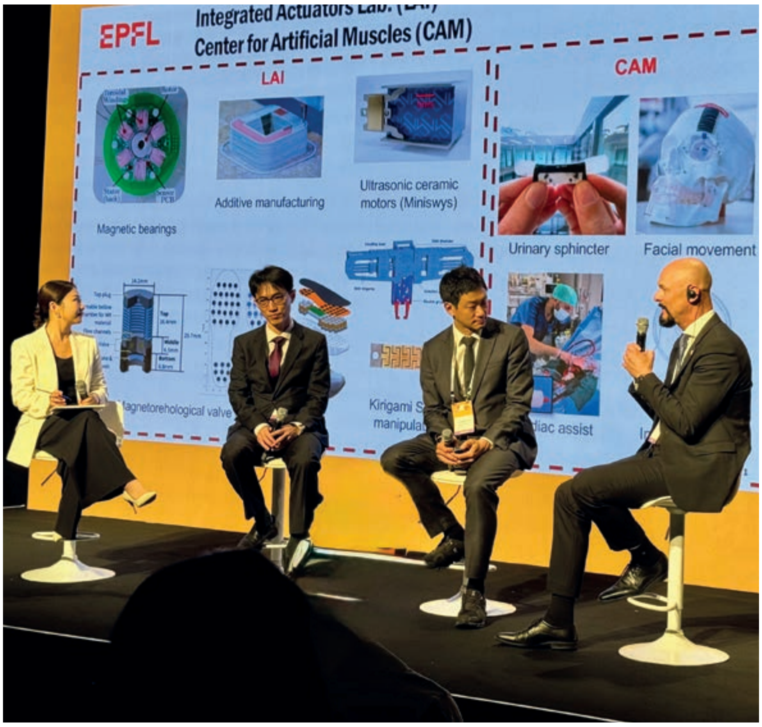
Center for Artificial Muscles
Report 2025

Center
for Artifical
Muscles



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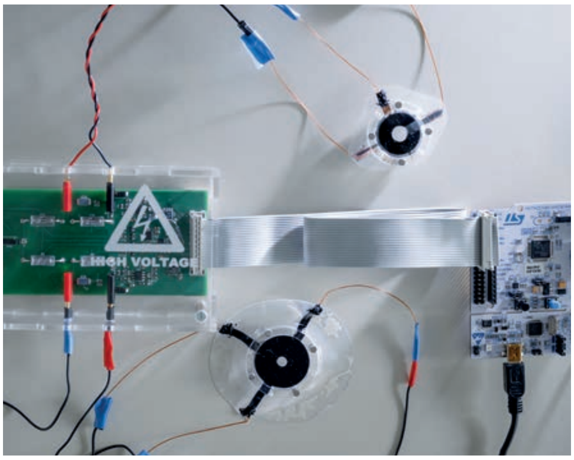
“What a great human adventure to perform and to succeed in creating these new medical devices”

PROF. YVES PERRIARD

Toward Living Actuators: *A New Paradigm for Restoring Human Function*



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Some of the most devastating medical conditions of our time are not linked to structural organ loss, but rather to impaired muscular contraction and actuation. Heart failure alone affects more than 64 million people worldwide and remains one of the leading causes of morbidity and mortality, with healthcare costs projected to exceed 70 billion dollars annually by 2030. Beyond the heart, the loss of muscular function deeply alters living conditions in dramatic ways. Irreversible facial paralysis can lead to permanent visual impairment, loss of social interaction, inability to work, as well as life-threatening infections. Urinary incontinence, affecting globally hundreds of millions of adults, remains a deeply distressing condition that compromises dignity, autonomy, and quality of life. Together, these disorders represent a major societal burden—medically, economically, and in terms of profound emotional and psychological impact—underscoring an urgent need for transformative therapeutic solutions.

For decades, technology has sought to compensate for failing biological functions through rigid mechanical devices. Yet, most medical technologies remain rooted in the paradigm of rigid robotic systems designed to move, pump, or support, but fundamentally incompatible with the soft, adaptive, and living nature of the human body. Rigid actuators and motors excel in controlled environments, but when implanted or interfaced with biological tissues, their limitations become evident. They lack compliance, cannot adapt dynamically to physiological changes, and often provoke inflammation, fibrosis, or mechanical mismatch over time. As a result, existing solutions struggle to restore natural motion, long-term functionality, and seamless integration with human tissues.

Artificial muscles based on dielectric elastomer actuators (DEA) therefore offer a fundamentally different approach. By converting electrical energy directly into soft, muscle-like contraction, DEA-based systems combine high strain, intrinsic compliance, and fast response in a form factor compatible with biological tissues. Since its creation in 2018, the Center for Artificial Muscles at EPFL, in close collaboration with the University of Bern and the University of Zurich, has been advancing this technology from foundational research toward clinical reality. The Center has positioned itself as a unique interdisciplinary hub where materials science, soft robotics, biomedical engineering, and clinical expertise converge to address unmet medical needs.

Over the years, the Center has progressively built a coherent technological and translational ecosystem, aiming to establish artificial muscles as a new class of medical devices for the human body. Its long-term ambition is to become the world's leading reference for DEA-based artificial muscles, enabling applications ranging from synchronized cardiac assistance to dynamic urinary continence restoration and expressive facial reanimation. This annual report reflects both the progress achieved in 2025 and the collective vision that continues to guide the Center: redefining the interaction between actuators and living tissues and laying the foundations for medical technologies that do not merely support the body but restore its natural function.

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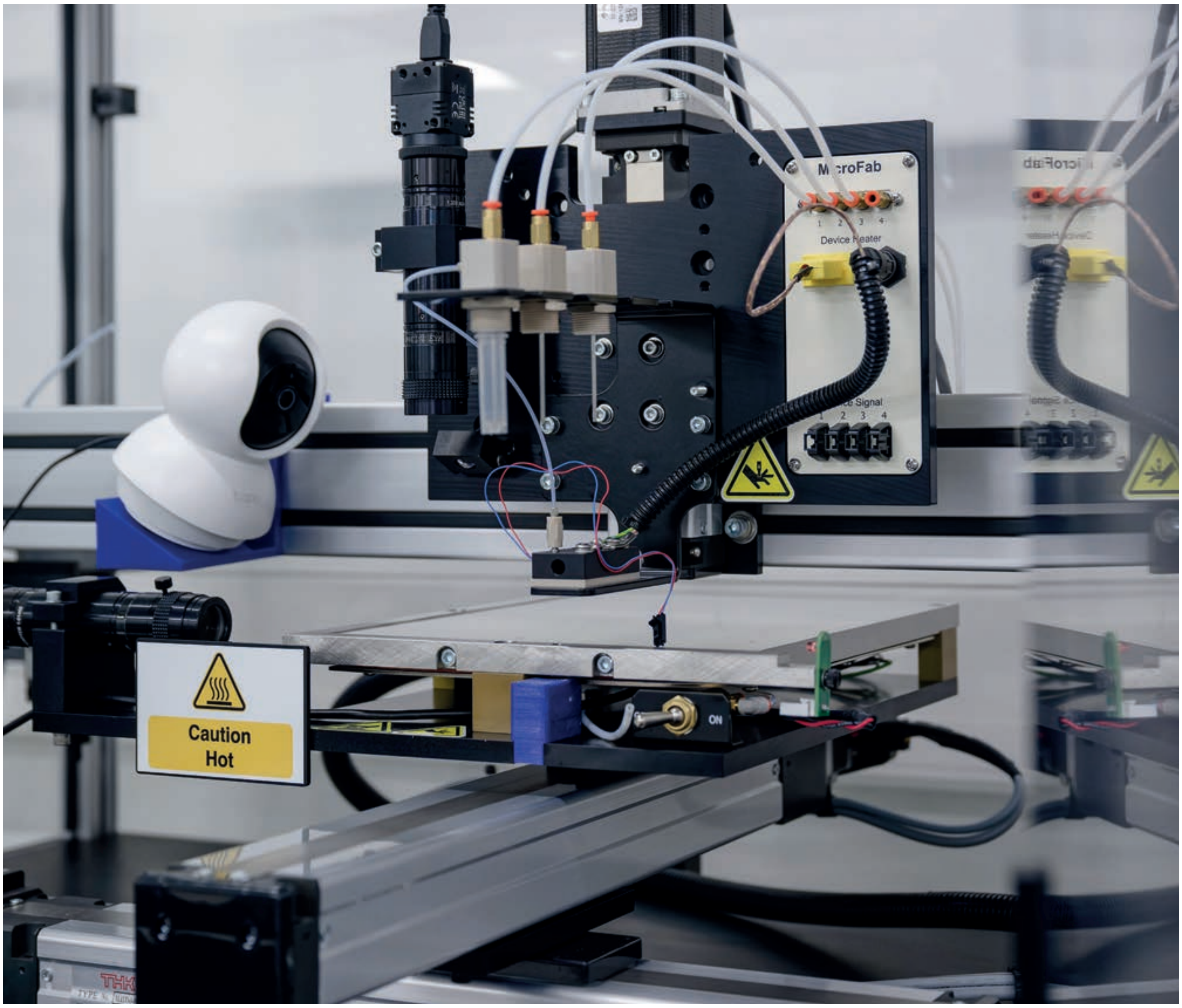

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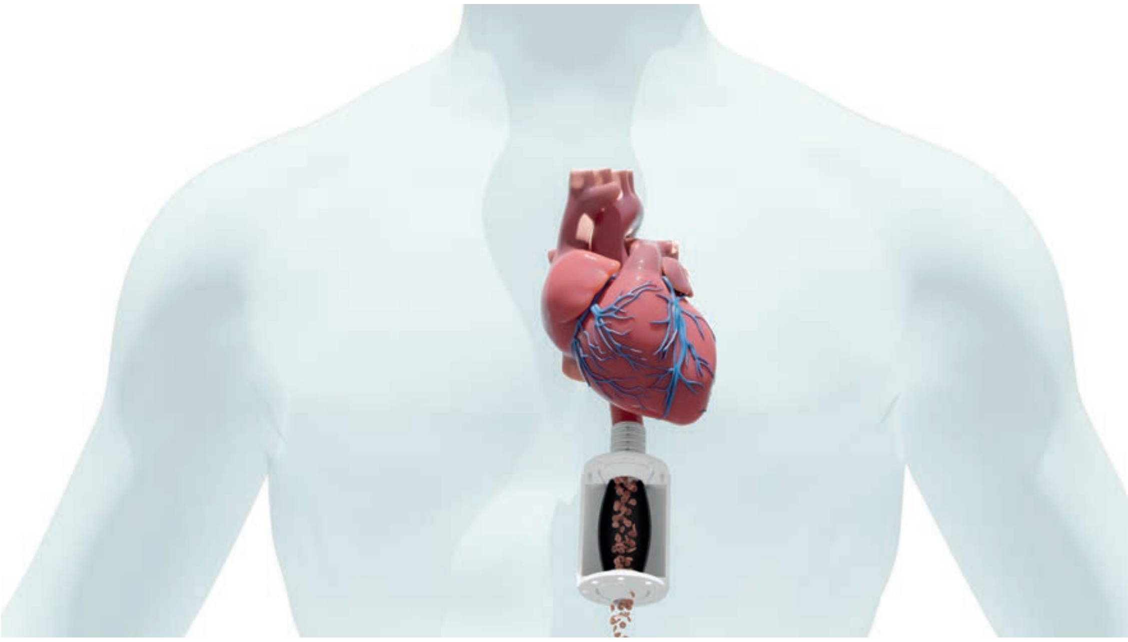
Content

Breakthrough Stories: *Key Advances of the Year*

A Soft Path to Supporting the Failing Right Heart

Ventricular failure remains one of the most difficult conditions to treat in advanced cardiac care. Existing ventricular assist devices (VADs) are often bulky, rigid, and poorly suited for long-term implantation in the delicate heart environment. Achieving adequate flow and pressure while preserving tissues and cells compatibility, durability, and physiological integration remains a major technological barrier. Overcoming these challenges requires a device that is not only powerful, but also soft, compact, efficient, and capable of operating reliably over extended periods.

During the past year, our team has advanced the development of a vacuum-enhanced tubular dielectric elastomer actuator (DEA)-based ventricular assist device toward readiness for chronic animal testing. Building on a previously demonstrated design known for its energy efficiency and intrinsic compliance, we focused on refining the architecture, materials, and integration strategies to improve long-term stability and reliability. The device operates as a soft electropneumatic system: a tubular, axially pre-stretched DEA enclosed in a vacuum chamber that induces radial pre-stretch, combined with mechanical valves at both ends to ensure unidirectional blood flow.

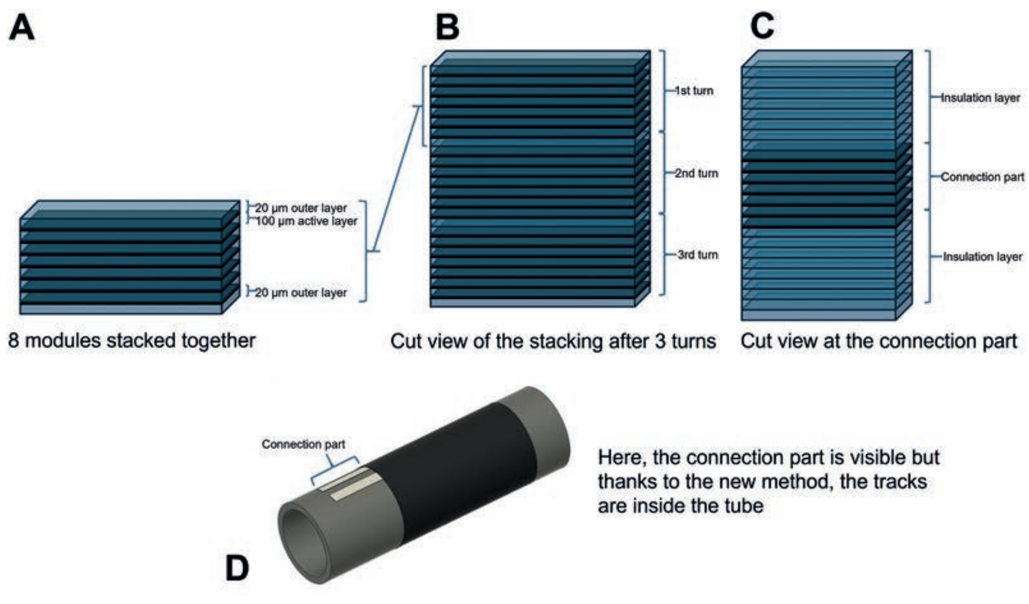


Concept of our DEA-based RVAD.

A key objective was miniaturization without performance loss. Through design optimization, we were able to reduce the overall device size by approximately 30% while preserving its hemodynamic capabilities. In parallel, we addressed critical fabrication and durability challenges associated with multilayer DEA assembly, electrical insulation, and electrode design—essential steps for chronic implantation.

Despite the significant reduction in size, the optimized right VAD maintained nearly identical functional performance, delivering up to 6.8 $L.min^{-1}$ at 5 Hz with a pressure head exceeding 30 mmHg—values sufficient for right ventricular support. This result demonstrated that soft robotic cardiac assist devices can be both compact and clinically relevant.

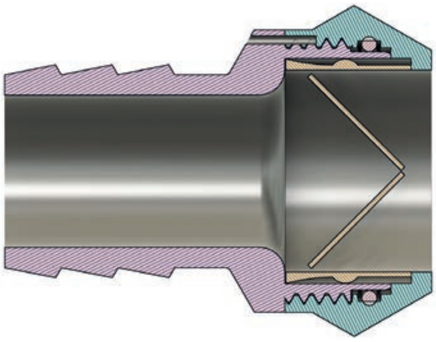
A major design breakthrough was achieved by rethinking the internal electrical architecture of the rolled DEA. Previously, thin outer insulation layers were sufficient for *in vitro* testing but proved vulnerable during *in vivo* handling. The new design uses the first and third turns of the rolled DEA as dedicated insulation layers, while the central turn serves as the active conductive region. Electrical connections are now made exclusively through the protected central section, improving insulation robustness without increasing the device size. Wires are routed through a precisely engineered hole crossing only the first and second turns, preserving the integrity of the outer insulation.



Manufacturing of DEAs including the new internal electrical architecture.

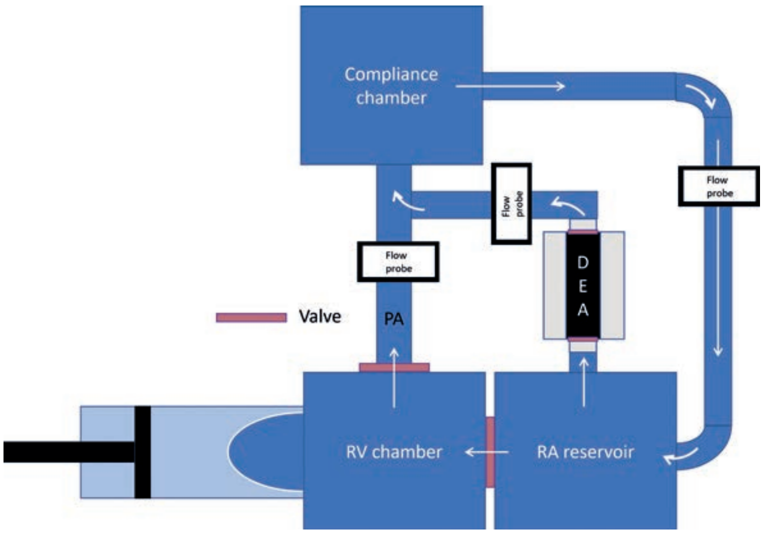
In parallel, electrode performance was significantly improved. By redesigning the electrodes and optimizing charge diffusion pathways, we achieved a fully carbon-based DEA with a reduced access resistance to 6–7 kΩ—approaching the performance of silver-coated electrodes with simplified manufacturing and improved scalability.

Fluidic performance was further enhanced by integrating two mechanical valves directly into the device, one at each end. A novel connector design—featuring an internal thread and O-ring joint within a wall thickness of just 0.65 mm—allowed the secure integration of standard 21 mm valves into a 25 mm DEA without modifying existing fittings. More importantly, the valves can be inserted and replaced from the outside, reducing cost and risk during experimentation.



Connectors' design welcoming the mechanical valves.

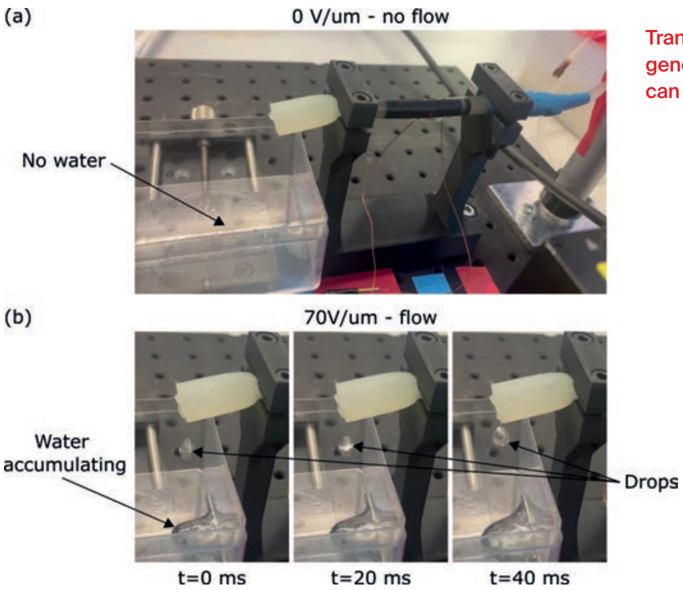
In vitro testing on the newly developed right-heart test bench confirmed the effectiveness of the complete system. When operated in parallel with the right ventricle, the device consistently delivered up to 4 $L.min^{-1}$ across a wide range of pre-existing flow rates. Pulmonary flow increased by up to 3.7 $L.min^{-1}$, reaching total outputs of 5.2 $L.min^{-1}$, while pulmonary pressure was moderately augmented during diastole—demonstrating physiologically meaningful support.



Right-heart testbench allowing to assess the DEA-based RVAD.

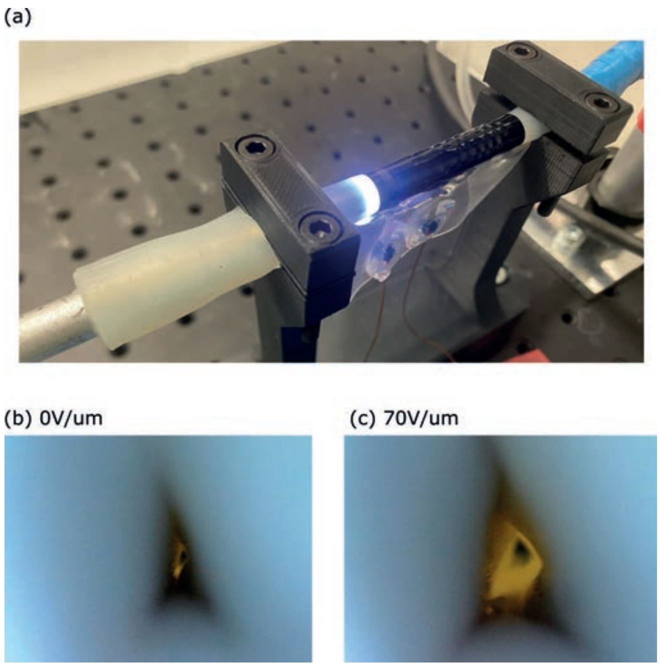
Engineering Soft Solutions for Urinary Health

Urinary incontinence affects millions of people worldwide, yet available interventions are often invasive, rigid, or insufficiently responsive to the dynamic demands of the human urinary system. At the same time, understanding how human cells respond to mechanical and electrical stimuli remains a longstanding challenge. Addressing both these issues—restoring urethral function and probing cellular mechanobiology—has been and remains a central focus.



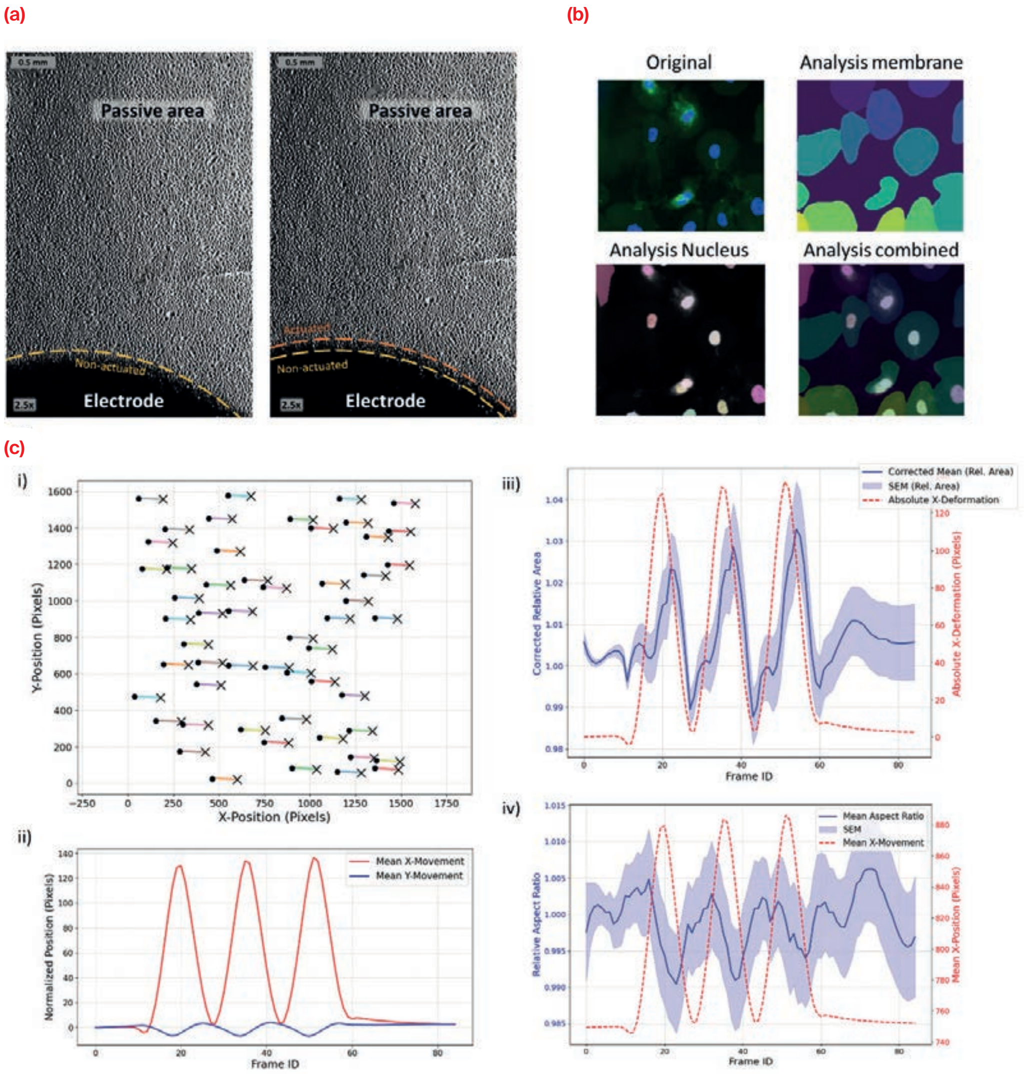
Transition from no flow (0 V.µm^{-1}) to active flow generation at 70 V.µm^{-1}, confirming that the DEA can expand sufficiently to allow passage of fluid.

Endoscopic visualization of the luminal opening during activation, clearly showing the reversible deformation of the urethral wall.



To tackle these challenges, we pursued two complementary approaches. First, we continued our development of a tubular dielectric elastomer actuator (DEA) cuff capable of mechanically supporting the urethra. Through electromechanical modeling, geometry optimization, and precise fabrication of double-layer DEAs, we engineered a system that can reversibly open and close the urethral lumen under physiologically relevant pressures. Second, we established a DEA-based cell-stretching platform to investigate how human urothelial cells respond to mechanical stimulation.

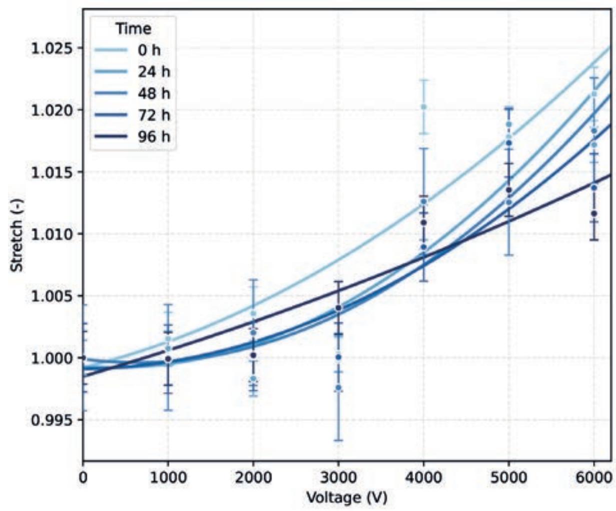
This platform delivers controlled, uniform strain while enabling high-resolution, non-invasive monitoring through a novel self-sensing algorithm, allowing us to quantify cell growth, stiffness changes, and activation of mechano-transduction pathways in real time.



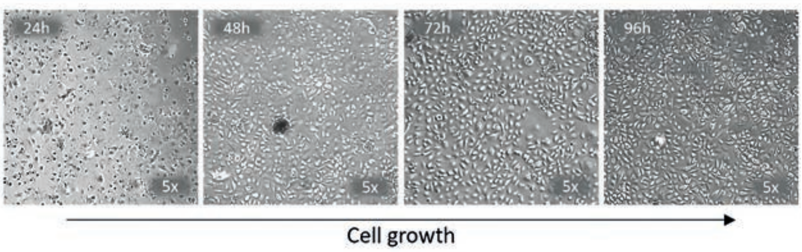
Impact of DEA activation on TEU-2 cell morphology: (a) Bright-field imaging shows no detectable changes in TEU-2 cell morphology, size, or structural integrity between control and activated conditions. (b) Fluorescence microscopy highlights membrane and nuclear staining with corresponding segmentation, while (c) quantitative analysis assesses nuclear position, cell displacement, relative area, deformation, and aspect ratio.

These efforts resulted in a significant breakthrough. The DEA urinary sphincter achieved electrically controlled urethral opening, producing urine-like flow under physiologically relevant pressures while maintaining high precision and full reversibility. Radial expansion of approximately 1 mm at 70 $V.\mu m^{-1}$ was observed, and optical imaging confirmed consistent luminal deformation. These experiments lead the first full electromechanical demonstration of a DEA-based artificial urinary sphincter at the Center for Artificial Muscles, providing a solid foundation for future optimization and preclinical studies. On the cellular side, we confirmed that DEA actuation preserves viability, genomic integrity, and normal cell-cycle progression, alongside activating key mechanosensitive genes. Moreover, self-sensing enabled label-free, real-time monitoring of cell growth, revealing a direct correlation between increasing cellular density and actuator stiffness—opening the door to advanced studies of differentiation, dedifferentiation, and mechanobiology in soft, electrically active systems.

(a)



(b)



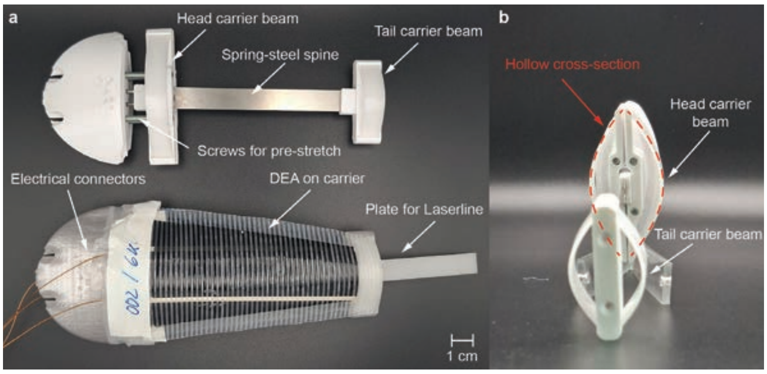
Different readouts to determine the cell growth on DEAs: (a) Stiffening effect visible in reduced stretch due to additional cells on membrane and (b) Optical readout for cell viability and growth.

Bringing Smiles Back: Soft Actuators for Facial Reanimation

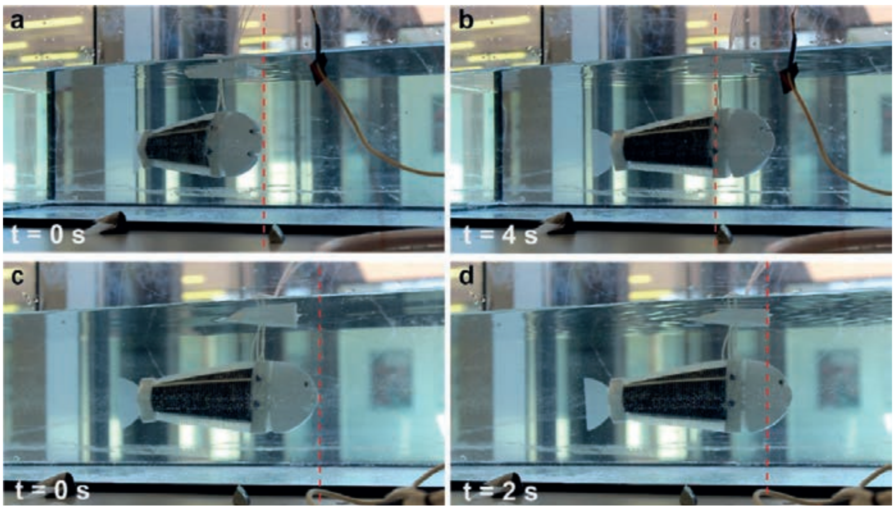
Restoring facial movement in patients with paralysis represents a unique set of challenges. The muscles responsible for expression are small, intricately arranged, and embedded within a complex three-dimensional anatomy. Delivering sufficient force, range of motion, and precise control within such a constrained space is beyond the capabilities of conventional planar actuators. To address these challenges, our research has focused on developing dielectric elastomer actuators (DEAs) specifically tailored for facial reanimation.

To effectively innovate, we created a biomimetic *ex vivo* platform—the DEA Fish—designed to test new actuator shapes, integration strategies, and 3D form factors in a controlled yet realistic setting. Using this platform, we explored trapezoidal DEAs, which allow optimal utilization of irregular spaces, and fiber-reinforced 3D actuators that conform to curved and bent surfaces without additional rigid components. The DEA Fish also enabled the development of robust high-voltage insulation, minimized connection cross-sections, and characterization of multiple bending modes—critical steps for translating laboratory prototypes to implantable systems. The actuators' thrust and swimming ability demonstrated functional actuation, providing confidence in their applicability for facial movement.

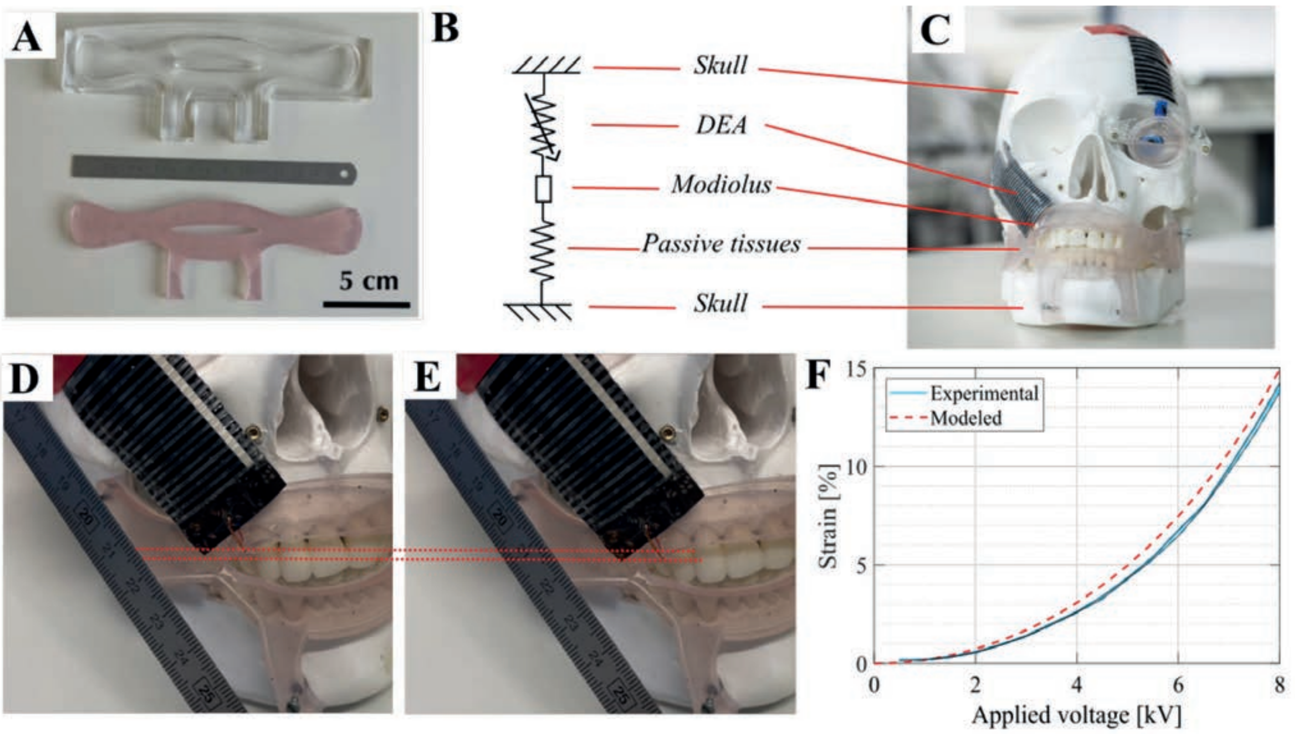
Hardware implementation of the biomimetic DEA Fish.



Swimming experiments demonstrating the propulsive capability of our robotic prototype.



Building on these insights, we constructed an anatomically accurate silicone-based skull model, replicating passive tissues and key muscle attachment sites such as the zygomaticus major. Mounting the DEAs between the skull and the corners of the mouth allowed us to mimic smiling motion. Single-layer and three-layer prestretched actuators achieved strains up to 7–7.6%, corresponding to millimeter-scale displacements sufficient to reproduce natural mouth movement. Increasing the actuator length allows further displacements of 7 mm, matching specifications for a typical smile. Two-layer reinforced DEAs were selected for enhanced encapsulation and safe operation in aqueous environments, preparing the way for *in vivo* testing.



The planar DEAs are mounted on an anatomically realistic skull.

Designing Electronics at the Edge of Voltage, Safety, and Physiology

Electronic developments are a cornerstone in the transition of dielectric elastomer actuators (DEAs) toward implantable cardiac assist devices. Within this context, electronics must operate at **exceptionally high voltages—ranging from several kilovolts up to 10 kV—** while remaining compatible with strict constraints on safety, efficiency, size, and long-term reliability.

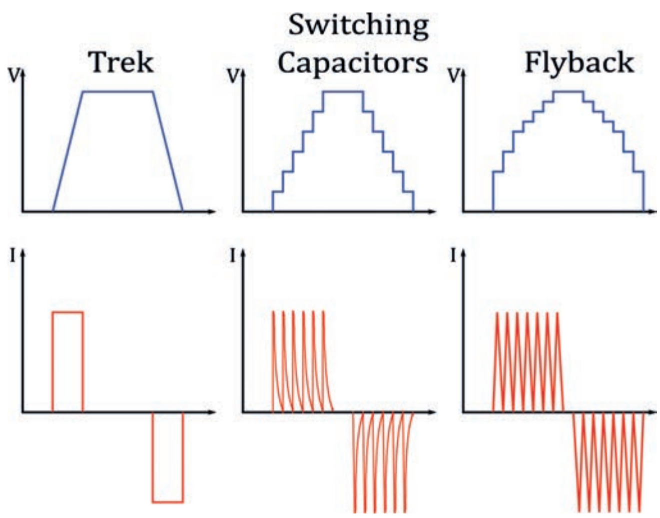
The ongoing research follows a system-level approach, covering high-voltage power supply, energy transfer from outside the body, communication, control, measurement, and modeling of the real electrical behavior of DEAs. Several high-voltage DC–DC conversion architectures are being explored, including Marx- and Flyback-type topologies, with particular focus in achieving voltage levels, overall efficiency, and energy recovery capabilities. A key aspect of these developments is to consider the DEA as a non-ideal load, whose electrical parameters evolve during actuation.

In parallel, we are also investigating energy transfer and communication solutions to ensure reliable interaction between the implanted system and the external environment while meeting constraints on safety, compactness, and biocompatibility. These building blocks are essential for system control, monitoring, and the long-term objective of moving toward an autonomous and integrable device.

The required voltage levels are such that they severely limit the operational range of many electronic components and directly impact architectural choices. Additionally, the number and size of high-voltage components often lead to bulky and complex topologies, which are incompatible with the required compactness of implantable systems. Another critical constraint arises from the risk of electrical breakdown in DEAs, which restricts the use of step-up strategies that generate high voltage peaks during transient operation.

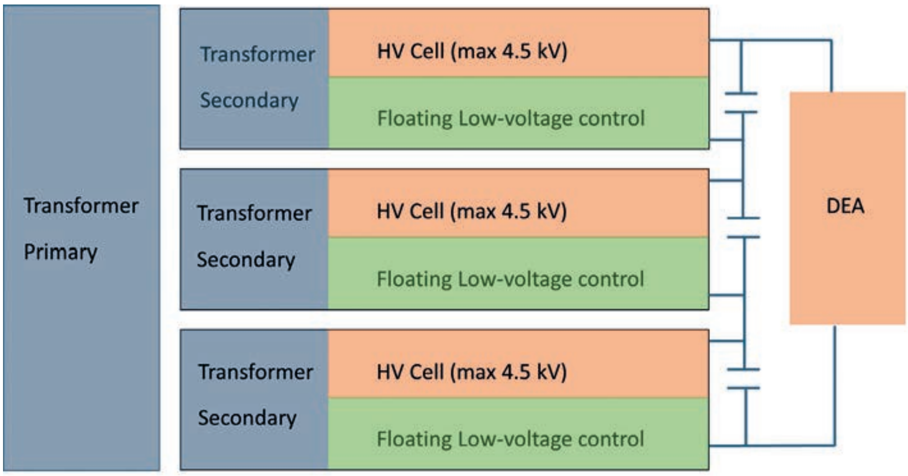
Beyond hardware limitations, a fundamental challenge lies in the electrical nature of the actuator itself. During actuation, DEAs exhibit time-varying electrical properties, including changes in capacitance and resistance. These variations strongly influence current and voltage waveforms and must be accounted for at the system level as different excitation waveforms are commonly used to power DEAs.

Voltage **(V)** and current **(I)** profile to power a DEA from different topologies.



To address the challenge of high-voltage generation and energy efficiency, several DC–DC step-up architectures were investigated, with particular attention given to Marx-type and Flyback-type topologies. These approaches are evaluated based on their ability to achieve kilovolt-level outputs, as well as their potential to enable energy recovery from the DEA, a key factor in improving overall system efficiency. Transformer-based and Flyback topologies may be more lossy than switched-capacitor circuits (such as the Marx voltage elevator); however, they offer an inherent advantage in the form of galvanic isolation.

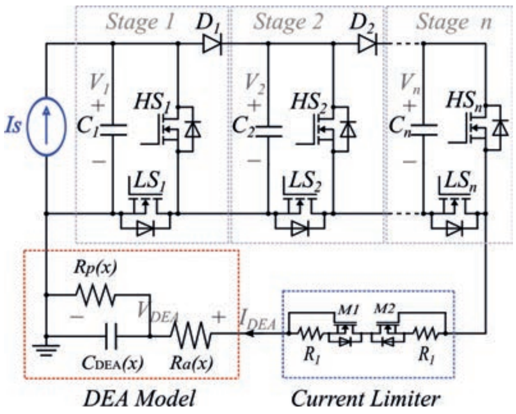
State-of-the-art high-voltage field-effect transistors cannot withstand drain–source voltages above 4.5 kilovolts, which remains below the operating voltage of current cardiac-assist DEAs developed at CAM. Stacking multiple transistors is a viable option, provided that appropriate measures are taken to mitigate control signal skew and that the control signals do not exceed device voltage thresholds, for instance by referencing them to floating grounds.



Flyback topology while stacking multiple transistors.

A major limitation of many existing charging topologies is that they are typically validated using an ideal capacitive model of DEA. While such models simplify analysis, they fail to capture the complex electrical response of real actuators under high-voltage excitation. In practice, DEAs behave as non-ideal, dynamic loads whose electrical characteristics evolve throughout the actuation cycle.

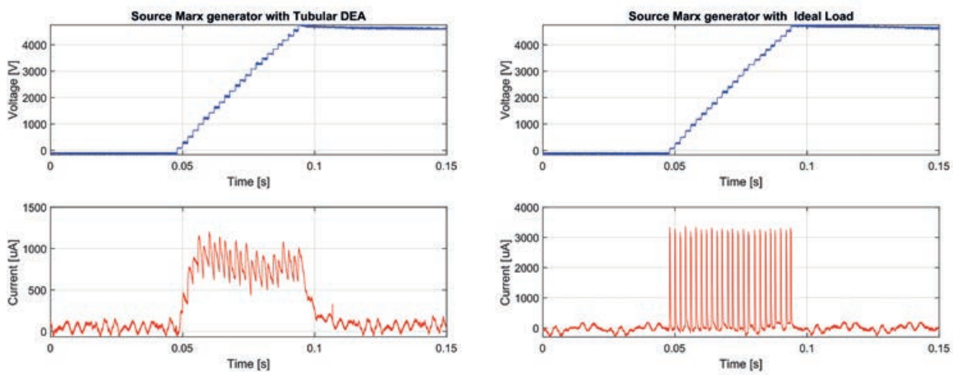
To explicitly address this gap, the performance of a Marx generator topology has been analyzed under both ideal load conditions and when driving a physical DEA. The topology is first introduced as a high-voltage step-up solution and then experimentally validated by charging a tubular DEA actuator with a capacitance of approximately 4 nF, designed for use in ventricular assist devices (VADs).



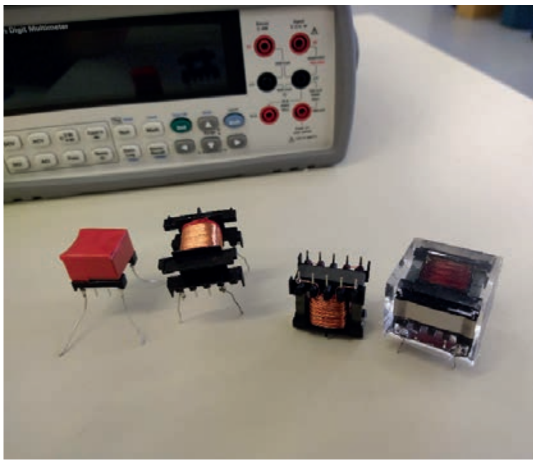
Adapted Marx generator reaching 7kV in output.

The validation results reveal clear differences between the ideal load and the physical DEA. While the ideal capacitive load suggests stable and predictable behavior, the current response measured with the tubular DEA exhibits a more complex and structured waveform, reflecting the intrinsic electromechanical coupling and time-dependent properties of the actuator. These observations demonstrate that idealized models do not fully represent real DEA operation and highlight the need to refine both electrical models and converter topologies.

Voltage and current response for an ideal load and a tubular DEA using Adapted Marx generator.



Finally, a probe was designed to reduce the need for specialized and expensive high-voltage equipment and to demonstrate the feasibility of embedded current and voltage sensing within the driving electronics of the cardiac assist system.



Isolated Voltage and Current Probe.

Engineering Trust in Soft Actuation: Materials, Processes, and Models

Across applications—from cardiac assistance and urology up to facial rehabilitation and electronic control—one challenge remains universal: performance in dielectric elastomer actuators increases with voltage, but so does risk. Higher electric fields lead to larger displacements and higher forces, yet they also bring the system closer to dielectric breakdown and long-term failure. Ensuring reliable, repeatable operations therefore requires better devices, as well as a more in-depth control of materials, manufacturing processes, and predictive models.

To address this challenge, we are pursuing complementary strategies that span over material screening, reliability testing, advanced modeling, and alternative fabrication routes, which all aim at identifying and enabling the most suitable dielectric elastomer actuator for demanding biomedical applications.

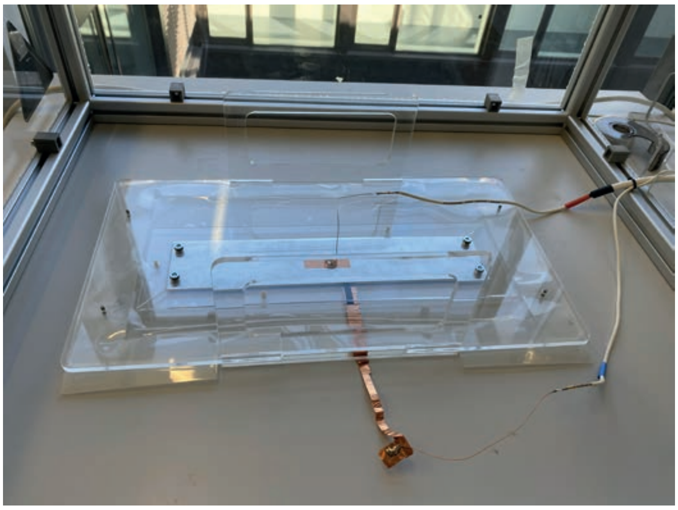
For tubular DEAs, where breakdown can compromise both performance and safety, material quality is of particular importance at the layer level. To this end, we developed a dedicated dielectric breakdown tester to evaluate individual Elastosil layers prior to assembly. The system connects directly to a pre-patterned electrode on one side of the elastomer, while an aluminum plate serves as the counter-electrode on the opposite side.

High voltage is then applied and gradually increased until a predefined criterion is met. To improve the quality of DEAs, there are two strategies:

- Selective screening, in which only layers capable of withstanding a specified voltage threshold are used for assembly.
- Controlled breakdown and repair, where the voltage is increased until a defect is revealed and subsequently corrected.

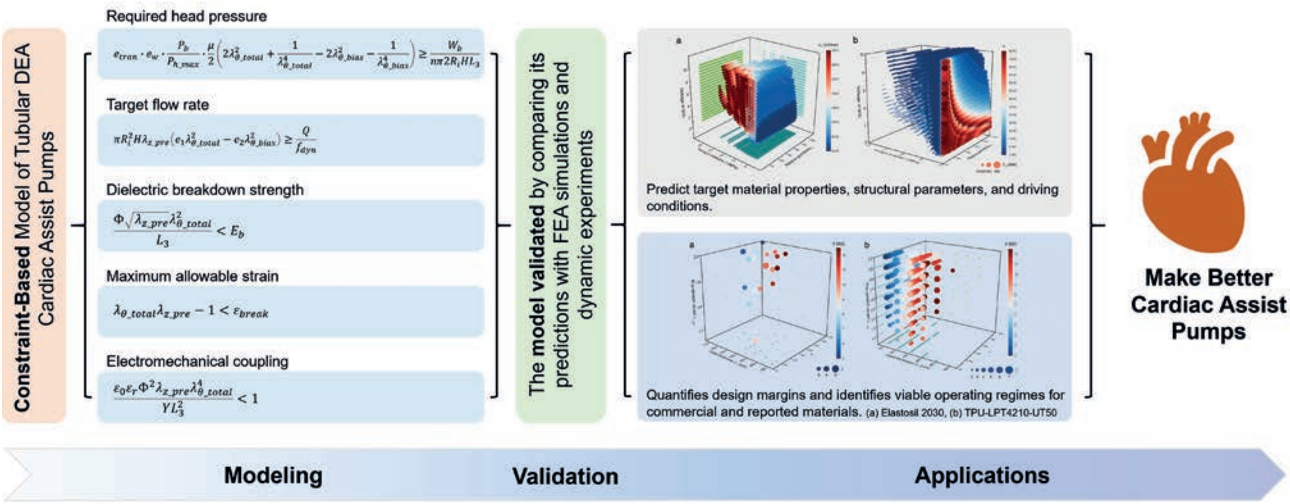
By detecting and addressing defects early on, we can significantly improve the reliability of high-voltage DEA devices while enabling operation closer to their performance limits.

Custom-made testbench to assess Elastosil Film.



Materials' selection and device architecture are further guided by a theoretical and computational modeling framework, that we developed internally to describe the deformation of tubular DEA pumps under the combined effects of driving voltage and physiological pressure. This model explicitly incorporates key constraints relevant to cardiac-assist applications, including target flow rate, required head pressure, dielectric breakdown strength, maximum allowable strain, and electromechanical coupling.

Validated against both finite element simulations and dynamic experimental data, the model serves as a powerful design compass. It enables the computation of feasible combinations of materials' properties, structural parameters, and driving conditions for a given pump geometry and performance target. Beyond defining target ranges—such as relative permittivity, elastic modulus, film thickness, number of layers, and operating voltage—the framework supports rapid screening of candidate dielectric elastomers without extensive prototyping.



The building of constraint-based model can accelerate materials' selection and design optimization of tubular DEA pumps for cardiac assist applications.

Importantly, the model can also be used to assess the suitability of existing materials, by directly substituting their measured properties and determining whether viable operating regimes exist. This capability substantially accelerates development cycles, reduces experimental overhead, and increases confidence in design decisions across a range of applications.

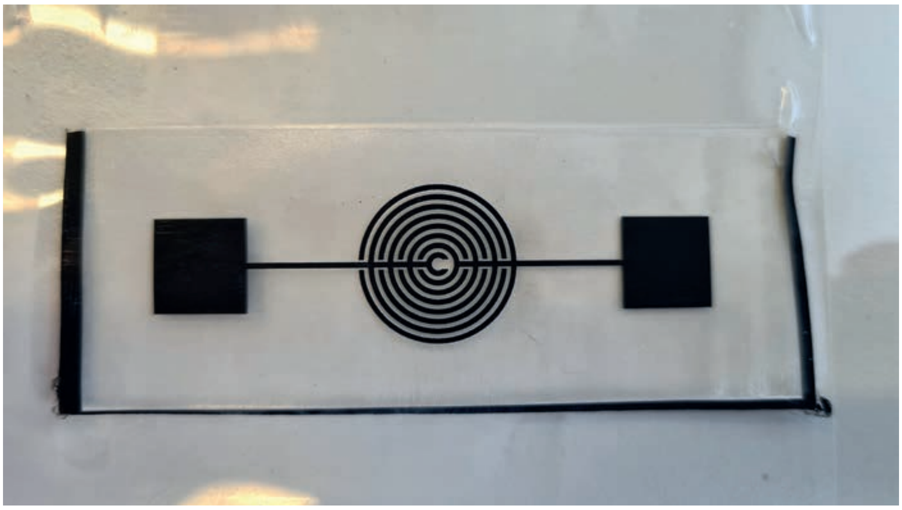
Improving DEA performance is not only a matter of material, but also of how devices are manufactured. In the current assembly process, liquid silicone adhesives are used to bond layers together; however these adhesives introduce an additional stiffness that can limit actuation performance. An ideal solution would be to assemble multilayer DEAs without the use of any adhesive whatsoever.

To this end and as an alternative bonding strategy, plasma activation is being explored. By exposing silicone surfaces to oxygen plasma for a few seconds, surface –H and –OH groups are removed, creating a transiently activated surface capable of forming new covalent bonds when brought into contact with another activated layer. Because this activated state is short-lived under ambient conditions, the assembly must be performed rapidly to prevent surface passivation.

Planar DEAs have already been manufactured using this approach, and ongoing tests aim to determine whether glue-free bonding results in improved displacement and mechanical compliance compared with conventional methods.

In parallel, laser ablation is being investigated as a flexible alternative to conventional electrode patterning. Instead of depositing carbon electrodes through laser-cut masks, laser ablation removes material directly to define electrode geometries without the need for intermediate tooling.

Features obtained by laser ablation.

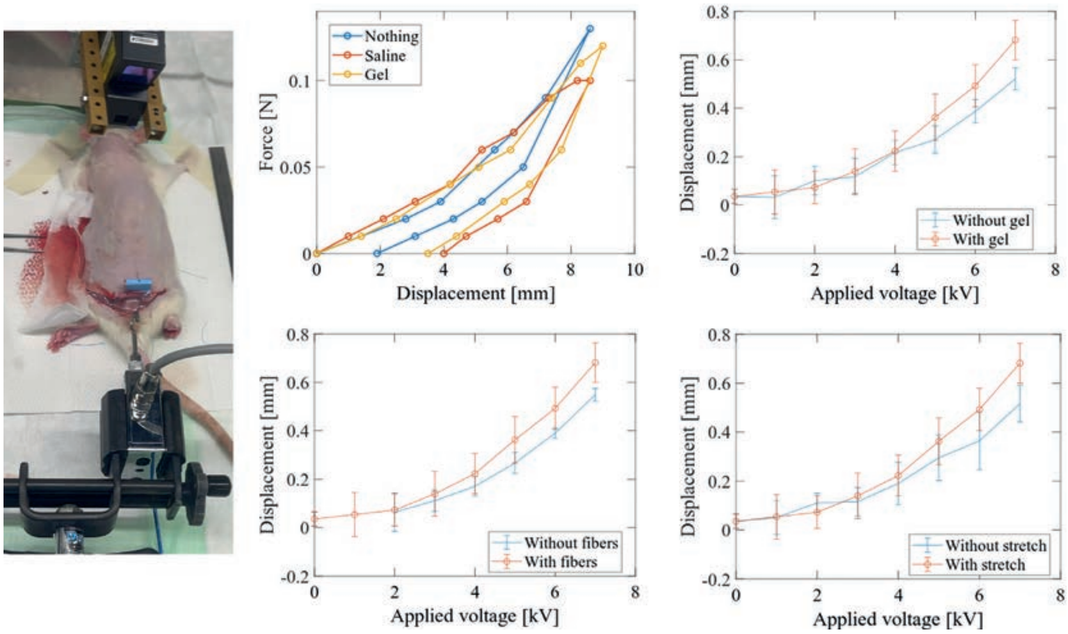


This approach enables the fabrication of integrated devices, such as capacitive pressure sensors, using a single planar process. By measuring changes in capacitance as a response to applied pressure, these sensors could provide localized feedback while remaining fully compatible with soft DEA structures. The ability to pattern functional elements in a single step and at a single level opens new pathways toward compact, multifunctional, and manufacturable soft devices.

From Proof of Concept to Living Systems

Translating soft actuation technologies from the laboratory to real-world medical applications requires a carefully staged preclinical roadmap. Our long-term objective is to reach chronic *in vivo* testing by 2027, a critical milestone toward clinical translation. As an intermediate step, one-day acute experiments in sheep are planned for 2026, leveraging the physiological relevance of large-animal models to evaluate device performance under realistic cardiovascular conditions. In parallel, initial *in vivo* studies have already been initiated in rats for facial reanimation, marking an important transition from *in vitro* validation to testing in living tissues.

Following the demonstration of reinforced dielectric elastomer actuators (rDEAs) for facial reanimation in the lab, *in vivo* experimentation introduces new challenges, including biocompatibility, long-term stability, and the integration of neural interfaces with biological tissues for actuator control. To ensure safety and ethical compliance prior to any future clinical trials, DEA implants are systematically evaluated in appropriate animal models. Also, implant performance is thoroughly characterized by examining the influence of gel application, fiber reinforcement, and initial mechanical pre-stretch, which is adjusted by adapting the attachment sites.



Experimental setting for the measurement of force-induced skin displacement in rats in different environments (Gel, saline) with different topologies (fiber-reinforcement and pre-stretch).

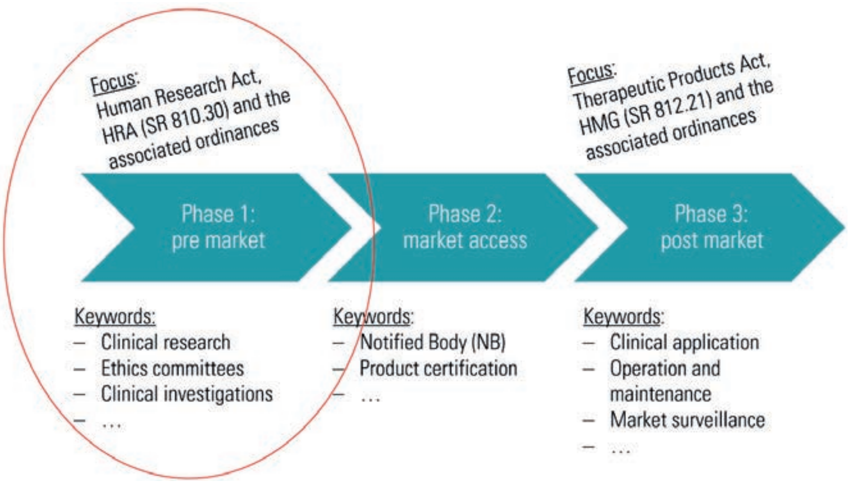
The reinforced DEAs achieve displacements of up to 0.78 mm at an applied voltage of 7 kV, representing a 40 % increase compared with non-reinforced actuators, which reach 0.56 mm under identical conditions. These results demonstrate how structural design choices directly translate into functional gains under *in vivo*-relevant conditions.

In parallel to technological developments, we are actively addressing the translational and business dimensions required to accelerate clinical adoption. Multiple commercialization strategies are being evaluated, including the creation of dedicated spin-off companies and the establishment of partnerships with existing industrial players. Strategic options are analyzed with respect to development timelines, regulatory requirements, investment needs, and alignment with unmet clinical demands.

A comprehensive translational and market assessments focused on the cardiovascular device is underway, encompassing:

- Market landscape analysis, including current and emerging medical devices, identification of competitors, as well as evaluation of potential industrial partners or acquirers.
- Market sizing and validation, combining top-down market data with a bottom-up approach based on targeted surveys of cardiovascular surgeons, providing insights into clinical workflows, patient populations, reimbursement environments, and pricing expectations.
- SWOT analysis to evaluate strengths, weaknesses, opportunities, and threats associated with clinical deployment.
- Reimbursement landscape analysis across healthcare systems, starting with Switzerland.
- Regulatory strategy development, including assessment of CE marking and FDA approval pathways and their implications for timelines and evidence generation.

Crucially, insights gained from these translational and market analyses directly inform the design of the next phase of preclinical studies, particularly chronic large-animal experiments. These studies will be essential for assessing the long-term durability, biocompatibility, safety, and tissue interactions of dielectric elastomer actuators.



Regulatory framework of medical devices following workshop with iss-ag (www.iss-ag.ch).

EPFL

What Makes This Center Unique: *Excellence, People, and an Open Network*

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Scientific Excellence Recognized

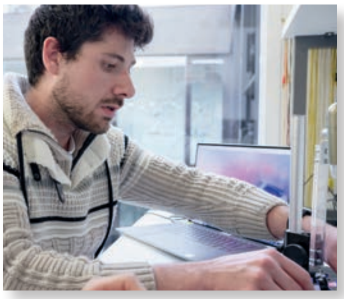
In 2025, a defining moment for the Center was the successful PhD defense of Stefania Konstantinidi, which exemplifies both the scientific ambition and the rigor fostered within the program. Her doctoral thesis, *"Reinforced Dielectric Elastomer Actuators: Anisotropic Designs for the Restoration of Facial Movements,"* addresses one of the most challenging aspects of soft actuation: combining high performance with precise, bio-inspired motion.

The work received unanimous and enthusiastic praise from the PhD committee, highlighting both its depth and impact. Members of the jury described the thesis as "an outstanding and impressive piece of work" and emphasized that it "reflects the author's dedication and expertise in the field." This recognition underscores the Center's ability to support cutting-edge research while training young scientists to perform at the highest international level.

- Reinforced Dielectric Elastomer Actuators: Anisotropic designs for the restoration of facial movements, S. Konstantinidi, Thesis 11305, Lausanne, EPFL, 2025.

Voices from the Next Generation

Beyond individual achievements, the Center's strength lies in the people who bring it to life every day. To capture this dynamic, we interviewed three PhD candidates currently working at the Center—**Simon Holzer, Quentin De Menech, and Maribel Caceres**—and asked them to reflect on their experience through three common questions.



Which collaboration has most changed the way you see your own field?

QDM: Collaborations at the interface between engineering and clinical urology reshaped the way I see my field. Working with clinicians like Prof. Fiona Burkhard and meeting patients made the challenges much more tangible. It became clear how strongly anatomical variability, surgical constraints, and patient safety shape what is truly "optimal" from an engineering perspective. This experience shifted my mindset from designing soft actuators that simply maximize performance metrics such as displacement or force to developing systems that are robust, compliant, and compatible with real physiological and clinical conditions. Confronting the gap between theory and clinical reality has been both humbling and motivating! It is precisely this challenge that makes the work meaningful and exciting when the ultimate goal is to help patients.

SH: The obvious answer would be, for me, the collaboration with the Urology team at Uni Bern. It stands to reason that their fundamentally different viewpoints would reveal many new aspects. However, I believe I was more shaped by working with electrical engineers. While our disciplines are often kept entirely separate during university studies, the professional world is frequently the exact opposite. Although our working methodologies are similar, the way we approach and understand a problem often differs completely. In a field like Dielectric Elastomer Actuators- electromechanical actuator- this difference in perspective has influenced me the most.

MC: The collaboration on powering DEAs with Prof. Almanza, particularly around topologies such as the Adapted Marx generator has motivated me to explore novel topologies and consider optimal methods. By studying general topologies, and adapting them to specific applications with more complex control strategies, I have gained initial insights into effective methodologies for operating DEAs.

What have you learned that doesn't appear in any paper?

SH: We can achieve more together. I am referring not only to teamwork with colleagues who bring diverse experiences to the table, but also to the exchanges with other researchers at scientific conferences. In this regard, I would recommend to every new PhD candidate to be courageous and open to also actively seek out direct dialogue with other researchers.

MC: We had the opportunity to explore different fields in wireless communication and energy transfer, gaining real experience with the challenges of non-idealities and additional physical effects. These factors must be carefully taken into consideration before any implementation to avoid abrupt changes in the real setup. On the other hand, we identified that powering DEAs is particularly challenging due to the load behavior, which is highly sensitive to high voltage and current peaks. Therefore, understanding these load-related challenges will help improve the effectiveness of driving a DEA.

QDM: One of the most important lessons I learned is how critical experimental intuition, iteration, and humility are when working in this field. Reality often resists ideal plans: many practical challenges only emerge under real operating conditions and cannot be fully anticipated by models or simulations. This taught me to accept uncertainty, to learn from failure, and to approach both data and science with humility. Through hands-on experimentation, I learned to interpret and understand results, adapt protocols pragmatically, and recognize when a solution is robust enough to move forward safely. These skills are essential in research, yet they are rarely visible in publications.

Which challenge required the most ingenuity?

MC: When considering new topologies that require achieving high voltages in a short time, existing methodologies are available; nevertheless, challenges remain related to form factor, efficiency, and power consumption. Relying solely on standard methodologies may limit performance. Therefore, investigating and innovating in these topologies is essential to meet the demands of powering DEAs.

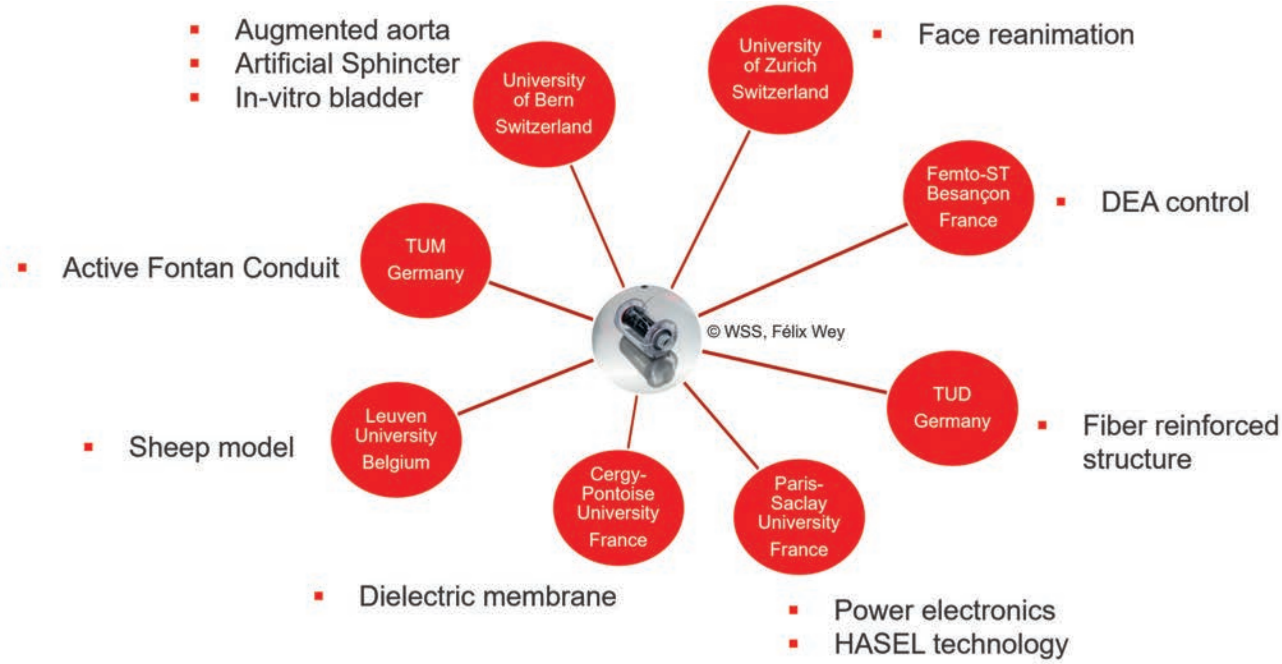
QDM: The challenge that required the most ingenuity was learning how to balance competing constraints rather than optimizing a single parameter. Designing a soft actuator for the body is a bit like working with living systems: improving one aspect often comes at the expense of another. Increasing force can reduce compliance, enhancing stability can limit motion, and simplifying fabrication can compromise performance. Progress came from accepting these trade-offs and finding workable compromises. This approach helped me to turn an abstract idea into a practical, testable device that could function under realistic conditions.

SH: In my opinion, applying concepts generally known in other fields to the technology we are currently working on, requires the most creativity and it is also the most enjoyable! The implementation path is often unclear, as there is frequently little groundwork in the existing literature or research. However, finding your own path is incredibly exciting, and when the results are positive, the sense of pride is even greater.

Their answers reveal a shared culture of interdisciplinarity, creativity, and hands-on problem solving. They highlight how working at the interface of materials science, electronics, biomechanics, and clinical applications reshapes their scientific perspective, and how many of the most valuable lessons emerge not from publications, but from experimental setbacks, informal exchanges, and collective troubleshooting. Together, these voices illustrate how the Center functions as a research hub, and as a training ground for independent, adaptable scientists.

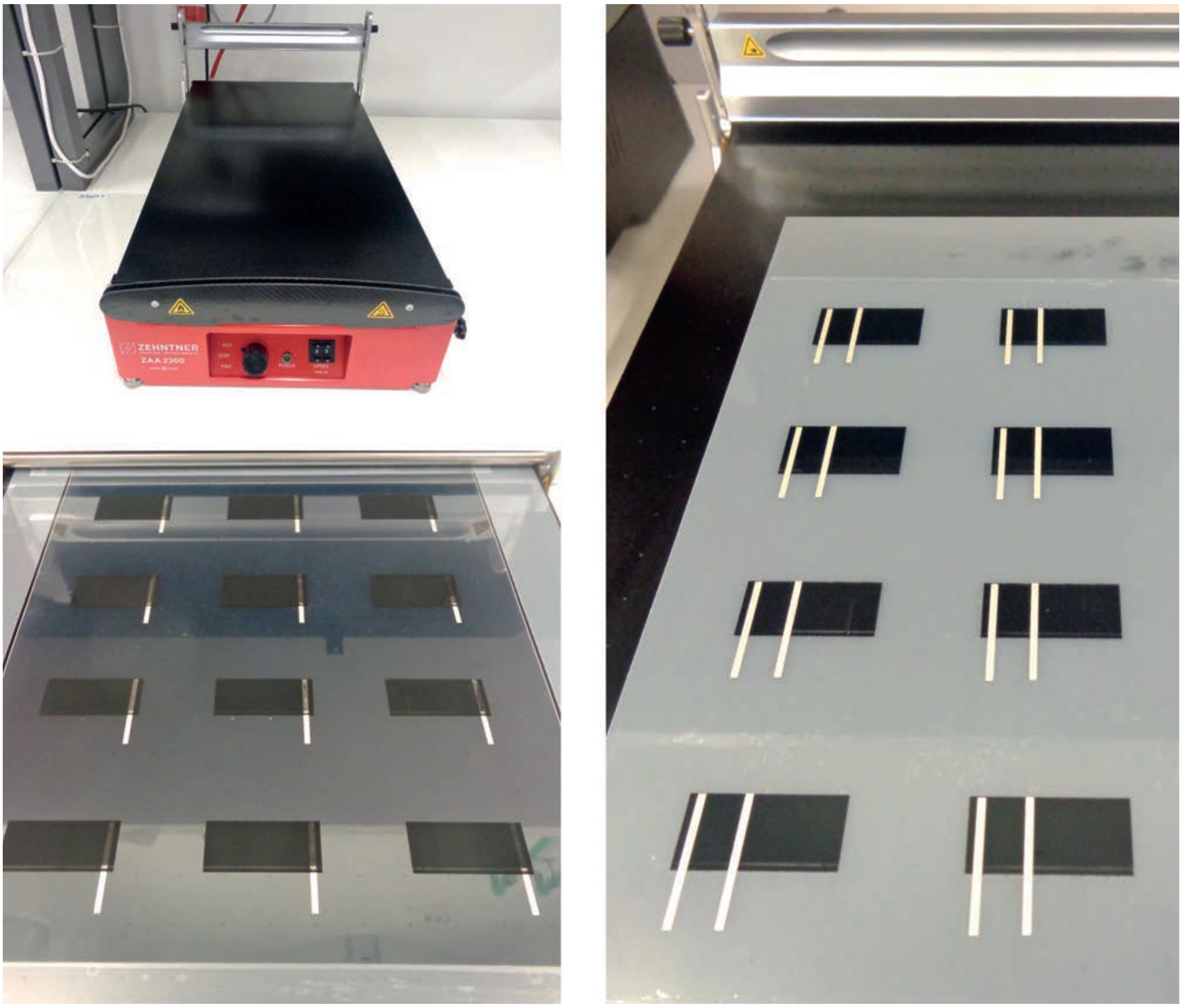
From a National Initiative to a European Network

Originally established as a Swiss collaboration between EPFL, the University of Bern, and the University of Zurich, the Center has progressively evolved into a European research network, with active collaborations in France, Germany, and Belgium. This expansion reflects both the growing relevance of the research topics and the Center's commitment to openness and knowledge exchange.

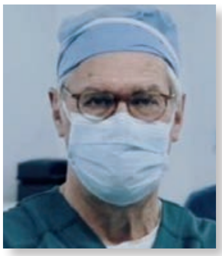


From a Swiss Center to a European network.

Such internationalization brings clear benefits: access to complementary expertise and infrastructure, exposure to diverse scientific cultures, while fostering the accelerated cross-fertilization of ideas. It also strengthens the robustness and visibility of the research, positioning the Center as a reference point for soft actuation and dielectric elastomer technologies in Europe.



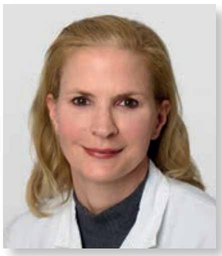
Batch of DEAs during cleanroom manufacturing.



Prof. THIERRY CARREL, University of Zurich

Thierry Carrel graduated from the University of Bern in 1984. He has then received board certification in General Surgery (1990), Cardiac Surgery (1993) and Vascular Surgery (1999). Following training at the University Hospital in Zurich and fellowships in Hannover, Paris, Helsinki and Baltimore, he was appointed in 1999 at the University Hospital in Bern as Chairman of the Clinic for Cardiovascular Surgery and as a Full Professor at the University until 2020. Between 2006 and 2008, he received the lead ad interim of the Clinic for Cardiac Surgery at the University of Basel. Between 2021 and 2022, he was appointed as a Deputy Director ad interim at the University Hospital of Zürich (Clinic for Cardiac Surgery). He is presently consultant for cardiac surgery at University Hospital Basel, Switzerland.

Since the beginning of his career as a surgeon, he has performed around 12'000 general surgeries and cardiac procedures as a surgeon, teacher, or assistant. He has mentored more than 35 surgeons and 12 professorships in Switzerland and abroad. He is the author and co-author of more than 850 peer-reviewed scientific publications (PubMed registered). In 2013, he received the Da Vinci Award of the European Association for Cardiac Surgery as the best teacher in Europe and in 2015 the honorary title (Dr. h.c.) of the University of Freiburg. In the last 20 years, he conducted numerous medical missions in Russia, Morocco, Uzbekistan and Mongolia. Between 2008 and 2020, he was Associated Editor of the European Journal of Cardio-thoracic Surgery and between 2018 and 2020, he was Member of the Board of Directors of the American Association for Thoracic Surgery.



Prof. NICOLE LINDENBLATT, University of Zurich

Nicole Lindenblatt is a Professor ad Personam for Reconstructive Microsurgery at the University of Zurich and serves as the Deputy Director of the Department of Plastic and Hand Surgery at the University Hospital Zurich. She is also the Director of the Zurich Lymphatic Network of Excellence. Her expertise includes peripheral and central lymphatic surgery, robotic microsurgery, pediatric lymphatic surgery, reconstructive and aesthetic facial and breast surgery, and treatments for facial paralysis.

She has achieved several milestones in her field. In 2021, she conducted the world's first robotic-assisted lymphatic surgery using the Symani® Surgical System. In 2023, she performed the first robotic-assisted central lymphatic reconstruction globally.

Her qualifications include becoming a specialist in General Surgery in 2007 and in Plastic, Reconstructive, and Aesthetic Surgery in 2011. She completed a DAFPRS International Fellowship in Facial Plastic and Reconstructive Surgery and a Fellowship in Lymphatic Surgery in Paris in 2013. Since 2015, she has been instrumental in developing Switzerland's first Lymphatic Surgery Program at the University Hospital Zurich, introducing innovative diagnostics, treatments, and patient-reported outcome measurements (PROMs). Between 2016 and 2018, she earned a European Master's degree in Surgical Oncology, Reconstructive, and Aesthetic Breast Surgery from Universitat Autònoma de Barcelona. In 2017, she held a visiting professorship at Memorial Sloan Kettering Cancer Center in New York.

Prof. DOMINIK OBRIST, University of Bern

Dominik Obrist is Professor of Cardiovascular Engineering at the ARTORG Center for Biomedical Engineering Research of the University of Bern. He holds a degree in mechanical engineering from ETH Zurich and earned his doctoral degree in 2000 at the Department of Applied Mathematics of the University of Washington. From 2000 to 2005, he worked for the supercomputer company Cray Inc. In 2005, Dominik Obrist returned to academia as a senior researcher at the Institute of Fluid Dynamics at ETH Zurich, where he established a research group focused on biomedical fluid dynamics. He was appointed Professor of Cardiovascular Engineering in 2013. His main research interests include the design of heart valve prostheses and the development of novel technology for the diagnosis and treatment of microvascular diseases, and he is co-founder of several start-up companies in the MedTech sector.

Prof. FIONA BURKHARD, University of Bern

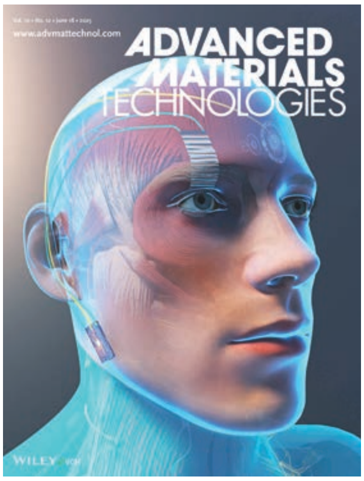
Fiona Burkhard is Associate Professor at the University of Bern and Chair of Functional Urology, including female urology, incontinence, neuro-urology, urological malformations and bladder reconstruction at the University Hospital of Bern. She has a special interest in functional outcome after continent urinary diversion, especially in women. She is past chair of the EAU guidelines on incontinence and past member of the EAU scientific office and EAU School of Urology. Her research is focused on the application of the development of engineering tools to support the function of the urinary tract in collaboration with ARTORG with the urogenital engineering group and molecular mechanisms of bladder dysfunction using integrated omics, big data and machine learning tools to discover novel diagnostics and therapeutics with the functional urology research group.

Prof. JÜRGEN HÖRER, Technische Universität München

Professor Jürgen Hörer is a clinically active heart surgeon carrying out research in the field of surgical treatment of congenital heart disease and risk evaluation. He is/has been coordinator of several international studies investigating the outcome of surgical treatment of congenital heart disease. After completing his medical school at the University of the Saarland, the University Paris VI and University of Bern, he completed his training in cardiac surgery at the German Heart Center Munich where he was deputy director for the congenital program. From 2015 to 2018, he was the head of the Department of Congenital Heart Disease at the Hospital Marie Lannelongue in Paris. In 2018, he was offered the Chair of the newly established congenital and pediatric cardiac surgery at Technical University Munich. He is the director of the Department for Congenital and Pediatric Cardiac Surgery at the German Heart Center and the head of the division for congenital and pediatric cardiac surgery at the University Hospital of the Ludwig-Maximilians-University in Munich. Jürgen Hörer is a member of numerous organizations, including the European Association for Cardio-thoracic Surgery, the European Congenital Heart Surgeons Association, the World Society for Pediatric and Congenital Heart Surgery, the German Society for Thoracic and Cardiovascular Surgery and the Collège Française de Chirurgie Thoracique et Cardio-Vasculaire.

EPFL

Visibility and Influence:
When Science Travels, Speaks, and Brings People Together



The Science That Circulates

The Center's research continues to gain strong visibility through high-impact scientific publications, reflecting both the maturity and the originality of the work. A major highlight of the year was the publication of results on facial reanimation using reinforced dielectric elastomer actuators, which reached the front page of the scientific journal "Advanced Materials Technologies". This distinction underscores the novelty of the approach and its relevance beyond the immediate research community.

- Towards Artificial Muscle Implants: Structured Reinforcement of Dielectric Elastomers. S. Konstantinidi; M. Koenigsdorff; A. O. Salazar; A. Benouhiba; T. Martinez; Y. Civet; G. Gerlach; Y. Perriard. Smart Materials and Structures. 2025. Vol. 34
- Soft Beats: A Dielectric Elastomer-Based Ventricular Assist Device for Next-Gen Heart Failure Management. A. Benouhiba; A. M. Walter; S. E. Jahren; D. Obrist; Y. Civet; Y. Perriard. Advanced Engineering Materials. 2025
- Design and Characterization of an Equibiaxial Multi-Electrode Dielectric Elastomer Actuator. S. Holzer; B. Tiwari; S. M. A. Konstantinidi; Y. Civet; Y. Perriard. Materials. 2025. Vol. 18
- Mechanical characterization and constitutive law of porcine urethral tissues: a hyperelastic fiber model based on a physical approach. Q. De Menech; A. Osorio Salazar; Q. Bourgogne; Y. Civet; A. Baldit; Y. Perriard et al. Biomechanics and modeling in mechanobiology, 2025
- DEyeA: Artificial Muscles for the Restoration of Eye Blinking Following Facial Paralysis. S. Konstantinidi; M. Koenigsdorff; P-J. Martin; A. Benouhiba; Y. Civet; G. Gerlach; Y. Perriard. Advanced Materials Technologies. 2025
- The elastic frontier: dielectric elastomer actuators in healthcare technology. A. Benouhiba; S. Holzer; S. Konstantinidi; Y. Civet; Y. Perriard. Smart Materials and Structures. 2025
- An efficient and compact supply for electroactive polymers. M. Almanza; C. Baron; G. Lan; Y. Wei; Y. Civet; Y. Perriard; M. Lobue. IEEE Transactions on Power Electronics. 2025
- Elimination of Necking and Aspect Ratio Dependence in Uniaxial Actuators by Continuous Fiber Reinforcement. M. Koenigsdorff; S. Konstantinidi; A. Endesfelder; P. Osipov; J. Mersch; M. Vorrath; M. Zimmermann; G. Gerlach; Y. Perriard. Advanced Robotics Research. 2025
- Future innovations for the treatment of facial nerve paralysis. A. Weinzierl; E. Piccinni; S. Kollarik; S. Konstantinidi; Y. Civet; Y. Perriard; G. Pietro; N. Lindenblatt. JPRAS Open. 2025. Vol. 45

The Science That Is Told

Beyond journals, the Center actively engages in oral dissemination, sharing its vision and results through invited talks and keynote lectures. These contributions provide opportunities to contextualize technical achievements, highlight interdisciplinary connections, and engage with broader audiences ranging from academic researchers to clinicians and industrial stakeholders.

- The Artificial Muscle Center: dedicated implant projects for soft robotics, SPIE 2025, Vancouver, Canada, March 2025
- From lab to life: soft actuators in medical innovations, Swiss-Korean Innovation week, Seoul, Korea, May 2025
- From heart pump to face reconstruction: success and challenges in soft actuator implants, Cyborg Futures – the challenge of implanting and integrating artificial muscles, London, England, June 2025
- From heart pump to face reconstruction: success and challenges in soft actuator implants, Zheijiang University, Hangzhou, China, November 2025

© Swiss embassy, Seoul, Korea

The Science That Brings People Together

Andres Osorio, Stefania Konstantinidi, Simon Holzer, Robosoft 2025, Best Demonstrator Award, 2nd Prize.

Conferences, workshops, and live demonstrations remain essential platforms for collective exchange and validation. This year, the Center's work was showcased through interactive demonstrations, allowing audiences to directly engage with functional devices rather than static results. Notably, one of these demonstrations was recognized at Robosoft 2025, highlighting both its scientific relevance and its ability to communicate impact through tangible experience.

- Contractile dielectric elastomer actuators with embedded active and passive structured fibers. S. Konstantinidi; M. Koenigsdorff; S. Holzer; Y. Civet; G. Gerlach, Y. Perriard. SPIE Smart Structures + Nondestructive Evaluation 2025, Vancouver, CA

- Force measurements of planar dielectric elastomer actuators. S. Holzer; S. Konstantinidi; Y. Civet; Y. Perriard. SPIE Smart Structures + Nondestructive Evaluation 2025, Vancouver, CA

- Development and validation of a dielectric-elastomer-based artificial urinary sphincter. Q. De Menech; A. Osorio Salazar; M. Favier; A. Walter; P. Germano; Y. Civet; Y. Perriard. SPIE Smart Structures + Nondestructive Evaluation 2025, Vancouver, CA

- Soft Implants for the Restoration of Facial Movements. Stefania Konstantinidi, Soft Robotic Actuation and Sensing Based on Functional Materials, RoboSoft 2025, Lausanne, Switzerland

What’s next?

The next phase of the research Center will focus on strengthening preclinical validation and advancing system-level integration across its technologies and experimental platforms. For the cardiac application, extended 12-hour *in vivo* studies will be conducted to evaluate device durability, biocompatibility, and physiological interactions under conditions representative of prolonged cardiac support. In parallel, dielectric elastomer actuators (DEAs) will be further characterized under realistic operating conditions, with continued refinement of electrical models as well as the consolidation of the overall system’s architecture to better bridge high-voltage electronics and physiological actuation, therefore moving closer to an integrable and implantable cardiac assist device.

In the area of facial reanimation, recent device modifications will be validated through a new series of experiments on the rat dorsum. Additionally, by leveraging the *in vitro* cell activation platform, activation protocols will be defined and optimized to achieve controlled and reproducible cellular responses—a critical step toward future translational and clinical applications.

They Make It Possible

The progress achieved by the Center for Artificial Muscles would not be possible without the steadfast support of the Werner Siemens-Stiftung. Beyond financial support, the Foundation provides something equally essential: trust, vision, and continuity. Their belief in the Center's mission empowers the team to pursue ambitious research, to bridge disciplines, and to move confidently from fundamental science to *in vivo* validation. The encouragement and engagement resonated deeply with the entire consortium, reinforcing a shared sense of purpose and responsibility toward patients.

We express our sincere and heartfelt gratitude to the Werner Siemens-Stiftung for making this journey possible. Their generosity has enabled the creation of a unique research ecosystem and has been instrumental in demonstrating the potential of soft actuators for medical applications through *in vivo* experiments.

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