Compartment Syndrome Detection through pH

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Abstract

Acute compartment syndrome (ACS) is a complex condition in which trauma causes increased pressure in a muscle compartment, which can lead to muscle ischemia and death. Current methods of ACS diagnosis are often inaccurate, with pressure-based diagnosis reaching a rate of 35% false-positive in one study. False-positive ACS diagnosis results in unnecessary fasciotomies, which are invasive and expensive procedures. More recent methods of ACS diagnosis continue to suffer from inaccuracy and a lack of supporting literature. Iridium Oxide (IrOx) wire electrodes are a new option to detect acidic environments indicating muscle ischemia. When paired with and Ag/AgCl reference, they generate a voltage that can be measured and converted to pH.

Problem Definition

- Current methods of diagnosis, such as pressure or oxygen measurement, are inaccurate or expensive
- pH diagnosis has been shown to be accurate and can likely be implemented more cheaply
- IrOx wire electrodes detect pH by generating voltage
- IrOx and Ag/AgCl reference can be paired and inserted in insulative tubing for needle-facilitated delivery into tissue

Figure 1: *Fasciotomy of the right arm [1].*

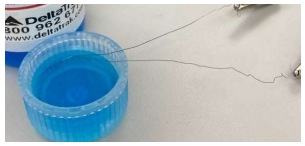


Figure 2: *IrOx and Ag/AgCl in pH buffer solution*

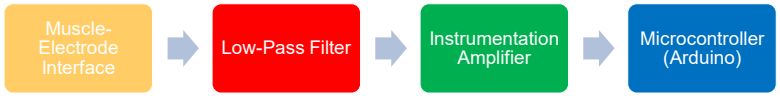
Design Specifications

Function:
- Create a device capable of measuring intramuscular pH in vivo associated with ACS (pH 5 to 7)
- Able to record at least 48 hours of pH measurements
- Minimally invasive pH sensing device

Size:
- The device should fit inside an 11-gauge and 16-gauge needle for testing with pigs and humans, respectively.
- Length of 3-6 cm to reach deeper muscle

Accuracy:
- The device should read the pH with an accuracy of 0.5 pH units

Circuitry Flow Chart and Equivalent Circuit



- Muscle-Electrode interface has the equivalent circuit model in Figure 4 (values obtained from Blau et. al.) [2].
- This voltage signal is then put through a low-pass filter to remove ambient (60 Hz) noise as the pH signal should have frequency near zero.
- This filtered signal is then amplified via an instrumentation amplifier with a gain of 15 V/V (23.5 dB) before being passed into the Arduino.

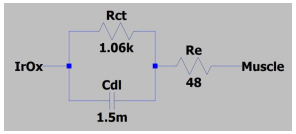


Figure 4: *LT Spice Schematic of the Iridium Oxide Electrode's equivalent circuit. Rs is the physiological saline resistance (Ω), Rct is the charge transfer resistance (Ω), Cdl is the double layer capacitance (F). Circuit element values from [2]*

IrOx vs Ag/AgCl Drift Testing

- Electrodeposited Ag/AgCl electrode relative to the ISFET pH electrode kit [3]
- Electrodeposited IrOx electrode relative to Ag/AgCl electrode
- To determine the length of time before each electrode type began to break down
- Each electrode was calibrated by creating a linear regression of the voltages it measured with the ISFET at pH 4, 7, and 10
- Each electrode was left in pH = 4

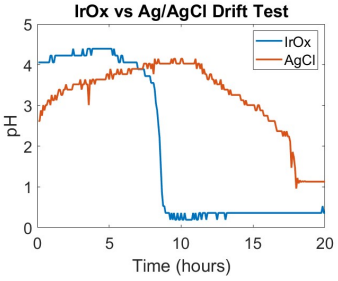


Figure 5: *pH drift of each Ag/AgCl electrode relative to ISFET and IrOx electrode relative to Ag/AgCl in pH 4*

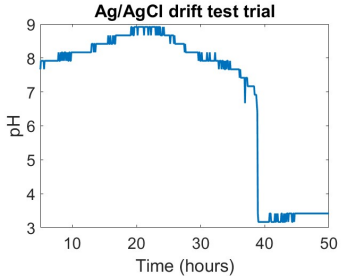


Figure 6: *Example of a different Ag/AgCl + ISFET drift trial (pH 7 in this case). Average of 7.57 pH with standard deviation of 0.162*

Table 1: *Standard deviation of measurements acquired from each electrode drift test in pH 4 solution.*

Electrode	Calculated Std Dev
IrOx	0.181
Ag/AgCl	0.334

IrOx Electrodeposition

Fabrication steps of IrOx electrode through electrodeposition [5]:

1. Set up Pt-Ir working electrode with Pt-Ir counter electrode, and Ag/AgCl reference electrode in electrodepositing solution.
2. Vary triangular waveform from 0 to 0.55 V at 50 mV/s for 50 cycles using potentiostat.
3. Apply pulse 0 to 0.55 V square wave at 0.5 s interval for up to 1600 cycles.

Figure 7: *IrOx and Ag/AgCl electrodes inserted into tube and needle.*

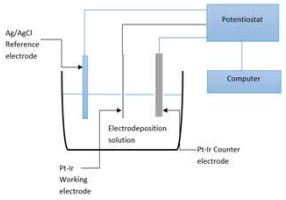


Figure 8: *Setup of IrOx electrodeposition*

Conclusion and Future Work

- Preliminary cadaver testing showed that an improved delivery method is required.
- Drift testing determined an improved electrodeposition protocol must be designed.
- Fabricate a design with electrodes on the outside of a catheter to increase solution contact. See figure 9 [4]
- Fabricate better electrodes.
- Construct a user interface.
- Perform animal testing with induced compartment syndrome.

Figure 9: *Four step process for electrode delivery (a) typical catheter (b) Adhesive coating (c) Electrodes adhered to catheter (d) Insulating layer*

References

[1] C. Doro, private communication, Sep 2019.
[2] A. Blau et al., "Characterization and optimization of microelectrode arrays for in vivo nerve signal recording and stimulations," Biosensors & Bioelectronics, vol. 12, no. 9–10, pp. 883–892, 1997.
[3] Winsense. "ISFET pH Sensor Kit," 2013. [Online]. Available: http://www.winsense.co.th/item/item_1.html
[4] J. Park, W.-M. Choi, K. Kim, W.-I. Jeong, J.-B. Seo, and I. Park, "Biopsy Needle Integrated with Electrical Impedance Sensing Microelectrode Array towards Real-time Needle Guidance and Tissue Discrimination," *Scientific Reports*, vol. 8, no. 1, Oct. 2018.
[5] R. D. Meyer, S. F. Cogan, T. H. Nguyen, and R. D. Rauh, "Electrodeposited iridium oxide for neural stimulation and recording electrodes," IEEE Trans. Neural Syst. Rehabil. Eng., vol. 9, no. 1, pp. 2–11, Mar. 2001, doi: 10.1109/7333.918271.

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