Compartment Syndrome Diagnostic Probe
Design Matrix

Team Members: William Bacon, Heather Barnwell, Alex Goodman, Kristina Geiger, Carly Rogers
Client: Dr. Christopher Doro
Advisor: Professor Walter Block

Introduction

In order to detect the presence of acute compartment syndrome within a patient, we evaluated three different biomarker sensor devices: a pH sensor, a glucose sensor, and a sodium conductance sensor. The devices were weighed on various criteria including accuracy and precision, ease of analysis, safety, ergonomics, ease of fabrication, cost, and reusability. The goal of this project is to create a diagnostic tool that accurately, continuously, and easily quantifies a biochemical marker associated with acute compartment syndrome. The intramuscular probe will be designed for our client, Dr. Doro in the orthopedic trauma clinic.

pH Probe

The pH probe design relies on inserting a needle with a calibrated pH sensor into the muscle. There is one probe measuring a buffer solution to calibrate the analyzer. The other probe will be inserted in the compartment to gather a reading. The main analyzing box will then allow the nurse to read the pH of the compartment to determine if the compartment has a dangerously low pH which is cause to determine compartment syndrome.

Glucose Probe

The glucose probe design relies on two relative glucose measurements. Since glucose levels in the body can alter based off of many factors, such as time since eating and diet, this relative reading system will eliminate the need for a set threshold. For example, if a patient were to come in after breaking one fibula, an 18G needle will be inserted into the muscle of the healthy calf and another in the injured muscle in question. These two 18G needles will be attached at the microcontroller and a differential in the values would help to diagnose compartment syndrome. This will be a continuous monitoring system, and glucose sensors already exist for the diabetic industry.

Sodium Conductivity Technology

In a compartment deprived of blood, the sodium levels will increase. By using a variation on ion selective conductivity technology, we would be able to measure the increasing ion conductivity in the muscle. This electrode would consist of two prongs inserted into the compartment and measure the flow of sodium between them. If the the reading is an unreasonably high conductivity, then it is appropriate to state that there is compartment syndrome in the patient. There are already electrode probes available, but not exactly specific for measuring sodium in the body.

Criteria (Weight)	**pH Probe**		**Glucose Probe**		**Sodium Conductivity Technology**	
Accuracy and Precision (25)	4	20	5	25	1	5
Ease of Analysis (20)	2	8	5	20	2	8
Safety (20)	2	8	4	16	4	16
Ergonomics (15)	3	9	5	15	5	15
Ease of Fabrication (10)	4	8	4	8	5	10
Reusability (5)	2	2	3	3	2	2
Cost (5)	3	3	4	4	3	3
Total	58/100		91/100		59/100	

Table 1: Design matrix comparing potential devices including pH probe, glucose probe, and sodium conductivity technology. The total numbers are out of 100, and the highest number represents the most feasible option with regards to the criteria.

Accuracy and Precision

This ranking carries the most weight considering the current limitations of compartment syndrome diagnosis include generating false-positives via oxygen pressure measurements. Our new device must replace this current standard of diagnosis by quantifying a novel biochemical marker. Because various biomarkers may correlate different with acute compartment syndrome, it's crucial we select the one that's the most consistent across patient populations, easiest to detect via probe, and is homogenous within a compartment. The glucose sensor scored the highest in this category because it relies on relative measurements within the patient, so individual discrepancies are factored out and there is no need for a threshold value.

Ease of Analysis

Refers to how easily this device is able to read and report data as well as ease of calibration and continuous use. The nurse or doctor should ideally be able to continuously monitor the chosen biomarker level without performing additional, time-consuming steps. The glucose probe received the highest score in this category because there are pre-existing glucose monitors that are capable of providing continuous, digital read-outs of glucose levels within the body.

Safety

Refers to the current standard of care and how comfortable the patient will be during the use of the probe, as well as the safety of the nurse. In current method for determining if a patient has compartment syndrome the nurse uses an eighteen gauge needle. It is required our new probe is up to or exceeding the current standards. The new probe should also be comfortable for the patient to have inserted into their compartment. Lastly, the nurse needs to be able to safely insert the probe into the patient without causing harm to their own body. The glucose probe received the highest score because of the ability to use a small needle, however there were concerns with using two needles and possible entanglement. The sodium conductivity technology was given the same score because similar technology is in use, but it requires two entry points.

Ergonomics

Refers to the ease and efficiency of use of the device. The doctor should be able to make this reading quickly and insert the needle with one hand so that the patient can be secured with the other. The device should be small and be able to be operated by one trained professional in the ER. The glucose probe and the sodium conductivity electrodes received the same score, they both require two needle insertions but they are relatively small needles and the operator should already have experience.

Ease of Fabrication

Refers to how easily our design team will be able to fabricate the sensor. The sensor will likely be composed of a probe that will be inserted into the patient and an analyzer that will read the measurements from the probe. Our team must be able to either buy or fabricate these two components using our current skill set. We will have access to the student shop. The sodium conductivity sensor received the highest score because we would be able to purchase all materials necessary for the sensor making fabrication as simple as connecting the parts together.

Reusability

Refers to the device having a main analyzation system that is able to be used repeatedly while the sterile sensing probes are disposable. The glucose probe was awarded the highest value in the reusability category because the computing boxes can be reused, and the needles will be relatively cheap and disposable.

Cost

Refers to the ability of the device to be tested and fabricated under the restrictions of a reasonable budget. The disposable piece should be very cheap to buy, and the reusable part of the design should be of reasonable price. The glucose probe received the highest score since continuous glucose probes can be found for under $100. The disposable needles to be used with such a probe would also be quite cheap.

Final Evaluation

After evaluating the final design matrix, we concluded that the relative measurements from the glucose probe would be the best option. It excelled in almost all of the categories and will offer the operator freedom with individual patient reading and continuous monitoring. It involves an easy application of two 18G needles, and similar technologies already exist in medicine. Calibration should be negligible because the difference in the readings should offer all of the needed information to diagnose compartment syndrome. A downfall of this device could include if a patient came in with multiple injuries where a reference measurement is not possible.