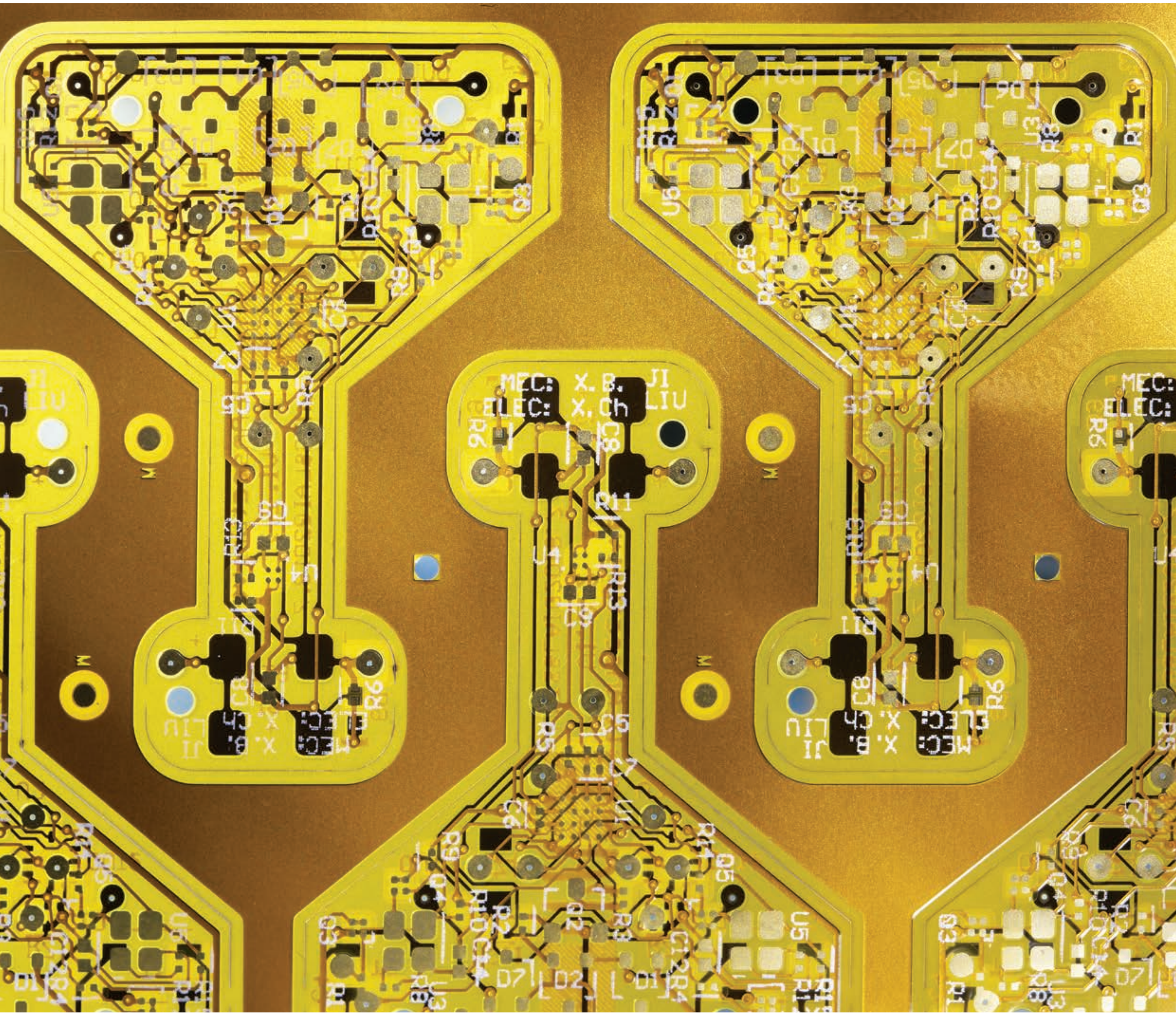
Center for Artificial Muscles
Report 2020



Center
for Artifical
Muscles

OBJECTIVE

Developing a dielectric-elastomer-augmented aorta as a cardiac assist device

INTRODUCTION

The Center for Artificial Muscles is fast becoming a leading reference for the development and clinical transfer of a brand-new technological approach to artificial muscles in the human body – the Dielectric Elastomer Actuator (DEA). This cutting-edge device is being developed by EPFL and the Universities of Bern and Zurich (its partners in heart surgery & the urological domain and in reconstructive medicine respectively) and is an undeniable game-changer in this field.

The controlled stiffness of the dielectric-elastomer based system perfectly matches the ultimate medical goals. This particular feature is usually difficult to exploit. As a result, the dielectric elastomer actuator can benefit from the heart's natural pressure to work efficiently. By doing so, we can reap the full benefit of this novel technology.

b UNIVERSITÄT BERN

University of Zurich UZH

Content

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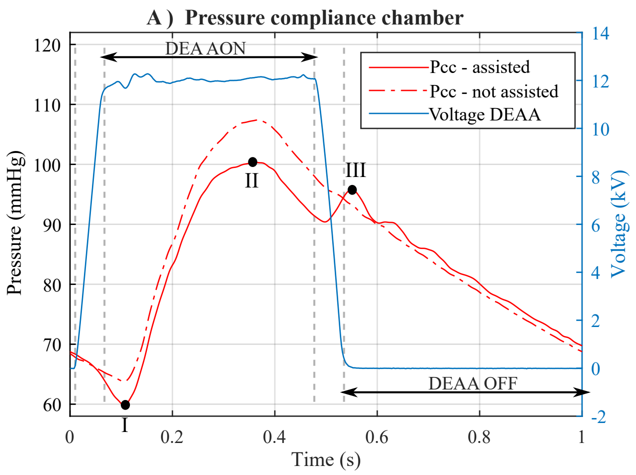
Scientific Highlights

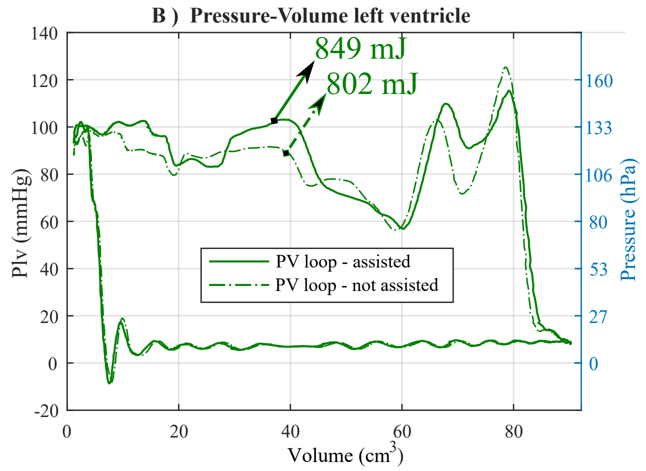
In-vitro experiments using a pulsatile have shown a reduction of 5.5 % of the heart's energy

After three years of intensive work, we propose the first dielectric-elastomer-augmented aorta (DEAA). To this end, we developed a tubular dielectric elastomer actuator (DEA) able to assist the heart by easing the deformation of the aorta in the systole and by increasing its recoil force in the diastole. With regard to the heart, the pressures in the left ventricle and in the compliance chamber (the `after-load' to be overcome by the ventricle) are reduced when the DEAA is switched-on, just before the opening of the aortic valve, compared to the condition without assistance. On the contrary, the pressure in the compliance chamber increases when the DEAA is switched-off during diastole.

The blood flow shows a similar pattern, characterized by a flow reduction during systole, which is compensated by the flow-increase during the diastole. With or without assistance, the average flow rate in a cycle stays constant (80.6 $ml.s^{-1}$ versus 80.4 $ml.s^{-1}$ with assistance or without, respectively).

The pressure drop seen on the left ventricle when ejecting the blood (afterload) is related to the energy saved. According to the pressure and the volume of the left ventricle, the work done by the left ventricle is reduced (from 849 mJ to 802 mJ) by 47 mJ thanks to the DEAA, i.e. 5.5% of assistance.

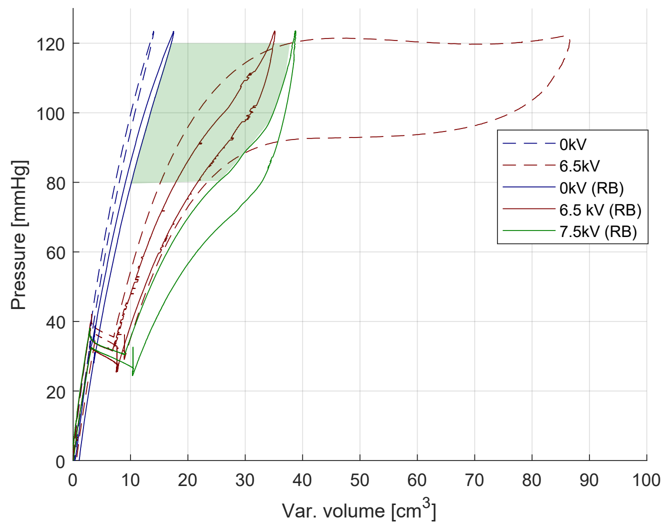


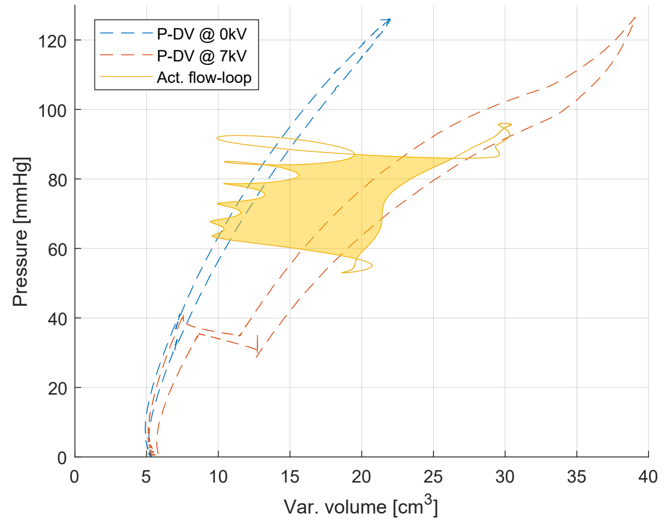


A powerful actuator

The main limit to activate a dielectric elastomer actuator is the maximum voltage before the electrical breakdown occurs between the layers. In addition, imposing the pressure while working above a certain voltage leads to instabilities, thus increasing the risk of premature failure.

A solution to increase the applied voltage is to radially constrain the DEA (radially blocked: RB). The variation of the radius is then set to a chosen value (bigger than the cylinder at rest). The RB DEA can then expand in the radial direction until the rigid tube blocks the latter. The DEA can then continue to increase in the length direction, so that the volume can expand as well. Static and dynamic measurements have shown that the energy, provided by the DEA, can almost double thanks to this technique.





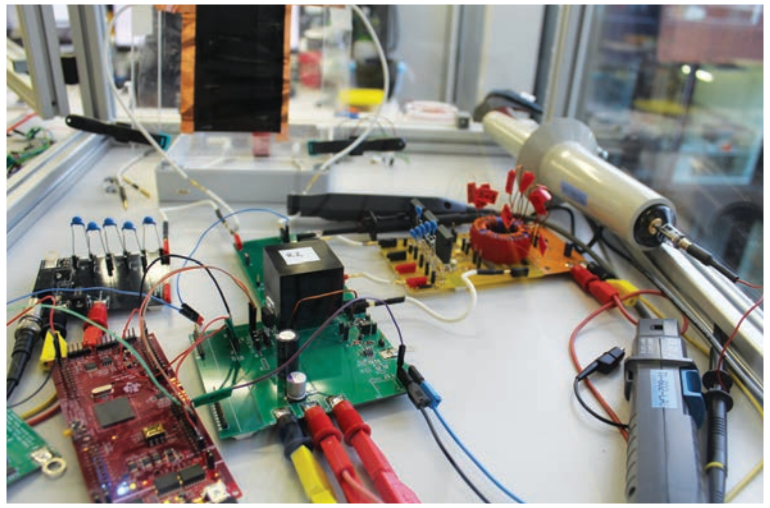
An efficient 8kV wireless power transfer

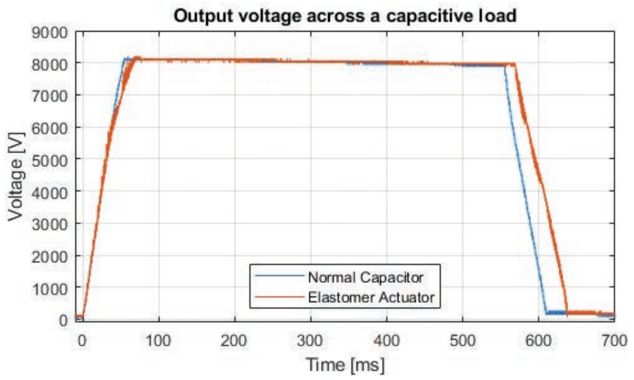
The proposed wireless power transfer consists of two planar 6 cm diameter Litz-wire coils, designed for maximum efficiency in a worst case scenario of a 2 cm gap between the two coils. A complete setup, consisting of an optimized series-resonant structure driven by a GaN half-bridge, allows maintaining a load-independent DC voltage of 12 V at the output of the wireless transfer.

On the secondary side, in the body, we have developed a new PCB (Printed Circuit Board) with increased integration to provide 3.3 V, 5 V and 12 V voltages to supply control electronics and high voltage generation. This card can therefore either supply the bidirectional 8 kV Flyback, developed at CAM, or a unidirectional 10 kV commercial power supply.

The custom-made high voltage source combines a very high voltage DC-DC converter with a high-voltage switch to respectively load and discharge the DEA at the desired voltage. With the latest iteration of the bi-directional module, we are able to reach the targeted output voltage of 8 kV from an input voltage of only 12 V, while still guaranteeing the operability of the energy-recovering electronics.

At 8 kV, a 100um thick DEA can operate near-optimally, while remaining at a safe distance of its breakdown voltage. It was therefore essential to reach that target. The system was then tested with one of our planar actuators, which demonstrated that the electronics worked well in their current state.

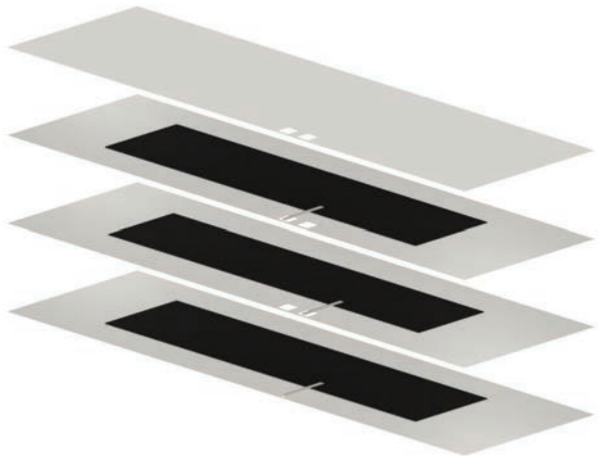


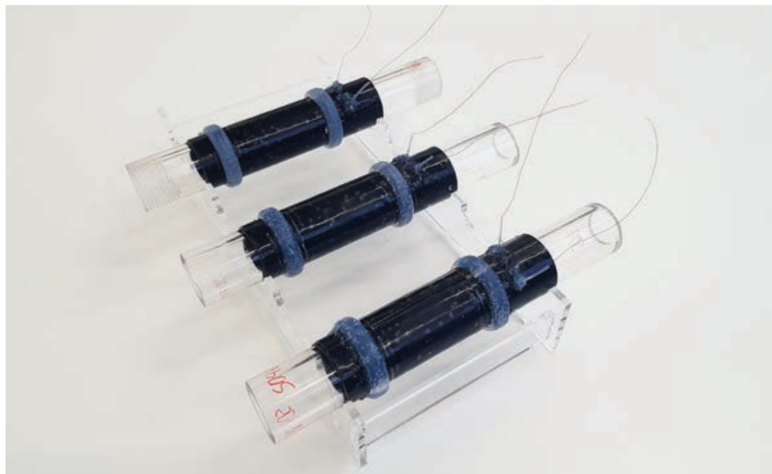


Toward DEA implantation in pigs

To-date, each extremity of the prototype corresponded to a pole (positive or negative). In order to confine the electric field and avoid any “visible” electrical features, we decided to place the electrical connectors close to each other (for further co-axial connector) and to use a metallic tape to link the electrodes. This tape was chosen to reduce the electrical resistance of the implant’s access electrode and to facilitate the electric distribution.

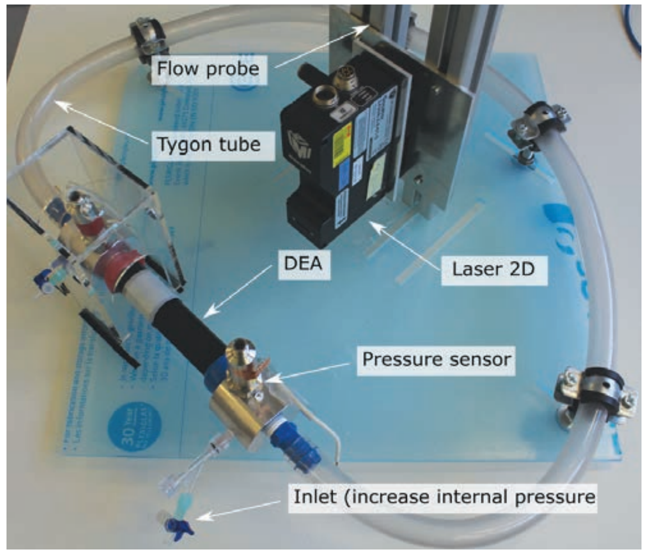
However, the prototype became more rigid because of its use and better results were obtained using a silicone-based silver ink, which produces a flexible, conductive track. The maximum attainable volume is then increased. In addition, we added two insulating layers to prevent electrical features from being in contact with their surrounding environment.

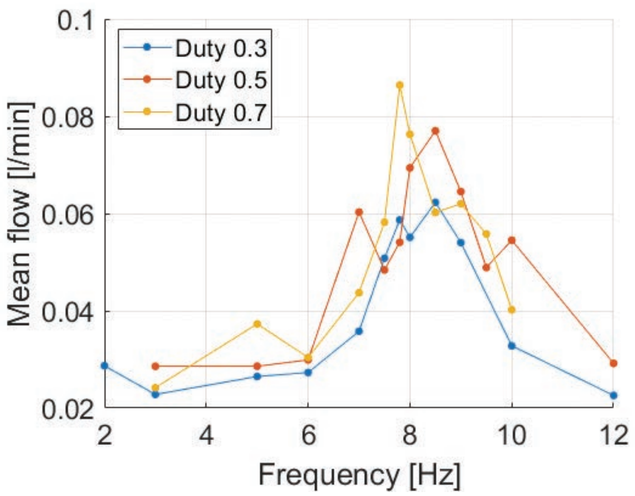




Impedance pump as an additional support mechanism

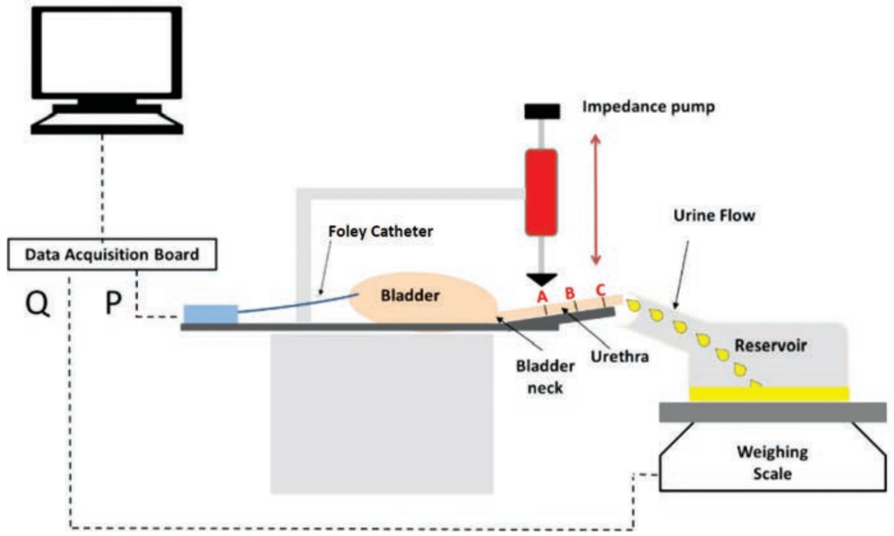
Only the potential energy provided within one cycle seems beneficial to alleviate the left ventricle in the pulsatile flow-loop. Although the mode of actuation suggests the possibility of pushing the level of assistance up to 160 mJ (compared to 50 mJ), our choice of having rising/falling time for DEAA activation/deactivation of 50 ms ensures its safe behavior. Faster switching time, which releases more kinetic energy, is not relevant in the two element lumps-based flow-loop, as it is not reliable to describe the high frequency behavior (oscillation) of a real body (continuous media with waves propagation and refection). In humans, different actuation modes, as well as harnessing interaction between the DEAA and complex human circulatory system, could be explored to better exploit the total energy that the DEAA can transfer. Paving the way to a more efficient actuation, we have tested our actuator into a valveless pumping system and have shown that a positive flowrate can be created with adequate electrical activation.





URODEA

Patients suffering from urinary retention are unable to urinate properly, which strongly affects their quality of life. To date, catheters are the most commonly used therapy for bladder emptying. However, catheters are frequently the main cause of urinary infections. Ex-vivo proof-of-concept studies have shown that an impedance pump can empty porcine bladders all the while avoiding contact with urine. This has warranted further studies to explore the full potential of a non-invasive solution for patients suffering from urinary retention.



A linear motor was used as impedance pump to compress the urethra at three different locations **(A, B, C)**, at four different frequencies. Resulting flow rates **(Q)** and intravesical pressure **(P)** were recorded.

Next steps

“2021: the year of the trials…”

We have conducted *in-vitro* experiments in a pulsatile flow-loop, replicating physiological flow and pressure conditions in the aorta, which showed that DEA leads to a reduction of afterload and ventricular stroke work. Such a mock-up cannot replace *in-vivo* testing however. Experiments in an acute animal model will therefore be essential to gain initial insight into the *in vivo* performance of the device. The results and statistics produced by this study will be used to design additional *in vivo* investigations (i.e. *in vivo* chronic experiments with a fully implanted device, including a wireless power supply) with the ultimate aim of eventually testing the device in patients.

Our experiments on animal models will attempt to answer the following questions:

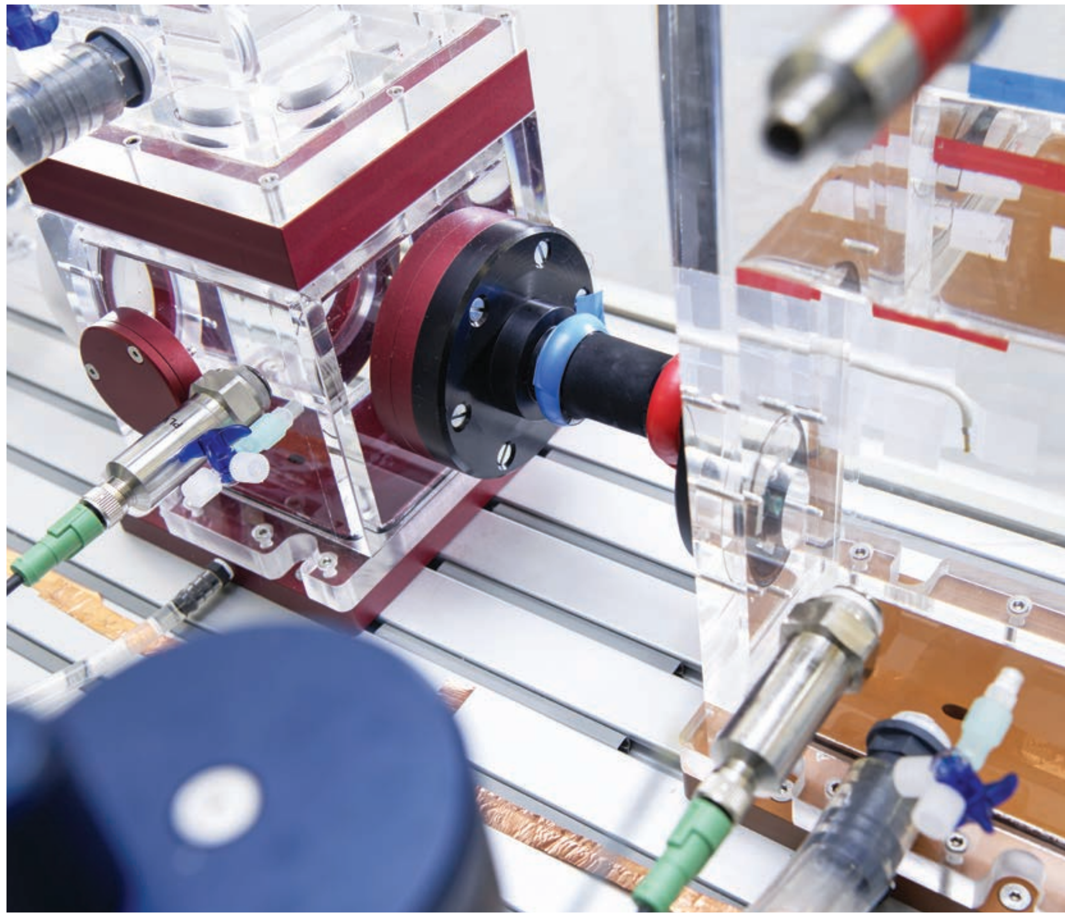
- Can our DEA device, plugged to the ascending (or descending) aorta of animals, reduce the afterload of the heart (e.g. lowering the end diastolic aortic pressure and maximum aortic systolic pressure)?
- What are the effects of our DEA device on the stroke work of the left ventricle (i.e. area of left-ventricle's pressure-volume loop) and on cardiac output/stroke volume?
- Can our DEA device cause aortic diastolic pressure augmentation and thereby increase coronary flow?

Regarding the urological studies, the first human, clinical trials will start early 2021 and will consist of testing the efficacy and safety of the proposed device in patients suffering from urinary retention. In parallel, we will investigate the design of soft actuators.

From a technical point of view, several challenges remain regarding the power electronics and the actuator performance. The design of the whole system, i.e. the actuator + radial limitation + physiological connection, is under progress. Lowering the voltage, improving the manufacturing process, while still targeting improved performance to support the heart, remain a critical part of the job to be done.

We also plan to further develop the control aspect of the system to allow the generation of voltage waveforms that differ from the basic trapezoid required for advanced modes of actuation. The communication between the inside and outside the body and a careful control of the DEA according to a biological trigger (a heart beat for example) must be implemented.

The complete integration and full optimization of the electronics will be done in 2021 to test the system *in situ*. The impact of the wireless transfer on the human body and regulations impacting thermal, electric and magnetic constraints are also key points to carefully analyze.



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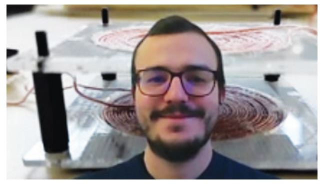
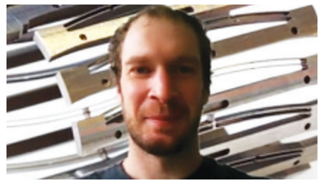
Team

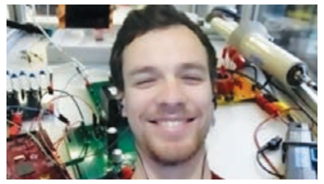
DIRECTOR	Prof. Yves Perriard
SCIENTIST	Alexis Boegli, Jonathan Chavanne, Yoan Civet, Francesco Clavica, Minh Trung Duong, Silje Jahren, Thomas Martinez
PHD STUDENT	Raphaël Mottet
SCIENTIFIC ASSISTANTS	David Moser, Armando Walter.










Partners

Prof. Thierry Carrel,
University of Bern

Prof. Nicole Lindenblatt,
University of Zurich

Prof. Dominik Obrist,
University of Bern

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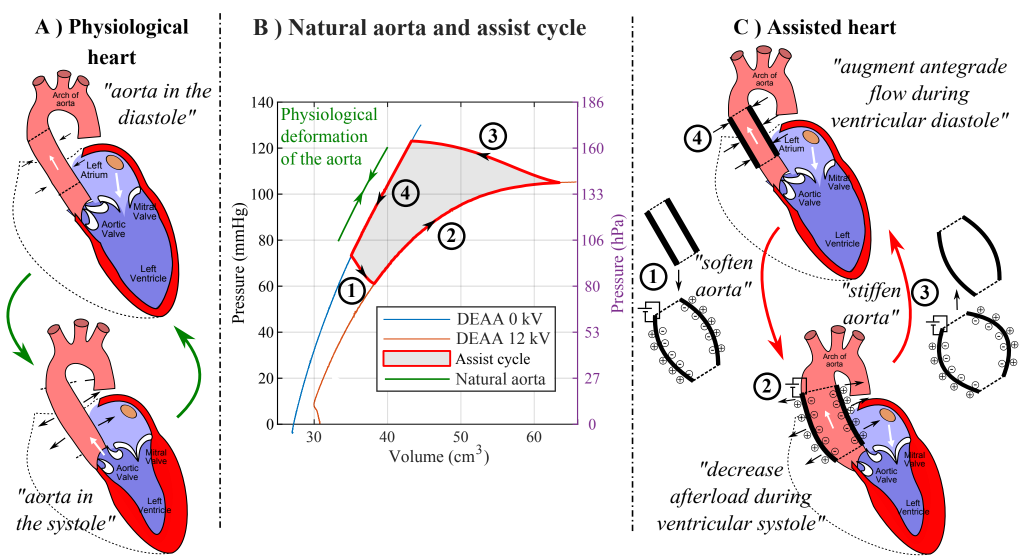
EPFL

Dissemination

“Feasibility of A Dielectric Elastomer Augmented Aorta”



M. Almanza, F. Clavica, J. Chavanne, D. Moser, D. Obrist, T. Carrel, Y. Civet, Y. Perriard, Feasibility of A Dielectric Elastomer Augmented Aorta. *Adv. Sci.* 2020, 2001974. https://doi.org/10.1002/advs.202001974

Conferences

R. Mottet, A. Boegli, Y. Perriard. "Control strategy for the discharge phase of an ultra-high voltage (> 7 kV) Bi-directional flyback converter driving capacitive actuators”, *Proceedings of the 23rd International Conference on Electrical Machines and Systems (ICEMS),* 2020

J. Chavanne, J. Haenni, T. Martinez, D. Moser, A. Walter, M. Almanza, F. Clavica, Y. Civet, Y. Perriard. "Manufacturing and tests of a tubular multilayer dielectric elastomer actuator for an impedance pump”, *Proceedings of the 23rd International Conference on Electrical Machines and Systems (ICEMS)*, 2020

T. Martinez, J. Chavanne, Y. Civet, Y. Perriard. "Identification of Material Parameters of a tubular dielectric elastomer actuator for a cardiac assist device”, *Proceedings of the 23rd International Conference on Electrical Machines and Systems (ICEMS),* 2020

Journal papers

M. Almanza, J. Chavanne, Y. Civet, Y. Perriard. “Towards the material limit and field concentration smoothing in multilayer dielectric elastomer actuators”, *Smart Materials And Structures*. 2020-04-01. Vol. 29, num. 4, p. 045044. DOI: 10.1088/1361-665X/ab72e7

L. Pniak, M. Almanza, Y. Civet, Y. Perriard. “Ultra High Voltage Switch for Bidirectional DC-DC converter Driving Dielectric Elastomer Actuator” *IEEE Transactions on Power Electronics*. 2020-05-15. DOI: 10.1109/TPEL.2020.2995047

Mantegazza A, Ungari M, Clavica F, Obrist D. 'Local vs. Global Blood Flow Modulation in Artificial Microvascular Networks: Effects on Red Blood Cell Distribution and Partitioning' Front Physiol. 2020 Sep 25;11:566273. doi: 10.3389/fphys.2020.566273. eCollection 2020.

X. Ji, X. Liu, V. Cacucciolo, Y. Civet, A. El Haitami, S. Catin, Y. Perriard, H. Shea. “Untethered Feel-Through Haptics Using 18-um Thick Dielectric Elastomers Actuators” *Advanced Functional Materials*. 2020-10-07. Vol. 30, num. 41, p. 1-10, 2006639. DOI : 10.1002/adfm.202006639

R. Mottet, M. Almanza, L. Pniak, A. Boegli, Y. Perriard. ”Ultra-High Voltage (7kV) Bi-Directional FlybackConverter Used to Drive Capacitive Actuators” IEEE transactions on Industry Applications, under review.

Patents

Dielectric Elastomer Actuator, EP20180821740

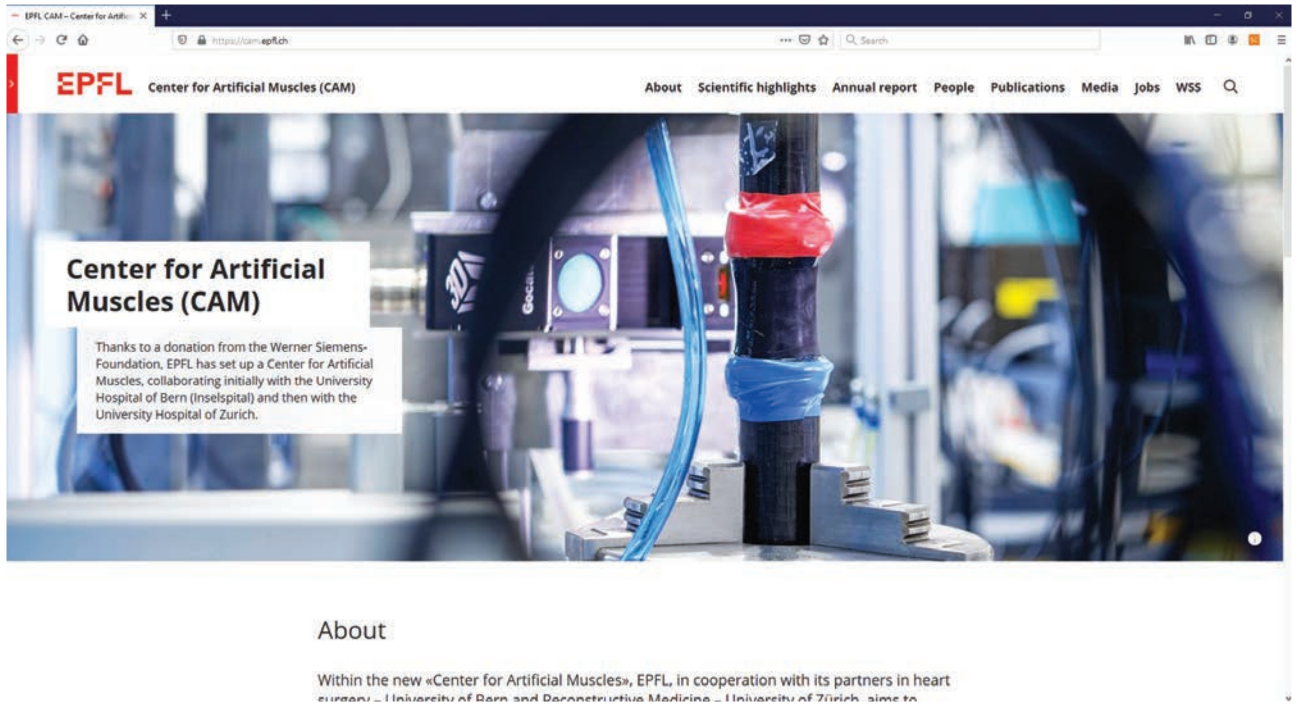
Award - Grants

- URODEA has won the 2020 venture startup competition in the category Health and Nutrition, June 2020
- Innosuisse core coaching grant 45342.1 SUCO-LS - URODEA, June 2020
- Innosuisse grant without implementation partner 41236.1 IP-LS - Feasibility study of a handheld device for non-invasive bladder emptying, November 2019

New website: cam.epfl.ch

The increasing digitalization of work, along with the new EPFL visual identity guidelines led us to re-think our website at cam.epfl.ch where people can follow our up-to-date developments and publications.

This much-needed makeover was accomplished with the support of a decidedly talented web designer: Aline Keller (www.alinekeller.ch).



Infrastructure

Targeting animal experiments in 2021 has increased the need for prototypes. We have therefore invested in a new laser cutter from Trotec™. This tool plays a key role in the manufacturing process and will facilitate the various tests that need to be conducted before medical implantation.

The assessment of the efficacy of the proposed actuator during pig experiments is a challenging task. The gold standard in cardiovascular research is to simultaneously acquire the pressure and the volume at the same location, i.e. in the lumen of the left ventricle, to quantify the stroke work of the heart (calculated as the area circumscribed by the pressure-volume loop). Meanwhile, the cardiac output is a key indicator of the stroke volume ejected by the left ventricle for each heartbeat. A full Pressure-Volume system from Millar™ and a flow probe from Transonic™ were bought in forecast of these upcoming experiments.

The Werner Siemens-Stiftung: Acknowledgement

“Promoting innovation in technology and the natural sciences”

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 established itself as one of the first international centers for regenerative urology, heart and facial surgery.

EPFL

WSS
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“My greatest wish is to enable patients with facial paralysis to smile again. I am therefore particularly enthusiastic about being part of the Center for Artificial Muscles”

PROF. NICOLE LINDENBLATT

“The idea to create an artificial muscle around the aorta to support a failing heart is a very creative idea, but also a challenging project. The strong team spirit at CAM is key to our success in conducting the basic research required and then progressing to in vivo experimentation”

PROF. THIERRY CARREL

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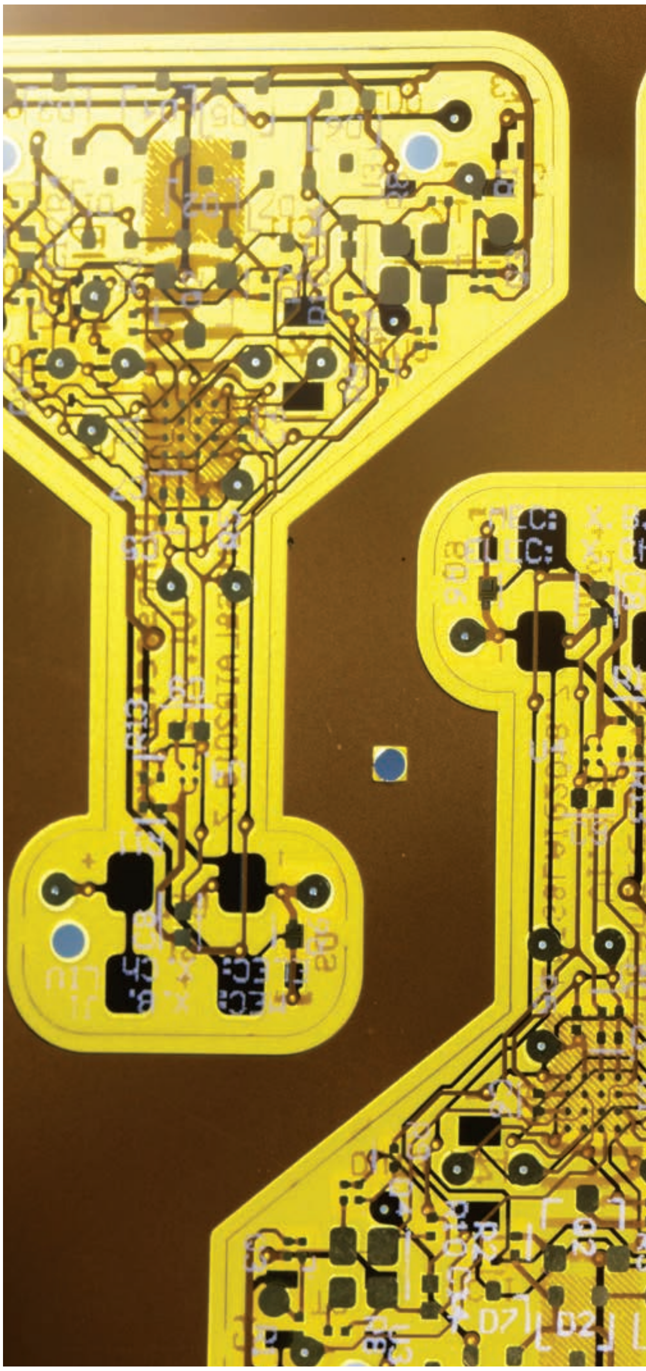

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