INTRAOCULAR PRESSURE SENSORS: NEW APPROACHES FOR REAL-TIME INTRAOCULAR PRESSURE MEASUREMENT USING A PURELY MICROFLUIDIC CHIP

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ABSTRACT

Periodic monitoring of intraocular pressure (IOP) values is crucial in glaucoma treatment. Since current measuring techniques lack accuracy, a microfluidic device is designed, tested and discussed in this work to explore unpowered IOP sensing capability. This device achieves a 0.061mm/mmHg sensitivity for lower pressures and a 0.667mm/mmHg for higher pressures.

KEYWORDS

Pressure sensor, intraocular pressure, glaucoma, microfluidics, implantable devices.

In this work, an approach for the monitoring of intraocular pressure (IOP) using a manometer-based microfluidic device is described. This device was designed for periodic monitoring of IOP in patients suffering from glaucoma. The current state-of-the-art IOP measurement technique, a tonometer, lacks accuracy due to unpredictable scleral compliance and variable cornea stiffness between patients. Therefore, a novel approach for IOP measurement is required. In the past few years, MEMS-based sensors have been researched but none are passive, they all require external power supply and involve a complex design. For example, an IOP sensor based on capacitance measurement proposed by Wise [1] and Irazoqui [2] can actively record IOP value, but need a solar battery or wireless charging to fulfill the power requirements. Piezoresistive IOP sensors [3], on the other hand, have shown an inability to integrate an antenna and a battery together and thus are not preferred. Tonometers [4] have been modified to use a soft contact lens to measure the cornea deformation, but the reasons for their inaccuracy have not been resolved.

However, mechanical IOP sensors using no battery or antenna may simplify the design and lower the cost as proposed by Tai et al. [5]. This IOP sensor is based on a Bourdon Tube and can be implanted suturelessly through the cornea and mounted on the iris securely. The bulky nature of this approach however may block incoming light through the pupil at night. Our work instead is based on a manometer-based microfluidic pressure sensor with an optical readout (Figure 1).

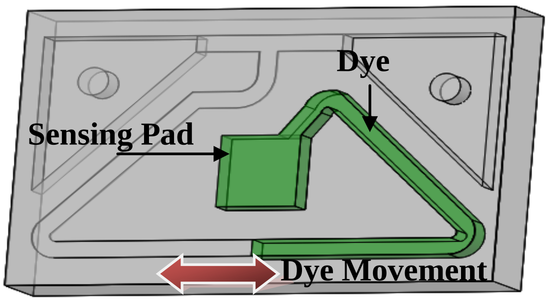

Figure 1 Sketch of the microfluidic IOP sensor and corresponding dye movement

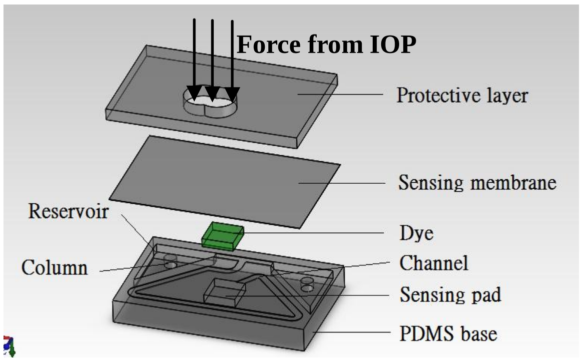

Figure 2 Exploded view of the microfluidic IOP sensor and the direction of the applied force on the IOP

This paper reports design and fabrication of this IOP sensor that can be implanted between the conjunctiva and the sclera. The principle for this sensor is similar to a manometer and involves a dye solution in a small reservoir (pressure sensing pad) covered with a flexible membrane, as shown in Figures 1 and 2. Elevation in IOP results in pressing of a thin membrane that in turn pushes dye solution out of the sensing pad and into a microchannel with smaller cross-section. Figure 3 shows this IOP sensor with a slice of swine conjunctiva. The sensor prototypes were fabricated using PDMS and indocyanine green/AK-Fluor as the dye used to facilitate optical readout of the pressure as shown in Figures 4 and 5. The movement of sensing dye corresponding to a change in pressure can be measured and calibrated to monitor IOP, as shown in Figure 6. The change in cross-section between sensing pad and microchannel helps amplify the dye movement thus improving the sensitivity. This paper will also illustrate how to minimize the effect of trapped air in the channel. The batch testing data showed low hysteresis and a sensitivity of 0.061mm/mmHg for the dynamic range between 0-22mmHg. It also showed a higher sensitivity of 0.667mm/mmHg with the range of the device closely matching that expected for glaucoma patients. The higher sensitivity in the latter gives better signal interpretation for the IOP sensing as it was needed. The sensor characterization was done using optical coherence tomography and Image J for a sensor “implanted” in an artificial eye model.

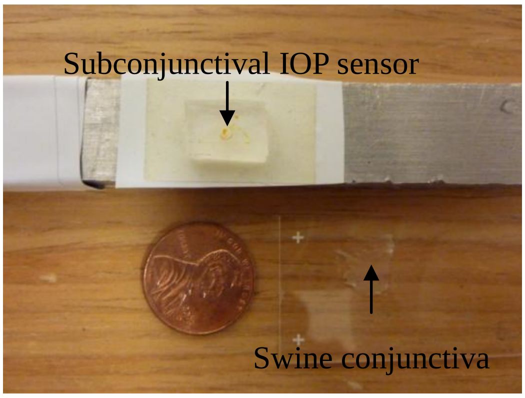

Figure 3 A subconjunctival IOP sensor and a swine conjunctiva versus a penny

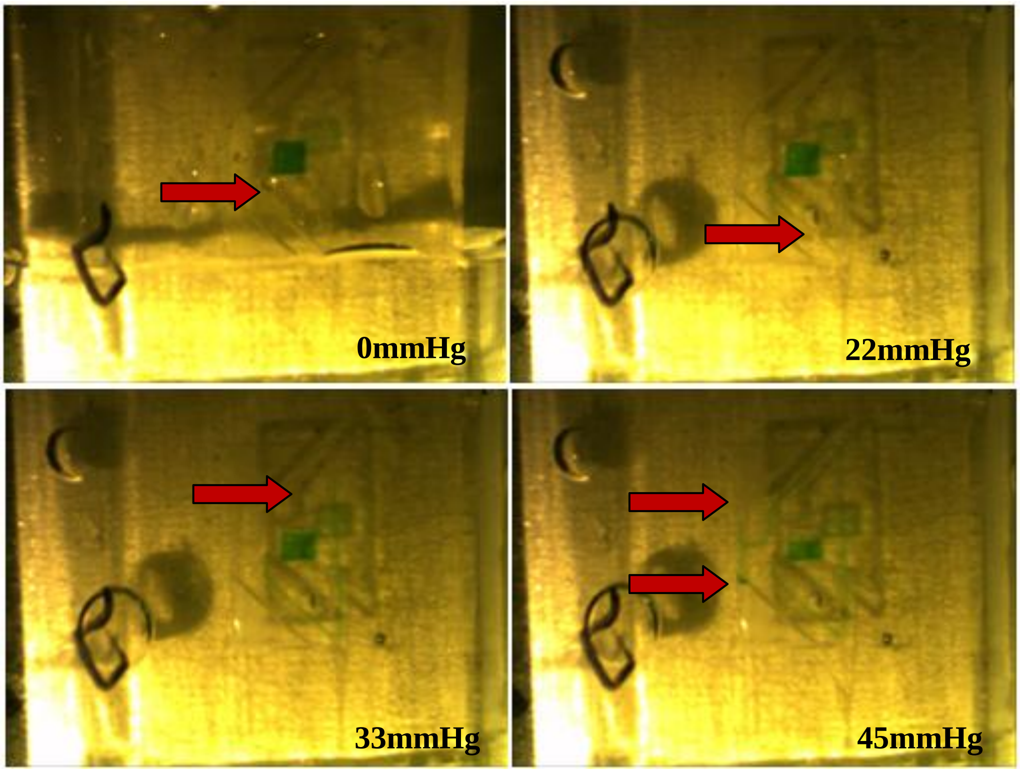

Figure 4 Amscope image of the subconjunctival IOP sensor with IC-green dye under 0.

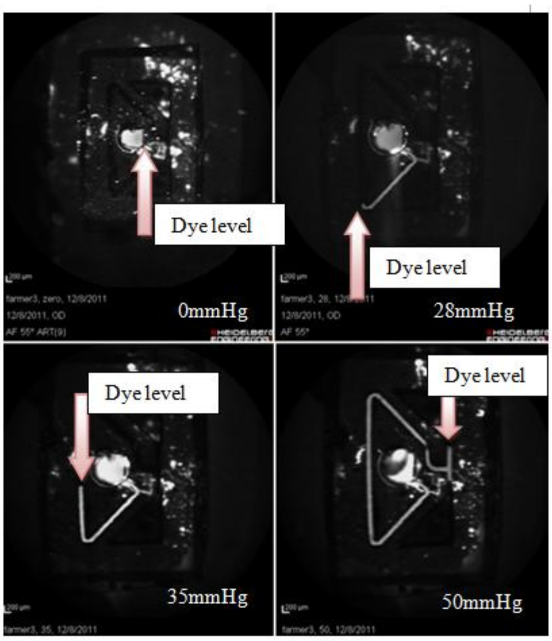

Figure 5 AK-Fluor dye movement under 0, 28, 35 and 50mmHg relative pressure. Recorded through an optical coherence tomography.

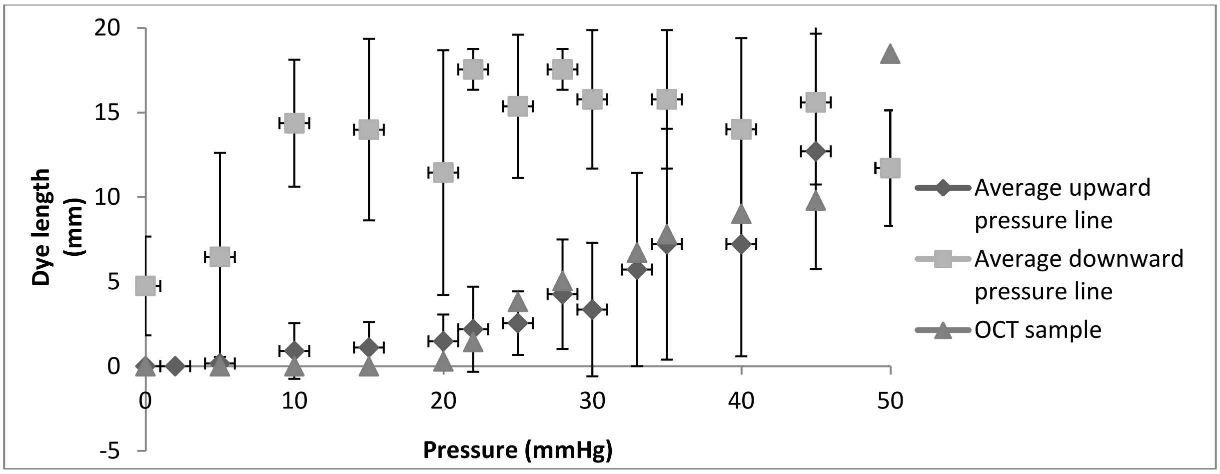

Figure 6 Dye length versus applied hydraulic pressure: OCT sample versus average dye length for both upward and downward pressure

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