Compartment Syndrome Detection through pH

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Client: Dr. Christopher Doro Advisor: Dr. Amit Nimunkar

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. However, Ion-Sensitive-Field-Effect-Transistor (ISFET) pH sensors are a new option to detect acidic environments indicating muscle ischemia, which we will be implementing and miniaturizing.

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
- ISFETs are small pH-sensitive electrodes which can be used in said implementation
- Reference electrodes are needed to accompany the ISFET (or other pH-sensitive electrode) but are much larger

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

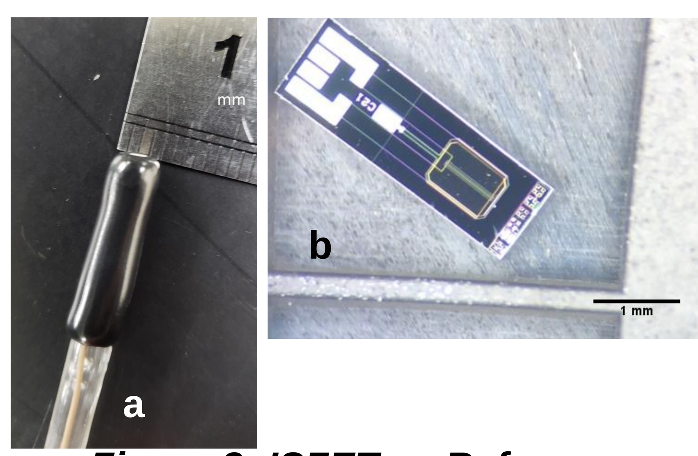

***Figure 2:* ISFET vs Reference Electrode.** *(a) Commercially available reference electrode. (b) ISFET bare die.*

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 dogs and humans, respectively.
- 3-6 cm in length to extend reach to deeper muscle

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

Final ISFET Apparatus

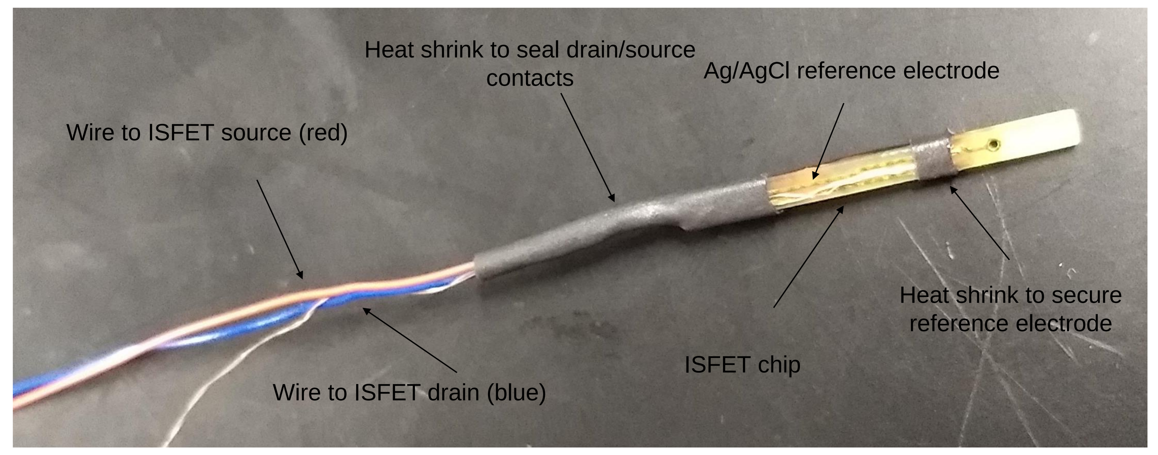

Figure 3: *ISFET probe with electrodeposited Ag/AgCl reference electrode attached. Sealed with heat shrink to minimize drain/source wire corrosion.*

Figure 4: *Analog front end [2] to acquire scaled voltage signal from ISFET*

- Electrodeposited Ag/AgCl reference electrode attached with heat shrink to ISFET
- Measure voltage across drain and source from analog front end
- Calibrate using linear regression to determine pH equation

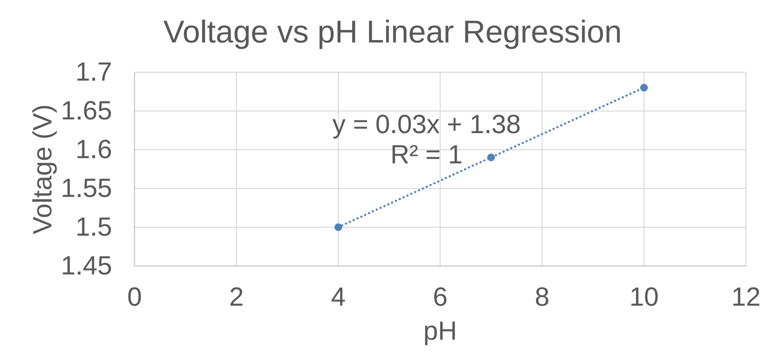

Figure 5: *Linear regression from electrodeposited reference electrode and ISFET*

ISFET pH Sensor Drift Testing

- Three Ag/AgCl reference electrodes: One from an ISFET pH electrode kit [2], one 450-micron diameter micro electrode [3], and one which we fabricated using electrodeposition of KCl on Ag wire
- 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 = 7 solution and the drift from neutral pH voltage reading was observed to determine variance over time (1 hour)

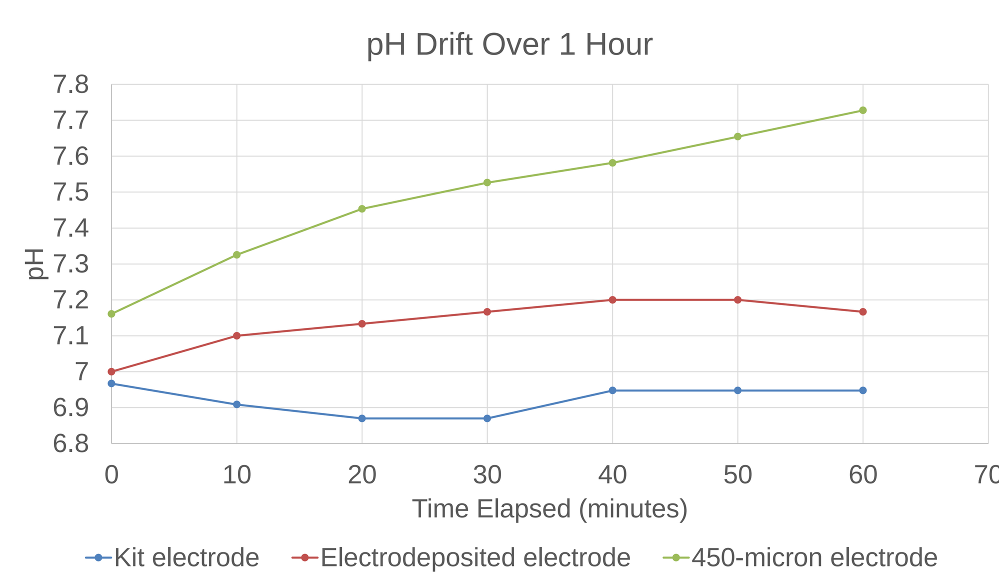

Figure 6: *pH drift of each reference electrode with the ISFET over one hour*

Reference Electrode	Calculated Std Dev
Kit	0.04
Electrodeposited	0.07
450 micron	0.20

Table 1: *Standard deviation of measurements acquired from each electrode drift test*

- The kit and electrodeposited electrodes demonstrated the lowest standard deviation; however, the electrodeposited electrode is much smaller in diameter and can be extended to a more optimal length (3-6 cm)

References

[1] C. Doro, private communication, Sep 2019.
[2] Winsense. "ISFET pH Sensor Kit," 2013. [Online]. Available: http://www.winsense.co.th/item/item_1.html
[3] World Precision Systems. "Micro Dri-Ref Reference Electrode." [Online]. Available: https://www.wpiinc.com/driref-450-micro-dri-ref-reference-electrode

Ag/AgCl Electrodeposition

Fabrication steps of Ag/AgCl electrode through electrodeposition:

1. A thin (anode) and thick (cathode) Ag wire are prepared and rinsed with ethanol to remove finger oils.
2. 3M of KCl (22.3g) solution made with 100 ml of distilled water and stirred.
3. The thin and thick wires are immersed in the KCl solution and connected to positive and negative terminal, respectively.
4. 1.5 V is passed through the circuit for 10 minutes until the thin Ag wire changed to purple-black color.
5. The fabricated Ag/AgCl wire is wiped and stored.

Figure 7: *Fabricated Ag/AgCl wire alongside a human hair*

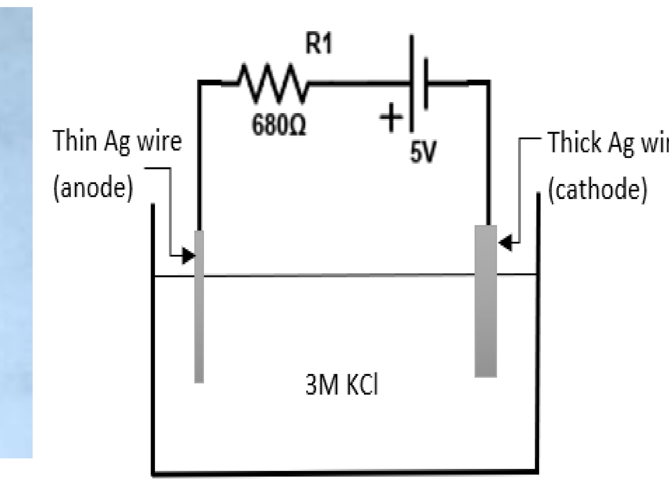

Figure 8: *Setup of Ag/AgCl electrodeposition*

Future Project Development

- Minimize to 16-gauge needle from an 11-gauge needle
- Fabricate and test Non-ISFET, IrOx based design

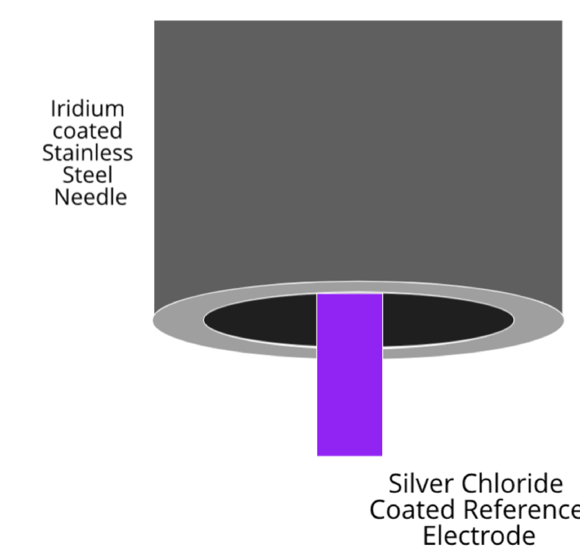

Figure 9: *Design for a Non-ISFET pH needle*

- Fabricate user interface
- Test in canine subjects
- Perform a 48-hour drift test

Acknowledgements

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