its seed financing round and the URODEA team is evaluating different partners for the product development of the commercial version of the medical device.



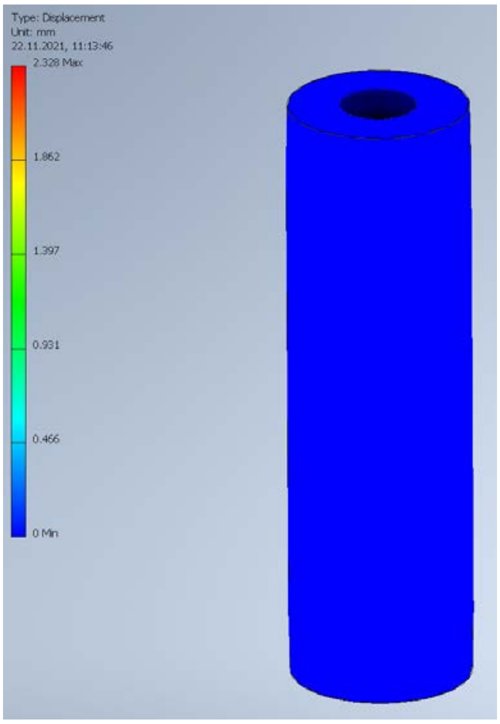
Facial Reanimation

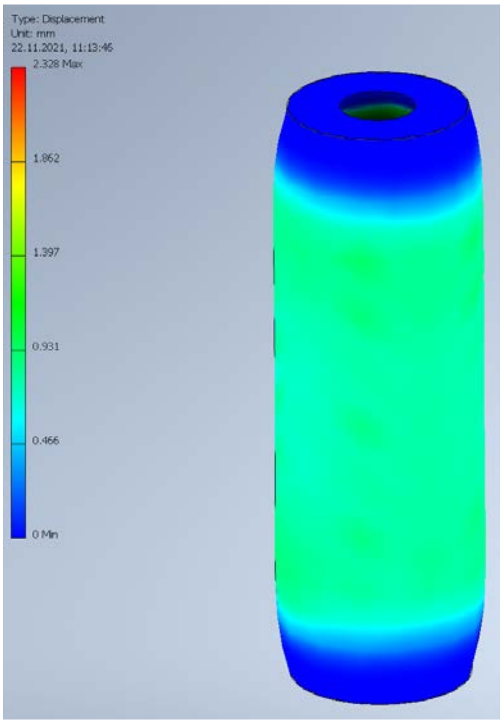
Facial paralysis can be of idiopathic nature, or it can be due to an infection, injury or tumor. It generally affects half the face. Patients therefore lose their facial mobility, which prevents them, among others, to blink, smile and chew correctly. In 30% of the cases, paralysis is chronic and irreversible. The current treatment consists of a neuronal transfer from the healthy side of the face to the paralyzed side, accompanied with a Gracilis muscle transfer coming from the patient's leg. Results are not perfect and are efficient mostly for young patients. The solution our team is proposing is to develop soft artificial muscles, which would replace the invasive muscle transfer. The actuator would be placed under the skin, as shown in the below figure, in order to offer a permanent solution to the paralysis and allow patients to perform natural movements. This solution improves patient quality of life, from a functional, aesthetic and psychological point of view.



Artificial Urinary Sphincter

Urinary Incontinence is the involuntary leakage of urine - a common and embarrassing problem that affects millions of people worldwide. It generally occurs when control over the urinary sphincters is lost or weakened. Within the Center for Artificial Muscle (CAM), we are developing an *in-vivo* proof of concept Artificial Urinary Sphincter (AUS) based on Dielectric Elastomer Actuators (DEA) technology. Our ambition is to support or even replace existing sphincters in order to improve the quality of life of patients suffering from urinary incontinence. We are currently focused on developing a solution that is compatible with female anatomy, as few are accessible today. In the last 3 months, a state-of-the-art urinary incontinence device and DEAs has been produced. We are currently developing an analytical model of the urethra, as well as a Finite Element Analysis (FEA) in order to understand the behaviour of such a complex system. In the coming months, we will use this model to design our first AUS. Our ambition and challenges in the coming years include testing and validation of our AUS as well as performing *ex-vivo* and *in-vivo* tests on animal urethras.





Dissemination

Conferences

Energy Analysis of a Cardiac Assist Device based on Dielectric Elastomer Actuator through an Equivalent Electrical Circuit, J. Chavanne; F. Clavica; T. Martinez; Y. Civet; D. Obrist, Y. Perriard, *IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*, Jul 12-16, 2021. p. 346-352.

Redefining Energy Density for a uniaxial Dielectric Elastomer Actuator, J. Chavanne; Y. Civet; Y. Perriard, *IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*, Jul 12-16, 2021. p. 1113-1118.

Wave propagation investigations in an in-vitro model of the male urethra, L. Ferrari, L. Bereuter, ML. Costantino, Y. Civet, Y. Perriard, B. Kiss, D. Obrist, F. Burkhard, F. Clavica, *Institution of Mechanical Engineers' conference – Incontinence: the engineering challenge XIII*, London, UK, November 2021.

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Schmitt trigger-based control strategy for the discharge phase of an ultra-high voltage bi-directional flyback, R. Mottet, A. Boegli, Y. Perriard, *Proceedings of the 24th International Conference on Electrical Machines and Systems (ICEMS)*, 2021.

Improved electrical behavior of dielectric elastomer actuators, A. Walter, T. Martinez, D. Moser, A. Walter, M. Almanza, F. Clavica, Y. Civet, Y. Perriard, *Proceedings of the 24th International Conference on Electrical Machines and Systems (ICEMS)*, 2021.

A Cockroft-Walton generator driven by wireless power transfer for implanted high-voltage generation, T. Martinez, J. Chavanne, Y. Civet, Y. Perriard, *Proceedings of the 24th International Conference on Electrical Machines and Systems (ICEMS)*, 2021.

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Ultra-High-Voltage (7-kV) Bidirectional Flyback Converter Used to Drive Capacitive Actuators, R. Mottet; M. Almanza; L. Pniak; A. Boegli; Y. Perriard, *IEEE Transactions On Industry Applications*. 2021-09-01. Vol. 57, num. 5, p. 5145-5156.

Feasibility of a Dielectric Elastomer Augmented Aorta, M. Almanza; F. Clavica; J. Chavanne; D. Moser; D. Obrist; T. Carrel; Y. Civet; Y. Perriard , *Advanced Science*. 2021-01-25. Vol. 8, num. 6, p. 2001974.

Evaluation of dielectric elastomers to develop materials suitable for actuation, P. Banet, N. Zeggai, J. Chavanne, G. T.M. Nguyen, L. Chikh, C. Plesse, M. Almanza, T. Martinez, Y. Civet, Y. Perriard and O. Fichet, *Soft Matter*, 2021, DOI: 10.1039/D1SM00621E.

Control-oriented modeling and analysis of tubular dielectric elastomer actuators dedicated to cardiac assist devices, N. Liu, T. Martinez, A. Walter, Y. Civet, Y. Perriard, *submitted to the IEEE Robotics and Automation Letters (RA-L)*, 2021.

Multistep charging for electroactive polymer with high access resistance, M. Almanza, L. Depreux, T. Martinez, Y. Civet, Y. Perriard, M. Lobue, *submitted to IEEE Transactions on Power Electronics*, 2021.

The Werner Siemens-Stiftung: Acknowledgement

The creation of this consortium would not have been possible without the generosity and commitment of the Werner Siemens-Stiftung. Through the Foundation's support, the Center for Artificial Muscles has shown its capability to become a trailblazer regarding the use of soft actuators for medical applications.

“Thanks to the support of the Werner Siemens Foundation, my long-standing wish to enable patients with facial paralysis to smile again has become a real possibility. I am therefore very enthusiastic about working together with an extremely competent and visionary team”

PROF. NICOLE LINDENBLATT

“The first, most challenging project to supply a forward flow within the descending aorta using a dielectric elastomer was successful. This major milestone was made possible through close collaboration between basic scientists from EPFL and clinicians from the University of Bern, based at the Inselspital. It opened the way for further experimental and applied research in the fields of surgery to create artificial muscles for other significant clinical purposes.”

PROF. THIERRY CARREL

EPFL

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PRINTING Repro – Print Center EPFL
A climate neutral printer – myclimate certified

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