Biodegradable piezoelectric force sensor for monitoring biological pressures

Eli J. Curry and Thanh D. Nguyen
University of Connecticut

Statement of Purpose: Monitoring of bio-physiological pressures such as intra-articular pressure, intra-abdominal pressure, intra-cranial pressure etc. is important to prevent dangerous internal force built up in diseased/impaired organs, and enable novel approaches of using mechanical stimulation for tissue regeneration. Pressure sensors are often required to be directly implanted with native soft tissues and organs, therefore they should be flexible and at the same time, biodegradable to avoid any invasive removal surgery. There has been recent achievements of biodegradable force sensors which are based on either Silicon piezo-resistive probe or capacitive biopolymer[1, 2]. The former has to depend on exotic electronic materials including Silicon and Silicon dioxide which have not been confirmed to be completely degradable and safe for use inside human body. The latter has large dimensions and requires expensive clean room facility for micro-fabrication process. In both of the cases, the force sensing mechanism relies on passive materials which need to be electrically powered. *Here, for the first time, we present a biodegradable piezoelectric force-sensor which only relies on medical biopolymers used commonly in many FDA-approved erodible implants to monitor biological force.*

Methods: We employed thermal annealing and mechanical drawing to create a highly piezoelectric poly-l-lactide polymer (PLLA) which could convert mechanical deformation into electricity and vice versa. The PLLA was folded into multi-layer (Fig. 1a) to increase the conversion efficiency and incorporated with Molybdenum electrode and layers of encapsulating Poly-lactide (PLA), forming a completely biodegradable pressure sensor with an entire size of only 5 x 5 x 0.2 mm in x, y and z (Fig. 1b).

Results: We showed this device could response to tiny force (down to a 100 gram or 1 N/cm^2) to self-generate charge. The charge was then amplified and integrated through a circuitry to output a voltage pulse as seen in Fig. 1c. We have shown the sensor was able to sensitively detect a wide range of pressure from 1 – 18 kPa (Fig. 1d), which is relevant to many biological pressures (e.g. intracranial pressure of ~ 1 – 7 kPa). With an encapsulation of 100 µm PLA, the sensor can sustain its performance inside PBS solution for 1.5 days (Fig. 1e right). Optical image (Fig. 1e left) shows the sensor's shape is retained after 1.5 day while after 30 days, the sensor exhibited an obvious degradation. Finally, we implanted this sensor into a thorax of a mouse model and demonstrated the sensor's ability to monitor thoracic pressure from movement of diaphragm (Fig. 1f). This sensor can be used for detecting respiratory disorder from obstructive pulmonary diseases.

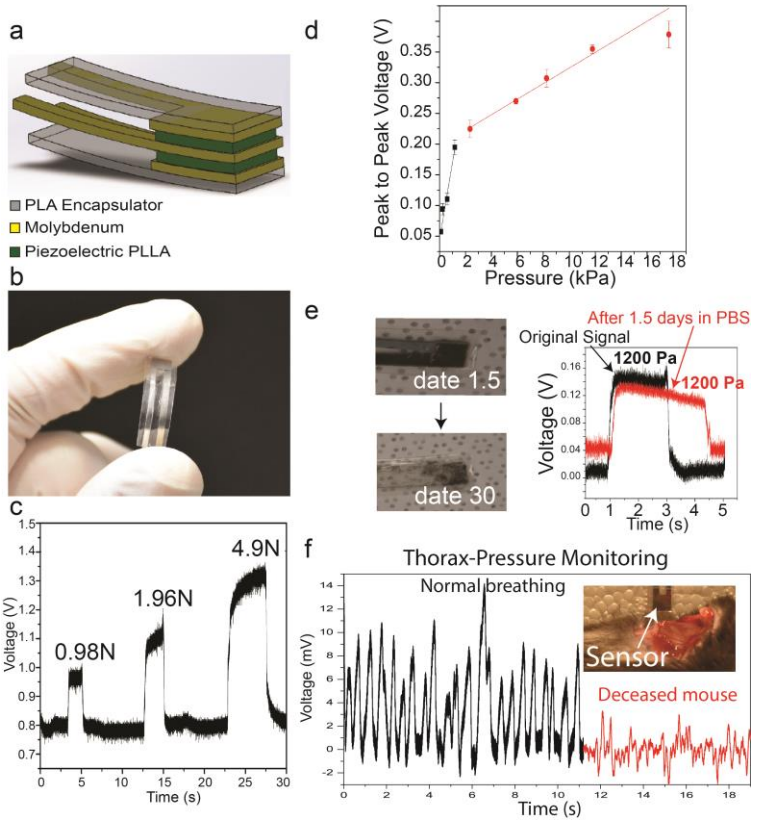

Figure 1. Biodegradable piezoelectric pressure sensor. **a.** Schematics to describe multi-layer piezoelectric sensor. **b.** Optical image of the fabricated sensor (5 x 5 x 0.02 cm). **c.** Response of the sensor to different applied static forces. **d.** Calibration on the sensor's voltage response to different applied forces. **e.** Degradation study (right panel) shows the same responses of the sensor after 1.5 days submerged inside a phosphate buffered saline (PBS), while optical images (left panel) shows the sensor after 1.5 days and 30 days submerged in PBS. **f.** Thorax pressure, measured by the PLLA sensor, in anesthetized mouse at normal condition and after the animal was deceased. Insert image shows the sensor right before implantation into the mouse thoracic diaphragm.

Conclusions: As such, we believe this novel biodegradable piezoelectric sensor offers an extremely useful tool to monitor important biological pressures. The sensor could be also integrated with tissues and organs, forming a bionic self-sensing systems which could enable many applications in regenerative medicine, drug delivery, and medical devices.

References: 1. *Nature* **2016,** 530, (7588), 71-76; 2. *Adv. Mater.* **2015,** 27, (43), 6954-6961. **Acknowledgement**: APP Uconn & NIH Trailblazer Award 1R21EB024787.