Biomimetic implants based on smart materials for severe incontinence treatment

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INTRODUCTION: As a much-needed alternative to conventional fluid-filled sphincter implants [1], one may fabricate biomimetic adaptive sphincters for treating severe incontinence (Fig. 1). Dielectric elastomer actuators (DEA) offer key advantages for the construction of an artificial sphincter, such as millisecond response times and power-to-mass densities similar to natural muscles. The realization of stacked, sub-micrometer thin DEA operating at medically acceptable voltages will open the way for smart implants that utilizes the ability of DEA to operate as actuator and sensor. Such a sphincter implant can actively monitor and adapt the closing pressure to the patient's activities.

METHODS: Molecular beam deposition (MBD), electrospray deposition, and spin-coating were used to fabricate single- and multi-layer DEAs from silicones. A layer of DMS-V05 in the sub-micron range (for MBD and electrospray) is deposited between two gold layers. These layers were typically 30 nm thick and fabricated by either sputtering or MBD onto a 50 µm-thick PEN substrate. The resulting asymmetric cantilevers (Fig. 1, top left) are tested for actuation properties. Alternatively, the sub-micron layer of DMS-V05 is replaced by a spin-coated 5 µm-thick layer of Elastosil. The electrode-elastomer-electrode units were stacked to create multilayer DEAs.

RESULTS: We have observed reliable actuation in spin-coated multilayer DEA, showing that at an elastomer layer thickness of above 1 µm a functional actuator can reliably be fabricated [2]. Below 1 µm, the surface microstructure of each layer plays a critical role in determining electrical conductivity and material adhesion, making it a challenge to achieve reliable actuation with both MBD and electrospray in this regime [3]. For MBD fabricated samples, we have observed initial indications of an actuation response, however the failure rate is still high. One key to success appears to improve the compatibility between the metallic and polymeric, i.e. mechanically stiff and soft layers of the actuator, so as to preserve the structural and mechanical integrity of the stacked structures.

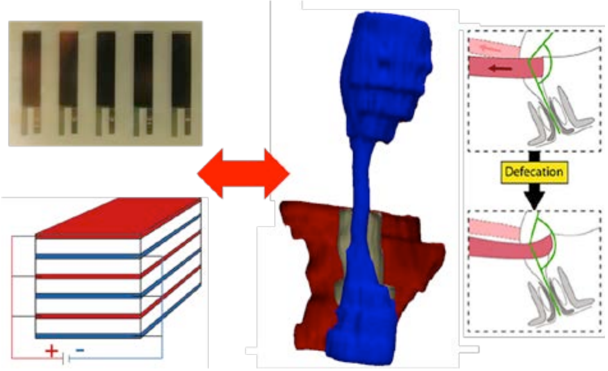

Fig. 1: Stacked actuators prepared from silicones with sensing capabilities (left) offer a biomimetic solution to treat severe incontinence. In this manner, the new implant actively adapts to the complex anatomy and function of the natural sphincter (right). A functional lumen imaging probe (FLIP) image shows the irregular shape of the internal (yellow) and external (red) anal sphincters. Defecation is accompanied by an angular modification of the rectum by the puborectal sling.

DISCUSSION & CONCLUSIONS: Biomimetic sphincter implants require engineered smart materials with actuation and sensing capabilities. The use of sub-micron stacked silicones and conducting layers for sphincter implants relies on a combination of sophisticated fabrication methods. The most effective means of fabrication depends on parameters including deposition rates, structural integrity, conductivity and above all mechanical stiffness.

REFERENCES: [1]E. Fattorini, T. Brusa, C. Gingert, et al. (2016), Annals of Biomedical Engineering, doi: 10.1007/s10439-016-1572-z. [2]M. Karapetkova (2016), Masters thesis, ETH Zürich. [3]V. Leung, E. Fattorini, M. Karapetkova, et al. (2016), Proc. SPIE 9797-21 in Bioinspiration, Biomimetics, and Bioreplication VI.

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