MitoSensor:

A lightweight and wearable sensor that can detect cell signaling, galvanic cell response and mitochondrial toxicity/dysfunction at the cellular level and relay the information back in a timely manner.

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Executive Summary

Mitochondrial dysfunction is caused by toxins disrupting the ATP and reproduction processes of mitochondria, the powerhouse of the cells. When mitochondrial homeostasis is disrupted, illness prevails. Once mitochondria enter hyperactive, or stunted glycolysis, the cell cycle becomes unbalanced, causing non-homeostatic programmed cell death. Mitochondria are the key to cellular function and theoretically should be the primary indicator of the presence and progression of diseases. Human epidermal cells have stem cell properties, but can be obtained with non-invasive means for culturing purposes. These cells produce microvolts from the ATP production cycle and are an indicator of deviation from homeostasis. Documenting this mV change can produce a database of cellular conductivity in the presence of numerous stressors and stimuli to gauge mitochondrial function and dysfunction. This, in theory, can be used to build an early indication system of disease.

The first phase of this project was dedicated to building a database. The second phase of this project was dedicated to seeing if the conductivity of cells that are stressed by toxins will increase due to an immune response and the viable cells' attempt to work harder against the toxin and to build a sensor that could read these changes in conductivity. Both phases were completed through laboratory experimentation over several years. At this point, or in the third phase, we are solely working on the model that supports the theory behind this project from both a visual and data processing aspect. The model was completed using NetLogo and will continue to be added to as further research is conducted and data is gathered.

Background Research-Fast Facts

Mitochondria: A double membrane-bound organelle found in all eukaryotic organisms. Mitochondria generate most of the cell's supply of adenosine triphosphate (ATP), used as a source of chemical energy

Mitochondrial Toxicity: Condition in which the mitochondria of a body's cells become damaged or decline significantly in number; it commonly occurs as a side effect of certain antiretroviral drugs.

Cellular Respiration: A set of metabolic reactions and processes that take place in the cells of organisms to convert biochemical energy from nutrients into adenosine triphosphate (ATP), and then release waste products such as carbon dioxide.

Epidermal Cells: The cells that are on the surface of the skin, the outer organ that encases the rest of the bodies' organs.

Galvanic Skin Response/Electrodermal Activity: It is a property of the human body that causes a change in the electrical resistance of the skin caused by some sort of stress.

Cell Signaling/Cell Voltage Change: A chemical response method in which one cell sends information to another cell through potassium positive and sodium positive pathways.

Cell Cycle: Series of events that take place in a cell leading to its division and duplication of its DNA to produce two daughter cells.

Programmed Cell Death: There are three types of cell death including, apoptosis, autophagisis, and necrosis. Each has a varying degree of "idleness."

Multimeter: Instrument designed to measure electric current, voltage, and resistance.

Janus Green B: Dye that detects the health of the mitochondria by changing different shades of green. When the mitochondria is working anaerobically the dye is pink.

Rhodamine: Dye that tests cell viability

Ciprofloxacin: Very commonly prescribed to fight against most strains of bacterial pathogens responsible for respiratory, urinary tract, gastrointestinal, and abdominal infections.

Penicillin: Used only for the treatment of mild to moderate infections, and not for severe or deep-seated infections.

Streptomycin: Used against infective endocarditis caused by enterococcus when the organism is not sensitive to Gentamicin, Tuberculosis, Plague and Tularemia infections.

Tetracycline: Commonly used against skin conditions. It is useful against the majority of high level illnesses, infections and parasites

Vancomycin: Used in infections where antibiotic resistance to other antibiotics are prevalent.

Osha: Used for sore throat, bronchitis, cough, common cold, influenza, swine flu, and pneumonia.

Rosemary: Used for digestion problems, including heartburn, intestinal gas (flatulence), liver and gallbladder complaints, and loss of appetite. It is also used for gout, cough, headache, and high blood pressure.

Cayenne Pepper: Consumption dilates the blood vessels and speeds the metabolism due to the high amounts of capsaicin. With consumption the amount of heat the human body puts off is influenced.

Cota: Used to cure ailments ranging from kidney problems, to digestive problems including stomach cramps, and to purify the blood.

Ginger: Used for nausea and arthritis pain.

Garlic: Used for many conditions related to the heart and blood system. These conditions include high blood pressure, high cholesterol, coronary heart disease, heart attack, and "hardening of the arteries."

Copper: It is a soft, malleable and ductile metal with very high thermal and electrical conductivity.

Volts: The volt is the SI measurement of electric potential, electric potential difference, and electromotive force.

Silver: It possesses the highest electrical conductivity, thermal conductivity, and reflectivity of any metal.

Conductivity/Resistivity: An intrinsic property that quantifies how strongly a given material opposes the flow of electric current. A low resistivity indicates a material that readily allows the flow of electric current.

Kanthal: The trademark for a family of iron-chromium- aluminium alloys used in a wide range of resistance and high-temperature applications.

Nichrome: Nichrome refers to any alloy of nickel, chromium, and often iron and/or other elements or substances. Nichrome alloys are typically used in resistance wire.

In Depth Background Research

Mitochondria

The mitochondrion (plural mitochondria) is a double membrane-bound organelle found in all eukaryotic organisms. Some cells in some multicellular organisms may lack them (mature mammalian red blood cells). A number of unicellular organisms, such as microsporidia, parabasalids, and diplomonads, have also reduced or transformed their mitochondria into other structures. Mitochondria generate most of the cell's supply of adenosine triphosphate (ATP), used as a source of chemical energy. Mitochondria are commonly between 0.75 and 3 μm in diameter but vary considerably in size and structure. Unless specifically stained, they are not visible. In addition to supplying cellular energy, mitochondria are involved in other tasks, such as signaling, cellular differentiation, and cell death, as well as maintaining control of the cell cycle and cell growth. Mitochondrial biogenesis is in turn temporally coordinated with these cellular processes. Mitochondria have been implicated in several human diseases, including mitochondrial disorders, cardiac dysfunction, heart failure and autism. The number of mitochondria in a cell can vary widely by organism, tissue, and cell type. For instance, red blood cells have no mitochondria, where liver cells can have more than 2000. The organelle is composed of compartments that carry out specialized functions. These compartments or regions include the outer membrane, the intermembrane space, the inner membrane, and the cristae and matrix. Although most of a cell's DNA is contained in the cell nucleus, the mitochondrion has its own independent genome that shows substantial similarity to bacterial genomes. Mitochondrial proteins (proteins transcribed from mitochondrial DNA) vary depending on the tissue and the species. In humans, 615 distinct types of protein have been identified from cardiac mitochondria, whereas in rats, 940 proteins have been reported. The mitochondrial proteome is thought to be dynamically regulated (Alberts, Johnson, Lewis, et. al., 2002).

Mitochondrial Toxicity

Condition in which the mitochondria of a body's cells become damaged or decline significantly in number; it commonly occurs as a side effect of certain antiretroviral drugs used to treat human immunodeficiency virus, or HIV, but has also been found in certain other drugs that target proteins, amino acid production, RNA and DNA functions within the body as part of their function, such as some high impact, broad spectrum antibiotics (Alberts, et. al., 2002).

Mitochondrial toxicity leads to disease, illness and potentially death. It is also an emerging factor in drug resistance. The disruption of cell function that accompanies the condition can cause both mild and severe problems in people suffering from mitochondrial toxicity. The most commonly observed symptom is muscle weakness, or myopathy and lactic acidosis, though other ailments including ulcers, lupus and many 'mystery diseases' can be eventually attributed to this syndrome. Other symptoms include peripheral neuropathy (numbness in the fingers and toes) and pancreatitis (inflammation of the pancreas), with the most severe being lactic acidosis, in which a build-up of lactic acid in the tissues of the body leads to loss of energy, organ failure, and eventually death (Alberts, et. al., 2002).

Epidermal Cells

Human epidermal cells are the cells that are on the surface of the skin, the outer organ that encases the rest of the bodies' organs. Together with the dermis these cells form the cutis or skin. The epidermis is a stratified squamous epithelium, composed of proliferating basal and differentiated supra-basal keratinocytes. The epidermis is ectodermal (primary germ cell) in origin. The epidermis is avascular (not directly supplied by blood cells) nourished by diffusion from the dermis. Blood capillaries are found beneath the epidermis. The epidermis serves as a barrier to protect the body against microbial pathogens, oxidant stress and chemical compounds

and provides mechanical resistance. Most of that function is played by the stratum corneum (Alberts, et. al., 2002).

Galvanic skin response/Electrodermal activity

Electrodermal activity (EDA), is the property of the human body that causes continuous variation in the electrical characteristics of the skin. Historically, EDA has also been known as skin conductance, galvanic skin response (GSR), electrodermal response (EDR), psychogalvanic reflex (PGR), skin conductance response (SCR), sympathetic skin response (SSR) and skin conductance level (SCL) (Boucsein, 2012).

The traditional theory of EDA indicates that skin resistance varies with the state of sweat glands in the skin. Sweating is controlled by the sympathetic nervous system, and skin conductance is an indication of psychological or physiological arousal. If the sympathetic branch of the autonomic nervous system is highly aroused, then sweat gland activity also increases, which in turn increases skin conductance. In this way, skin conductance can be a measure of emotional and sympathetic responses. The study of EDA has led to such important and vital tools as the electrocardiograph (ECG or EKG) and the electroencephalograph (Boucsein, 2012).

Human extremities, including fingers, palms, and soles of feet display different bio-electrical phenomena. They can be detected with an EDA meter, a device that displays the change electrical conductance between two points over time. The two current paths are along the surface of the skin and through the body. Active measuring involves sending a small amount of current through the body. Some studies include the human skin's response to alternating current, including recently deceased bodies. There is a relationship between emotional arousal and sympathetic activity, although the electrical change alone does not identify which specific emotion is being elicited. These autonomic sympathetic changes alter sweat and blood flow,

which in turn affects GSR and GSP. The response of the skin and muscle tissue to external and internal stimuli can cause the conductance to vary by several microsiemens or minutely microvolts. A correctly calibrated device can record and display the subtle changes (Boucsein, 2012).

The combined changes between electrodermal resistance and electrodermal potential make up electrodermal activity. Galvanic skin resistance (GSR) is an older term that refers to the recorded electrical resistance between two electrodes when a very weak current is steadily passed between them. The electrodes are normally placed about an inch apart, and the resistance recorded varies according to the emotional state of the subject. Galvanic skin potential (GSP) refers to the voltage measured between two electrodes without any externally applied current. It is measured by connecting the electrodes to a voltage amplifier. This voltage also varies with the emotional state of the subject. A painful stimulus such as a pinprick elicits a sympathetic response by the sweat glands, increasing secretion. Although this increase is generally very small, sweat contains water and electrolytes, which increase electrical conductivity, thus lowering the electrical resistance of the skin. These changes in turn affect GSR. Another common manifestation is the vasodilation (dilation) of blood vessels in the face, referred to as blushing, as well as increased sweating that occurs when one is embarrassed. EDA is highly responsive to emotions in some people. Fear, anger, startled response, orienting response, and sexual feelings are among the reactions that may be reflected in EDA. These responses are utilized as part of the polygraph or lie detector test. EDA in regular subjects differs according to feelings of being treated fairly or unfairly, but psychopaths have been shown to manifest no such differences. This indicates that the EDA record of a polygraph may be deceptive in a criminal investigation (Boucsein, 2012).

EDA is a common measure of autonomic nervous system activity, with a long history of being used in psychological research. Many biofeedback therapy devices utilize EDA as an indicator of the user's stress response with the goal of helping the user to control anxiety. Oftentimes, EDA monitoring is combined with the recording of heart rate, respiratory rate, and blood pressure, because they are all autonomically dependent variables. EDA measurement is one component of modern polygraph devices, which are often used as lie detectors. EDA measurement is also becoming more popular in hypnotherapy and psychotherapy practices for detecting depth of hypnotic trance prior to the commencement of suggestion therapy. When traumatic experiences are recalled by the client, immediate changes in sweat rate can indicate that the client is experiencing emotional arousal (Boucsein, 2012).

External factors such as temperature and humidity affect GSR measurements, which can lead to inconsistent results. Internal factors such as medications can also change GSR measurements, demonstrating inconsistency with the same stimulus level. Lastly, galvanic skin responses are delayed 1–3 seconds (Boucsein, 2012).

Cell swelling is an indicator of sub-lethal cell damage, where the cell’s membranes swell outward as certain substances enter the cell through osmosis, and cause an imbalance of the cell structure. The cell can be recovered, or it can enter apoptosis from this stage. The swelling is an indicator of the accumulation of electrolytes or inducers within the cell beyond the cell’s normal capacity or functioning point. Apoptosis is generally signaled by cell shrinkage or cell swelling (NCI, 2011).

Cell Signaling/Cell voltage change

Cell Signaling is a chemical response method in which one cell sends information to another cell through K+ Na+ pathways. This is also how cells communicate with each other,

particularly when they are going through cell cycle changes or environmental stimuli changes. The mitochondria in their ATP production process communicate to other cells through cell membrane potential, a chemically reactive positive or negative charge that goes through one membrane to another. This also produces the noticeable cell voltage, through energy production from the electrolytes produced with ATP production. A higher level of resistance indicates homeostasis within the cell pathways and the stability of glycolysis, while a higher rate of conductivity shows instability in the cell cycle and pathways, therefore an interruption in the conductivity, through an excess of Na+ processing (Alberts, Johnson, Lewis, et. al., 2002).

Cell Cycle

The human body relies on DNA within the nucleus of a cell to send out instructions for body functions and body energy usage. A huge amount of information resides within the DNA and through cellular reproduction processes can separate genetic material and share it via cell division. These methods are called mitosis and meiosis. Mitosis is a process that produces two cells, each of which is identical to the original parent cell. Mitosis is preceded by replication of the cell's DNA so each 'daughter cell' will have a full amount of genetic material. Traditionally in animals, mitosis is used for growth and repair of somatic body cells. This generally leads to asexual reproduction. Meiosis produces four cells from an original parent cell that is not identical to the parent cell, and only has half the parent cell's genetic matter. This is traditionally known as sexual reproduction. (Alters and Alters, 2008)

The cell cycle is the life cycle of the cell. These include prophase, pro-metaphase metaphase, anaphase telophase, interphase and cytokinesis. The cell cycle spends the most amount of time in interphase. This is the part of the cell cycle that includes cell growth, replication of cell organelles, replication of DNA, assembly of the parts of mitosis and the

condensation of DNA. This phase is subdivided into stages G_1, S and G_2. The G_1 stage is the time gap between the last cell division and the start of DNA replication, during which time the cell is growing. This growth period occupies the major portion of the cell's lifespan, where the cell doubles its size and carries out its normal life functions. S (Synthesis) stage produces a complete replica of the cell's DNA for cell division. By the end of this stage, the cell contains two complete, identical copies of the hereditary information. The G_2 stage signifies the time gap between the end of DNA replication and the beginning of cell division. The coils of DNA condense into tightly compacted masses that become visible chromosomes during mitosis. Each chromosome contains two copies of hereditary information in sister chromatids, connected by a centromere. Mitosis is a continuous sequence of events that occurs just after interphase, resulting in the separation of the sister chromatids. (Alters and Alters, 2008)

The first phase of mitosis, prophase is when the chromosomes have condensed. As prophase continues, the chromosomes continue to shorten and thicken. The nucleolus disappears because the cell is no longer capable of producing ribosomal RNA (rRNA). The microtubules (thin tubes of protein structures) are formed. The centrosome is the area in which these microtubules are organized. The centrosomes of animal cells begin to move away from each other in the beginning and by the end, each member of the pair has moved to an opposite end or pole of the cell. As the spindle fibers formulate, the nuclear membrane breaks down and the spindle fibers build a bridge between centrosomes from one pole to another. The spindle fibers then attach to kinetochores. This connection is critical to the separation and movement of sister chromatids during later stages of mitosis. The next stage of animal cell mitosis is metaphase. This occurs when the pairs of sister chromatids align in one plane at the center of the cell. This will indicate where the future plane of the cell division will be. After metaphase comes anaphase.

In this phase, the sister chromatids are pulled in two different directions simultaneously. The chromatids separate into chromosomes and move rapidly toward opposite poles of the cell. They are pulled by the kinetochore by attached and shortening microtubules. This separation produces duplicate sets of hereditary material. The final phase, telophase is the preparation of the cell for cytokinesis. The spindle fibers are chemically disassembled and disappear. The nuclear envelope reforms around each set of chromosomes, which begin to uncoil, and the nucleolus reappears as rRNA. This phase is like prophase in reverse order. (Alters and Alters, 2008)

Mitosis is complete after telophase. The process of cell division is not. The portion of the cell outside the nucleus; cytoplasm is divided starting in telophase and completed in cytokinesis, where the separation of one cell into two takes place. In animal cells, this occurs by pinching the cell in two by a belt of microfilaments encircling the cell at the metaphase stage. As the microfilaments contract, a cleavage furrow appears around the circumference of the cell. As the contraction proceeds the furrow deepens until the opposing edges of the cell membrane make contact with one another. The membranes fuse, producing the cell separation. (Alters and Alters, 2008)

Programmed Cell Death

Cancer and cellular toxicity causes mitochondria to be ‘reprogrammed’, and in the case of tumorigenic activity, the cells are encapsulated and oxygen is cut off, therefore forcing the mitochondria to work in anaerobic conditions, forcing glycolysis. Glycolysis is a series of biochemical reactions from which one molecule of glucose is oxidized to two molecules of pyruvic acid and a small amount of ATP. Increased activity in the glycolytic pathway is an indicator of disease in humans. Malignant, rapidly-growing tumor cells have glycolytic rates that are up to 200 times higher than those of their normal tissues of origin. (NCI, 2012)

Mitochondria are also suspected to play a role in the aging process. Once the mitochondria are forced into glycolysis, they continue to feed cancerous mutations. If these reprogrammed mitochondria are shut off or eliminated, then glycolysis can be shut down, and the surrounding cells can either escape the cancerous mutation cycle, or can be remediated. The mitochondria can also be re-programmed to return to the production of ATP as a primary energy source, which cancerous material is not as prone to reproduce under. Cancerous material feeds off of sugar based chemicals for their energy source and relies heavily on carbohydrates, to reproduce biochemically. Certain chemicals interrupt these carbohydrate and anaerobic cycles, forcing oxygen into the reaction, and balancing off any free radical reactions (American Cancer Society, 2012).

Genetically programmed cell death (apoptosis, PCD), is one of the many concepts that is used to treat cancer. Some cells of the human body self-destruct after a limited lifespan, while others are programmed to last the lifetime of the organism. Those that self-destruct are replaced by the body with new cells produced from cell division of the survivors. Cancer is an indicator of a disruption of the cell's life cycle, where cells that should die do not and develop from failure of programmed cell death and divide uncontrollably. Apoptosis is a type of PCD in which cell suicide is pre-programmed; the cell membrane remains intact as the cell dies so that it does not release its contents and trigger a local inflammatory reaction. The dying cell splits into small membrane-bound bodies that are engulfed and digested by white blood cells. Many compounds have been tested as apoptosis agents (Alters and Alters, 2008).

Programmed Cell Death or PCD has had three main pathways identified: Type I: Apoptosis, Type II: Autophagisis and Type III: Necrosis. Apoptosis, as described above, is cell death produced by biochemical changes that lead to morphology changes and death. These

morphology changes include blebbing, (irregular bulge in the plasma membrane caused by localized decoupling of the cytoskeleton from the plasma membrane) membrane cell shrinkage, nuclear fragmentation, chromatin condensation, and chromosomal DNA fragmentation. Apoptosis occurs naturally in the cell cycle, including in the development of body parts. Apoptosis is responsible for appendages such as fingers and toes to be separated, and can either lead to mutagenic qualities or death of the cell. This process produces cell fragments (apoptotic bodies) that phagocytic cells engulf and remove before the contents of the cell can spill out and cause damage in surrounding cells. The process of apoptosis can be controlled by a large and diverse range of cell signals that can originate extracellularly (extrinsic inducers) which include toxins, hormones, growth factors, nitric oxide or cytokines or intracellularly (intrinsic inducers). These inducers must either cross the plasma membrane or transducer to produce a response; the positive or negative triggering of apoptosis. The cell will initiate intracellular apoptotic signaling in response to stresses, which can potentially lead to a 'cell suicide'. The cell death is precipitated by enzymes, produced by the apoptotic signals that cause regulatory proteins to initiate apoptosis, which allows the selection of apoptosis in certain cells, or can stop the process should the cell no longer need to die. These two main methods of regulation are targeting mitochondria functionality, or transducing the signal through adaptor proteins to apoptotic mechanisms. Apoptosis occurs very quickly (NCI, 2011).

Viral proteins can cause intracellular stress which induces apoptosis. This response to internal stimuli causes a caspase cascade which in turn triggers a series of morphological changes within the cell. Once the caspase cascade has started, it is an irreversible process resulting in certain cell death. Apoptosis in HeLa cells is inhibited by proteins produced by the cell. Inhibitory proteins target retinoblastoma tumor suppressing proteins. These tumor

suppressing proteins regulate the cell cycle, but are rendered inactive when bound to an inhibitory protein (Oyagbemi, et. al., 2010).

Janus Green B

Janus Green B $C_{30}H_{31}ClN_6$ is a basic dye and vital stain used in histology. It is also used to stain mitochondria supravitally. The indicator Janus Green B changes color according to the amount of oxygen present. When oxygen is present, the indicator oxidizes to a blue color. In the absence of oxygen, the indicator is reduced and changes to a pink color. Janus Green B is reduced to diethyl safranine and to leucosafranine by the lactic dehydrogenase and the glucose dehydrogenase enzyme systems. Reduced flavoprotein is the immediate reactant which carries out this reduction and therefore any DPN-flavoprotein enzyme system should be capable of carrying out this reduction (Chemspider, 2016).

Rhodamine B

Rhodamine B is a red or pink fluorescent dye that is commonly used as a tracer dye within water to determine the rate and direction of flow and transport. These dyes fluoresce and can be detected easily and inexpensively. These dyes are used extensively in biotechnology applications including fluorescence microscopy, and other visual highlighting applications. Rhodamine B is used in biology as a staining dye for cells and bacterium. Its luminescence quantum yield is 0.65 in basic ethanol. The fluorescence yield is temperature dependent. Rhodamine B is also used as a biomarker for rabies in animals, and as an indicator of where pesticides have been used. Rhodamine also attaches to matter that processes oxygen and is still considered living, but will also attach to a free radical or free radical affected matter, making it darker and staining it a red color. It will not chemically impact or interact with other chemicals,

being a neutral chemical, and being a tracer, so it will not have a chemical impact on the cancer cell layer or tumor. (NCI. 2011)

The Fluorescence Absorption Test for Cell Viability works on the concept that a live cell will still undergo the different cell stages, and will take in certain nutrients from the environment and absorb them for use via the cell wall. Fluorescent dyes have a small enough particulate structure as to be able to absorb the dye in the cell if it is living or viable, and will simply show up on the outside of the cell wall if the cell is dead. Fluorescent dyes will also attach to the inner 'dark matter' of the cancer cell making it more apparent under the microscope, but will also highlight the transparency of a clear or healthy cell. The Fluorescence Absorption Test for Viability is being used in some exploratory surgeries to highlight cancerous cells while still in the body to be able to differentiate from the healthy cells, these are also used as tracers to attempt to determine which cells are diseased and which are healthy in endoscopic procedures. (Estevez, 2009)

Ciprofloxacin
Antibiotic part of a group of drugs called fluoroquinolones. (2^{nd} generation)
Very commonly prescribed.
Is commonly used against most strains of bacterial pathogens responsible for respiratory, urinary tract, gastrointestinal, and abdominal infections (including E. coli, S. epidermis, anthrax)
Is a broad spectrum antibiotic with good tissue penetration.
Is commonly used in situations where the infection agent is not identified.
Works on both gram positive and gram-negative bacteria.
35^{th} most commonly prescribed drug, 5^{th} most prescribed antibacterial.
Was recently granted a 'black box' warning for the number of serious side effects produced, including mitochondrial toxicity and related symptoms.
Side effects include: increased risk of tendon damage and/or rupture and for exacerbation of muscle weakness in patients with the neurological disorder myasthenia gravis, and other muscular related ailments, potential seizures, nausea, vomiting, diarrhea and dizziness.
Chemical name: 1-cyclopropyl-6-fluoro-4-oxo-7-(piperazin-1-yl)-quinoline-3-carboxylic acid: $C_{17}H_{18}FN_3O_3$

Can develop high resistance with many different bacteria.
Reports to have a half-life of 4 hours, but high level traces can be found months after oxidation.
Are not supposed to be recommended for respiratory infections.
Ciprofloxacin should not be taken with antacids containing magnesium or aluminum, highly buffered drugs, or with supplements containing calcium, iron, or zinc.
Inhibits the drug-metabolizing enzyme CYP1A2 and thereby can reduce the clearance of drugs metabolized by that enzyme.
Functions by inhibiting DNA gyrase, (a type II topoisomerase) and topoisomerase IV, enzymes necessary to separate bacterial DNA, inhibiting cell division.
Was developed to replace other antibiotics that had already become active in antibiotic resistance.
Pathogens, including enterococci, Streptococcus pyogenes and Klebsiella pneumoniae (quinolone-resistant) now exhibit resistance. Some Burkholderia cepacia, Clostridium innocuum and Enterococcus faecium strains have developed resistance to ciprofloxacin in varying degrees
Can also be considered a potential treatment for breast cancer and other reproductive system cancers.
Induces apoptopic activity in cells and works primarily from deconstructing the outer cell walls of the invading bacterial structure.

Penicillin
Phenoxymethylpenicillin, commonly known as penicillin V. (oral use)
Exerts a bactericidal action against penicillin-sensitive microorganisms during the stage of active multiplication.
Acts by inhibiting the biosynthesis of cell-wall peptidoglycan
Not active against beta-lactamase-producing bacteria, which include many strains of Staphylococci
3,3-Dimethyl-7-oxo-6-(2-phenoxyacetamido)-4-thia-1-azabicyclo[3.2.0]heptane-2-carboxylic acid. Formula: C16H18N2O5S
Primarily used against gram positive bacteria, but is minorly effective against gram negative bacteria.
Used only for the treatment of mild to moderate infections, and not for severe or deep-seated infections since absorption can be unpredictable. Primarily used for: Infections caused by Streptococcus pyogenes (incl. Tonsillitis, Pharyngitis, Skin infections), Anthrax (mild uncomplicated infections), Lyme disease (early stage in pregnant women or young children), Rheumatic fever (primary and secondary prophylaxis), Streptococcal skin infections, Spleen disorders (pneumococcal infection prophylaxis), Initial treatment for Dental Abscesses, Moderate-to-severe gingivitis, Avulsion injuries of teeth, Sickle Cell Disease of the blood, odontogenic infections.
High level of protein binding.
Has a short half-life.
Is mostly filtered before excretion, has a higher level of metabolism.
Is not as effective as stronger antibiotics.

May occasionally cause transient nausea, vomiting, epigastric distress, diarrhea, and black hairy tongue.

Streptomycin
Antimycobacterial = type of drug used to treat Mycobacteria infections.
Aminoglycoside, derived from the actinobacterium Streptomyces griseus. Bactericide.
The first effective treatment for tuberculosis.
Adverse effects of this medicine are ototoxicity, nephrotoxicity, fetal auditory toxicity, and neuromuscular paralysis. Fever, rashes, tinnitus, vertigo and ataxia, nephrotoxicity and kidney malfunction are amongst the side effects of this drug.
5-(2,4-diguanidino-3,5,6-trihydroxy-cyclohexoxy)- 4-[4,5-dihydroxy-6-(hydroxymethyl) -3-methylamino-tetrahydropyran-2-yl] oxy-3-hydroxy-2-methyl-tetrahydrofuran-3-carbaldehyde Formula: C21H39N7O12
Used against: Infective endocarditis caused by enterococcus when the organism is not sensitive to Gentamicin, Tuberculosis, Plague (Yersinia pestis) & Tularemia infections.
Can easily develop resistance.
20% may not be metabolized and may be excreted whole.
Is used as a pesticide, to combat the growth of bacteria, fungi, and algae.
in combination with penicillin, is used in a standard antibiotic cocktail to prevent bacterial infection in cell culture.
Can cause mitochondrial toxicity.
Is a protein synthesis inhibitor. It binds to the small 16S rRNA of the 30S subunit of the bacterial ribosome, interfering with the binding of formyl-methionyl-tRNA to the 30S subunit.
Inhibits gram positive and gram negative bacteria.

Tetracycline
Broad-spectrum polyketide antibiotic (class of secondary metabolites produced by certain living organisms in order to impart to them some survival advantage, highly active).
Produced by the Streptomyces genus of Actinobacteria.
Protein synthesis inhibitor.
Commonly used to treat skin conditions. But was also used to treat cholera. It is first-line therapy for rocky mountain spotted fever (Rickettsia), Lyme disease (B. burgdorferi), Q fever (Coxiella), psittacosis and lymphogranuloma venereum (Chlamydia), mycoplasma pneumoniae and to eradicate nasal carriage of meningococci, acne. Also used against the plague. Used as a biomarker. Shuts off ulcers and some cancers, against mosquito repopulation.
C22H24N2O8
Gram positive and gram negative.
Is useful against the majority of most high level illnesses, infections and parasites.

Bacteria acquire resistance to tetracycline from horizontal transfer of a gene that either encodes an efflux pump or a ribosomal protection protein.
Side effects include: Stain developing teeth (even from mother to child), Discolor permanent teeth (yellow-gray-brown), from infancy and childhood to eight years old, Be inactivated by Ca2+ ion, so are not to be taken with milk, yogurt, and other dairy products, Be inactivated by aluminium, iron and zinc, not to be taken at the same time as indigestion remedies, cause skin photosensitivity, cause drug-induced lupus, and hepatitis, cause micro-vesicular fatty liver, tinnitus, interfere with methotrexate by displacing it from the various protein binding sites, cause breathing complications, anaphylactic shock, affect bone growth of the fetus, Fanconi syndrome, Stevens–Johnson syndrome, toxic epidermal necrolysis and erythema multiform associated with doxycyline use.
Inhibits protein synthesis by blocking the attachment of charged aminoacyl-tRNA to the A site on the ribosome. Tetracycline binds to the 30S subunit of microbial ribosomes. It prevents introduction of new amino acids to the nascent peptide chain.

Vancomycin
Glycopeptide antibiotic.
(1S,2R,18R,19R,22S,25R,28R,40S)- 48- {[(2S,3R,4S,5S,6R)- 3- {[(2S,4S,5S,6S)- 4- amino- 5- hydroxy- 4,6- dimethyloxan- 2- yl]oxy}- 4,5- dihydroxy- 6- (hydroxymethyl)oxan- 2- yl]oxy}- 22- (carbamoylmethyl)- 5,15- dichloro- 2,18,32,35,37- pentahydroxy- 19- [(2R)- 4- methyl- 2- (methylamino)pentanamido]- 20,23,26,42,44- pentaoxo- 7,13- dioxa- 21,24,27,41,43- pentaazaoctacyclo[26.14.2.23,6.214,17.18,12.129,33.010,25.034,39]pentaconta- 3,5,8(48),9,11,14,16,29(45),30,32,34,36,38,46,49- pentadecaene- 40- carboxylic acid Formula: C66H75Cl2N9O24
Effective mostly against Gram-positive bacteria
Naturally occurring antibiotic made by the soil bacterium Amycolatopsis orientalis
Comparatively rare halo-organic compound, containing 2 covalently bonded chlorine atoms.
Bacteria were relatively slow to acquire vancomycin resistance
Used in infections where antibiotic resistance to other antibiotics were prevalent.
First-line treatment for complicated skin infections, bloodstream infections, endocarditis, bone and joint infections, intestinal infections, and meningitis caused by methicillin-resistant S. aureus.
Has developed major resistances to many bacteria.
Excreted unchanged, does not metabolize well.
Side effects include: pain, thrombophlebitis, kidney and hearing damage, anaphylaxis, toxic epidermal necrolysis, erythema multiforme, red man syndrome, superinfection, thrombocytopenia, neutropenia, leukopenia, florid petechial hemorrhages, ecchymoses, wet purpura tinnitus, and dizziness and/or ototoxicity.
Vancomycin biosynthesis occurs via different nonribosomal protein synthases (NRPSs).
Vancomycin acts by inhibiting proper cell wall synthesis in gram-positive bacteria.

Osha

Osha is a plant. Historically, the root has been used as medicine by Native American and Hispanic cultures. Today, osha is used for sore throat, bronchitis, cough, common cold, influenza, swine flu, and pneumonia. It is also used to treat other viral infections including herpes and AIDS/HIV. Some people use it for indigestion. Some people apply osha directly to the skin to keep wounds from getting infected.

Osha can be confused with the very poisonous plant hemlock. The leaves of the two plants are very similar. Osha must be identified by the root, which people say has an unpleasant celery-like odor. Osha grows at higher elevations in the western US and is difficult to cultivate. The popularity of osha has led to over-harvesting of the wild plant. As a result, osha has been designated an endangered plant by conservationists. Osha contains chemicals that might help fight bacterial and viral infections (Marshner, 2012)

Rosemary

Rosemary is an herb. Oil is extracted from the leaf and used to make medicine. Rosemary is used for digestion problems, including heartburn, intestinal gas (flatulence), liver and gallbladder complaints, and loss of appetite. It is also used for gout, cough, headache, and high blood pressure. Some women use rosemary for increasing menstrual flow and causing abortions (Marshner, 2012)

Rosemary is used topically (applied to the skin) for preventing and treating baldness; and treating circulation problems, toothache, a skin condition called eczema, and joint or muscle pain such as myalgia, sciatica, and intercostal neuralgia. It is also used for wound healing, in bath

therapy (balneotherapy), and as an insect repellent. In foods, rosemary is used as a spice. The leaf and oil are used in foods, and the oil is used in beverages. In manufacturing, rosemary oil is used as a fragrant component in soaps and perfumes. Although it's not clear how rosemary works for hair loss, applying it to the scalp irritates the skin and increases blood circulation (Marshner, 2012).

Cayenne pepper

Cayenne pepper, is a cultivar of *Capsicum annuum,* which is related to bell peppers, jalapeños, paprika, and others. The *Capsicum* genus is in the nightshade family (Solanaceae). It is a hot chili pepper used to flavor dishes. The fruits are generally dried and ground, or pulped and baked into cakes, which are then ground and sifted to make the powdered spice of the same name. Cayenne is used in cooking spicy dishes, as a powder or in its whole form (such as in Korean, Sichuan, and other Asian cuisine), or in a thin, vinegar-based sauce. It is generally rated at 30,000 to 50,000 Scoville units. It is also used as an herbal supplement. Cayenne pepper, by weight, is high in vitamin A. It also contains vitamin B6, vitamin E, vitamin C, riboflavin, potassium, and manganese. However, given the very small amount of cayenne pepper typically consumed in a serving, it makes a negligible contribution to overall dietary intake of these nutrients (Westerterp-Plantenga, et. al, 2009).

Cayenne pepper consumption dilates the blood vessels and speeds the metabolism due to the high amounts of capsaicin. With the consumption of cayenne peppers, the amount of heat the human body puts off is influenced. In animal studies, capsaicin has the ability to boost metabolism, which in turn causes weight loss. This increases circulation and blood flow to all major organs, facilitating oxygen and nutrient delivery. Capsaicin may support a healthy energy balance while suppressing appetite. Capsaicin has been shown to increase energy expenditure, so

acts as a metabolism booster and is beneficial in long-term weight loss. A correlation has been shown between substrate oxidation and capsaicin. Capsaicin treatment sustained fat oxidation during weight maintenance, but did not affect weight regain after modest weight loss. Cayenne pepper is also claimed to be an aphrodisiac because it contains capsaicin. It has also been shown to aid in the oxidation of adipose tissue, regulate high blood pressure, promote healthy liver function and tissue production, help regulate the digestive system, and promote healthy mucus production in the membranes that line internal organs (Westerterp-Plantenga et. al., 2009.)

Cota

Cota is the Spanish word for Hopi or Navajo tea, which is also called greenthread due to the fact the stems look like "little green threads". Cota is a species of flowering plant in the aster or *asteraceae* family, relating it to daisies and sunflowers. It is native to most parts of the Americas, including the central and western United States, where it grows in many different types of habitat. The herb grows over much of the plains and mountain states, reaching up to Wyoming, Montana, Nebraska, and South Dakota. It is centralized to the southwest, particularly the Hopi and Navajo nations, primarily through New Mexico, Colorado and Arizona. The extended range of habitat is made possible by the fact that several species exist and the growth conditions between the different species vary from high altitude to the plains. Another term to reference this plant includes 'roadside tea' due to the fact that the plant can be found near the road side. The herb known as Navajo tea is derived mainly from *T. megapotamicum, T. simplicifolium, T. filifolium, and T. subnudum*. Its taxomony is as follows: Magnoliophyta (angiosperm), Magnoliopsida (dicot), Asteraceae (Compositae). This perennial is also known as *T. gracile* (Kane, 2011).

Cota is primarily a medicinal herb, which has been used to cure ailments ranging from kidney problems, to digestive problems (including stomach cramps), and to purify the blood. Cota is considered useful for the Kidneys, used against gonorrhea, and as a nervous stimulant. One of the more common uses of Cota is as a toothache remedy and against mouth sores (PDR, 2007). It has been used as a cure against breast cancer at the genetic level, and has the potential for restoring cell cycle damage in other parts of the body against various cancers (Figueroa, 2012).

What makes Cota so effective as a medicinal remedy are the phytochemicals and antioxidants within the plant, which has not been greatly analyzed but has been concluded to contain flavonoids including luteolin, the plant also contains chalcone glycosides, notably marein (Ateya, et. al., 1982). Cota is also used as a fabric dye, particularly in rugs to give the thread a particularly bright yellow hue. The yellow of the flowers is primarily due to the flavonoids within the flower (Lovejoy, et. al., 2012).

Ginger

Zingiber officinale is a flowering plant, in the family *Zingiberaceae* whose rhizome, ginger root or simply ginger, is widely used as a spice or a folk medicine. It is a herbaceous perennial which grows annual stems about a meter tall bearing narrow green leaves and yellow flowers. *G*inger produces clusters of white and pink flower buds that bloom into yellow flowers. Because of its aesthetic appeal and the adaptation of the plant to warm climates, ginger is often used as landscaping around subtropical homes. It is a perennial reed-like plant with annual leafy stems, about a meter tall. Traditionally, the rhizome is gathered when the stalk withers; it is

immediately scalded, or washed and scraped, to kill it and prevent sprouting. Ginger produces a hot, fragrant kitchen spice.

Oral or topical uses of ginger to treat various disorders, such as nausea or arthritis pain, are under research, but there are no conclusions possible from these studies about its effectiveness or safety in long-term use. In limited studies, ginger was found to be more effective than placebo for treating nausea caused by seasickness, morning sickness, and chemotherapy, although it was not found superior to placebo for treating postoperative nausea. Some studies indicate taking ginger during pregnancy may cause harm to the fetus or increase the mother's risk of bleeding. Allergic reactions to ginger generally result in a rash. Although generally recognized as safe, ginger can cause heartburn and other side effects, particularly if taken in powdered form. Un-chewed fresh ginger may result in intestinal blockage, and individuals who have had ulcers, inflammatory bowel disease, or blocked intestines may react badly to large quantities of fresh ginger. It can also adversely affect individuals with gallstones. There are suggestions that ginger may affect blood pressure, clotting, and heart rhythms. Studies are inconclusive about the effects of using ginger for nausea or pain associated with various ailments. Side effects of consuming powdered ginger are gas, bloating, heartburn and nausea. One traditional medical form of ginger historically was called "Jamaica ginger"; it was classified as a stimulant and carminative and used frequently for dyspepsia, gastroparesis, slow motility symptoms, constipation or colic. It was also frequently employed to disguise the taste of medicines. Ginger is commonly used to treat various types of “stomach problems,” including motion sickness, morning sickness, colic, upset stomach, gas, diarrhea, nausea caused by cancer treatment, nausea and vomiting after surgery, as well as loss of appetite. Other uses include pain relief from arthritis or muscle soreness, menstrual pain, upper respiratory tract infections, cough, and bronchitis. Ginger is also

sometimes used for chest pain, low back pain, and stomach pain. Some people pour the fresh juice on their skin to treat burns. The oil made from ginger is sometimes applied to the skin to relieve pain. (WebMD, 2015).

Garlic

Allium sativum is an herb. Garlic is a seasoning and a food, and has been used as a medicine to prevent or treat a wide range of diseases and conditions. The fresh clove or supplements made from the clove are used for medicine. Garlic is easy to grow and can be grown year-round in mild climates. In the typical serving size of 1-3 cloves (3-9 g), garlic provides no significant nutritional value with the content of all essential nutrients below 10% of the Daily Value (DV). When expressed per 100 grams, garlic contains several nutrients in rich amounts (> 20% DV), including vitamins B6 and C, and the dietary minerals, manganese and phosphorus. Per 100 gram serving, garlic is also a good source (10-19% DV) of certain B vitamins including thiamine (Vitamin B1), and pantothenic acid (Vitamin B5), as well as certain dietary minerals including calcium, iron, and zinc (WebMD, 2015).

Garlic is used for many conditions related to the heart and blood system. These conditions include high blood pressure, high cholesterol, coronary heart disease, heart attack, and "hardening of the arteries" (atherosclerosis). Garlic actually may be effective in slowing the development of atherosclerosis and seems to be able to modestly reduce blood pressure. It also has indications for use in the prevention and treatment of cancers. Garlic has been used to treat enlarged prostate (benign prostatic hyperplasia; BPH), diabetes, osteoarthritis, hayfever (allergic rhinitis), traveler's diarrhea, high blood pressure late in pregnancy (pre-eclampsia), cold and flu. It is also used for building the immune system, preventing tick bites, and preventing and treating

bacterial and fungal infections. Other uses include treatment of fever, coughs, headache, stomach ache, sinus congestion, gout, rheumatism, hemorrhoids, asthma, bronchitis, shortness of breath, low blood pressure, low blood sugar, high blood sugar, and snakebites. It is also used for fighting stress and fatigue, and maintaining healthy liver function. Garlic is an antibacterial, an antifungal, and has some indications to be antiviral (WebMD, 2015).

Copper

Chemical element with symbol Cu, atomic number 29. It is a soft, malleable and ductile metal with very high thermal and electrical conductivity. A freshly exposed surface of pure copper has a reddish-orange color. It is most commonly used as a conductor of heat and electricity, a building material, and as a constituent of various metal alloys. Copper is found as a pure metal in nature, and was the source of the first metal to be used by humans, around 8,000 BC. Its compounds are commonly encountered as copper(II) salts, which often produce blue or green colors to minerals such as azurite, malachite and turquoise and have been widely used historically as pigments. The corrosion state is also used in architecture and art. The corrosion also protects the metal rather than completely deteriorating it. Copper not only corrodes in oxygen, but also will undergo galvanic corrosion when exposed to other metals. Copper tarnishes when exposed to sulfides, which react with it to form various copper sulfides. Copper is recyclable (Hammond, 2004).

Copper is essential to all living organisms as a trace dietary mineral because it is a key constituent of the mitochondrial respiratory enzyme complex cytochrome c oxidase. In mollusks and crustaceans copper is a constituent of the blood pigment hemocyanin, which is replaced by the iron-complexed hemoglobin in fish and other vertebrates. The main areas where copper is found in humans are the liver, muscle and bone. Copper compounds are used as

bacteriostatic/antimicrobial substances, fungicides, and wood preservatives. Certain isotopes of copper are used in radiation based emission topography. Compounds that contain a carbon-copper bond are known as organocopper compounds. They are very reactive towards oxygen to form copper(I) oxide. The human body contains copper at a level of about 1.4 to 2.1 mg per kg of body mass. Required Daily Amount for copper in normal healthy adults is estimated to be 0.97 mg/day and as high as 3.0 mg/day.[122] Copper is absorbed in the gut, then transported to the liver bound to albumin. After processing in the liver, copper is distributed to other tissues in a second phase. Copper transport in the tissues involves the protein ceruloplasmin, which carries the majority of copper in blood. Ceruloplasmin also carries copper that is excreted in milk, and is particularly well-absorbed as a copper source. A lack of copper can cause anemia-type symptoms and cellular dysfunction. An overdose of copper can cause liver failure, DNA damage, and the potential enhancement of neurological diseases such as Alzheimer's (Hammond, 2004).

Volts

The volt is the SI measurement of electric potential, electric potential difference, and electromotive force. The volt is named in honor of the Italian physicist Alessandro Volta. It is defined as the difference in electric potential across a wire or metal conductor when an electric current of one ampere dissipates one watt of power. It is also equal to the potential difference between two parallel, infinite planes spaced 1 meter apart that create an electric field of 1 newton per coulomb (C, SI unit of electric charge). It is also the potential difference between two points that will impart one joule of energy per coulomb of charge that passes through it.

Silver

Silver is the metallic element with the atomic number 47. Its symbol is Ag. A soft, white, lustrous transition metal, it possesses the highest electrical conductivity, thermal

conductivity, and reflectivity of any metal. The metal occurs naturally in its pure, free form (native silver), as an alloy with gold and other metals, and in minerals such as argentite and chlorargyrite. Most silver is produced as a byproduct of copper, gold, lead, and zinc refining. The electrical conductivity of silver is the highest of all metals, even higher than copper, but it is not widely used for electrical purposes due to its much higher cost. An exception to this is in radio-frequency engineering, particularly at VHF and higher frequencies, where silver plating is employed to improve electrical conductivity of parts and wires (at high frequencies current tends to flow on the surface of conductors, not their interior, hence silver plating greatly improves overall conductivity). Silver also has the lowest contact resistance of any metal (WebElements, 2012).

Conductivity/Resistivity

Electrical resistivity (also known as resistivity, specific electrical resistance, or volume resistivity) is an intrinsic property that quantifies how strongly a given material opposes the flow of electric current. A low resistivity indicates a material that readily allows the flow of electric current. Electrical conductivity or specific conductance is the reciprocal of electrical resistivity, and measures a material's ability to conduct an electric current. Many resistors and conductors have a uniform cross section with a uniform flow of electric current, and are made of one material.

Electrons in an atom do not take on arbitrary energy values. Rather, electrons only occupy certain discrete energy levels in an atom or crystal; energies between these levels are impossible. When a large number of such allowed energy levels are spaced close together (in energy-space)—i.e. have similar (minutely differing) energies—these energy levels together are

an "energy band". There can be many such energy bands in a material, depending on the atomic number {number of electrons (if the atom is neutral)} and their distribution (besides external factors like environmental modification of the energy bands). The material's electrons seek to minimize the total energy in the material by going to low energy states; however, the Pauli exclusion principle means that they cannot all go to the lowest state. The electrons instead "fill up" the band structure starting from the bottom. The characteristic energy level up to which the electrons have filled is called the Fermi level. The position of the Fermi level with respect to the band structure is very important for electrical conduction: only electrons in energy levels near the Fermi level are free to move around, since the electrons can easily jump among the partially occupied states in that region. In contrast, the low energy states are rigidly filled with a fixed number of electrons at all times, and the high energy states are empty of electrons at all times (Giancoli, 1995).

In metals there are many energy levels near the Fermi level, meaning that there are many electrons available to move. This is what causes the high electronic conductivity of metals. An important part of band theory is that there may be forbidden bands in energy: energy intervals that contain no energy levels. In insulators and semiconductors, the number of electrons happens to be just the right amount to fill a certain integer number of low energy bands, exactly to the boundary. In this case, the Fermi level falls within a band gap. Since there are no available states near the Fermi level, and the electrons are not freely movable, the electronic conductivity is very low. A metal consists of a lattice of atoms, each with an outer shell of electrons that freely dissociate from their parent atoms and travel through the lattice. This is also known as a positive ionic lattice. This 'sea' of dissociable electrons allows the metal to conduct electric current. When an electrical potential difference (a voltage) is applied across the metal, the resulting electric

field causes electrons to drift towards the positive terminal. The actual drift velocity of electrons is very small, in the order of magnitude of a meter per hour. However, as the electrons are densely packed in the material, the electromagnetic field is propagated through the metal at nearly the speed of light. Near room temperatures, metals have resistance. The primary cause of this resistance is the collision of electrons with the atoms that make up the crystal lattice. This acts to scatter electrons and lose their energy on collisions rather than on linear movement through the lattice. Also contributing to resistance in metals with impurities are the resulting imperfections in the lattice. The larger the cross-sectional area of the conductor, the more electrons per unit length are available to carry the current. As a result, the resistance is lower in larger cross-section conductors. The number of scattering events encountered by an electron passing through a material is proportional to the length of the conductor. The longer the conductor, therefore, the higher the resistance. Different materials also affect the resistance. In electrolytes, electrical conduction happens not by band electrons or holes, but by full atomic species (ions) traveling, each carrying an electrical charge. The resistivity of ionic solutions (electrolytes) varies tremendously with concentration – while distilled water is almost an insulator, salt water is a reasonable electrical conductor. Conduction in ionic liquids is also controlled by the movement of ions, but here we are talking about molten salts rather than solvated ions. In biological membranes, currents are carried by ionic salts. Small holes in cell membranes, called ion channels, are selective to specific ions and determine the membrane resistance (Giancoli, 1995).

Kanthal

Kanthal is the trademark for a family of iron-chromium- aluminium (FeCrAl) alloys used in a wide range of resistance and high-temperature applications. Kanthal FeCrAl alloys consist of

mainly iron, chromium (20–30%) and aluminium (4–7.5 %). The alloys are known for their ability to withstand high temperatures and having intermediate electric resistance. As such, it is frequently used in heating elements. Kanthal alloy has a melting point of 1,500 °C (2,730 °F). Special grades can be used as high as 1,425 °C (2,597 °F). Kanthal is moderately oxidative resistant and can handle temperature extremes (Kanthal.com, 2016).

Nichrome

Nichrome (NiCr, nickel-chrome, chrome-nickel,) generally refers to any alloy of nickel, chromium, and often iron and/or other elements or substances. Nichrome alloys are typically used in resistance wire. They are also used in some dental restorations (fillings) and in other applications. Nichrome wires are oxidative resistant and can handle most temperature extremes. It is silvery-grey in colour, is corrosion-resistant, and has a high melting point of about 1,400 °C (2,550 °F). Due to its resistance to oxidation and stability at high temperatures, it is widely used in electric heating elements, such as in appliances and tools. Typically, nichrome is wound in coils to a certain electrical resistance, and current is passed through it to produce heat. Nichrome is also used in fireworks and the pyrotechnics industry (Science Education Foundation, 2002).

Experimentation

The intent of phase one is to test cultured epidermal cells for their mitochondrial and cell reaction to stressors by monitoring the cell activity microscopically and testing conductivity before introduction, immediately after introduction and after five minutes of exposure to determine the level of mitochondrial function and reaction. This will lead to a database of cell reaction and conductivity that can be used in non-invasive indication of mitochondrial dysfunction that is an early sign of disease. The independent variables are the stressors and

stimuli being introduced to the cells. Dependent variables are the cell reaction and conductivity reaction which will be used as indicators of mitochondrial activity (function/dysfunction). The control group were the cells as they were plated without any additions, the constants were the sterility of the cell harvesting and plating, as well as the sustainability of the cells' viability through dextrose feeding and incubation. The amount of solution added and the assays used were also constant. The overall testing environment was also constant.

Controls	Variables
Source of cells	Stressors and stimuli
Cell culturing procedures	
Cell feeding procedures	
Dye methodology/viability testing	
Amount of stressors and stimuli	
Method of observing mitochondrial changes	
Overall environment/temperature	
Method of observation	
Janus Green/Rhodamine B	

The intent of phase two was to develop a sensor material that is sensitive enough to track cellular change at the mitochondrial/ATP production level. By testing existing materials such as silver as an electrode with a galvanic cell response sensor, then by testing copper, and wire hybrids Nichrome and Kanthal to determine their ability to detect cellular change in conductivity and resistivity.

Controls	Variables
Cell cultures and techniques	Type of wire
Incubation Time	Toxicity agents
Testing time and testing methods	Differing test areas
Sterility	
Amount of solutions added	
Feeding times and methods	
Epidermal cell source	
Dyes/Dye amount	
Software programs and measuring abilities	

The following were the procedures that we used:

Cellular Monitoring through conductivity

a. Make nutrient agar plates according to protocol. Pour slightly thicker than normal with wires included within the nutrient agar. Add 1mL Gentamycin to agar solution.
b. Sterilize surface area of skin with 70% isopropyl alcohol (self and adult volunteer).
c. Gently scrape surface area of skin to remove dead skin cells.
d. Place nutrient agar disk onto area, flip agar back into plate.
e. Place 5 drops of pre-prepared dextrose/nutrient broth solution on top of plate. Take conductivity/resistance of each plate before and after dextrose feed.
f. Cover nutrient agar plate, place in incubator for 48 hours at 37 deg. C, adding more dextrose/nutrient broth solution as needed to prevent drying.
g. Remove plates from incubator, set on microscope. View growth of cells
h. Test conductivity/resistance of each cell plate.
i. Add one microdrop per cell cluster of 50% dilution of Rhodamine B and 50% Janus Green B, allow to set for 9 minutes, while testing conductivity/resistance of each plate.
j. Determine cell viability and mitochondrial viability through microscope observation, note colormetric change.
k. Add mitochondrial stressors to the top of the cells in 1 md doses and determine the conductivity/resistivity change in the cells. Place and compare all information into database for multiple trials.

Body Voltage Testing

a. Using own self (diabetic) and an adult with no diabetes, test self-microvolt resistance and conductivity by zeroing out a voltmeter that has micro volt testing capabilities, then having the individual test their voltage by holding the ends of the probes every two hours for 12 hours. Repeat over 5 days (non-invasive).

b. Test various areas around the body for best surface conduction/resistance production by placing the probes on surface areas easily accessed by personal accessory access (i.e. behind the ears, wrists, fingers, between fingers, etc.) (non-invasive)

c.

Determining the most accurate sensor for cellular monitoring.

a. Make nutrient agar plates according to protocol. Pour slightly thicker than normal. Add 1mL Gentamycin to agar solution.

b. Sterilize surface area of skin with 70% isopropyl alcohol (self and adult volunteer).

c. Gently scrape surface area of skin to remove dead skin cells.

d. Place nutrient agar disk onto area of no skin cells, flip agar back into plate.

e. Slip in sterilized (by alcohol) 10 cm electrode wires through agar, and gently bend outwards on either side.

f. Place 5 drops of pre-prepared dextrose/nutrient broth solution on top of plate. Take conductivity/resistance of each plate.

g. Cover nutrient agar plate, place in incubator for 48 hours at 37 deg. C, adding more dextrose/nutrient broth solution as needed to prevent drying.

h. Remove plates from incubator, set on inverted microscope. View growth of cells away or towards the different wires.

i. Test conductivity/resistance of each cell plate, through exposed wires.

j. Add one microdrop per cell cluster of 50% dilution of Rhodamine B and 50% Janus Green B, allow to set for 9 minutes, while testing conductivity/resistance of each plate.

k. Determine cell viability and mitochondrial viability through microscope observation, note colormetric change.

l. Clamp wires to positive and negative terminals of volt meter, and test the conductivity/resistance/mV passing through each cell cluster by gently touching the end of a 3 cm wire to the voltage cluster.

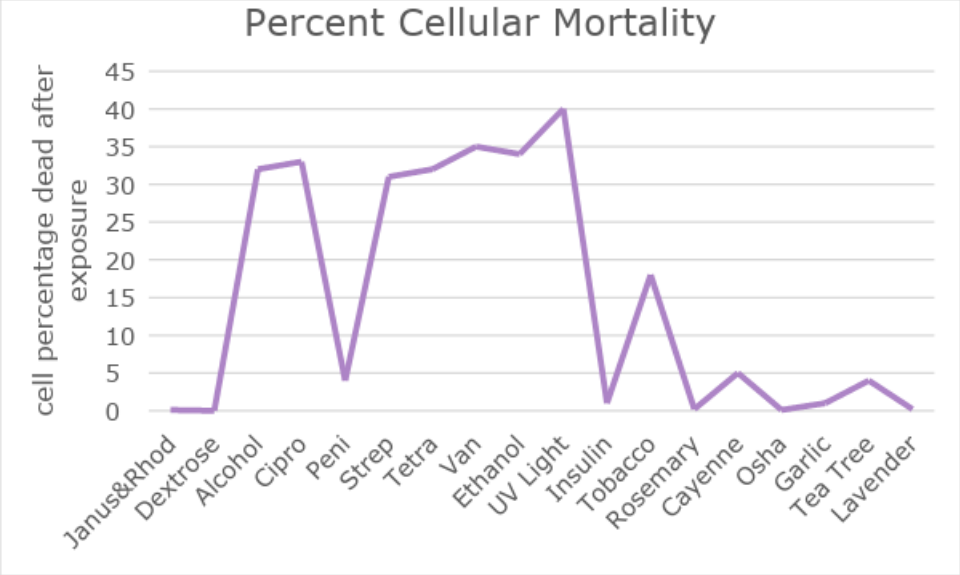
m. Add mitochondrial stressors to the top of the cells in 1 md doses and determine the conductivity/resistivity change in the cells.

Building the sensor

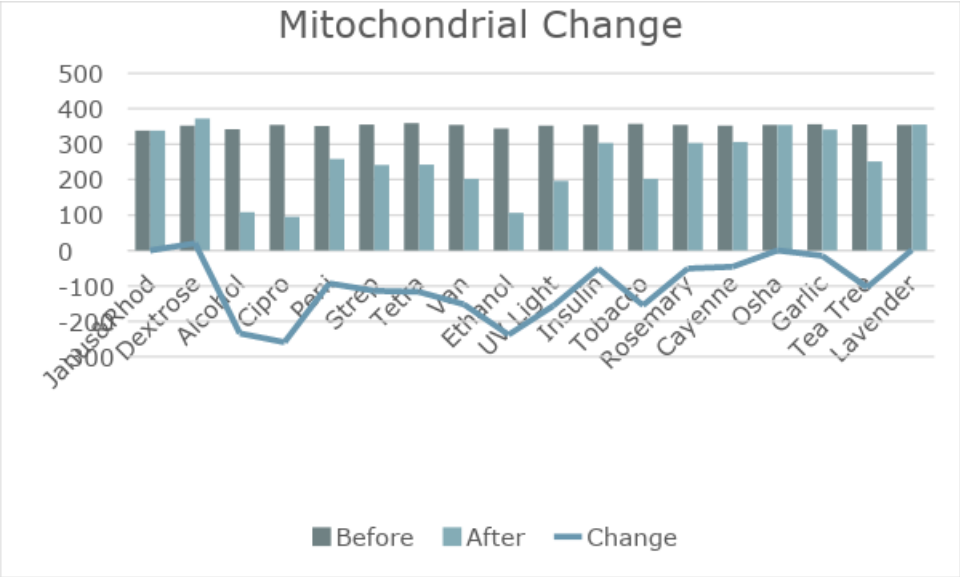
a. After determining the best wires for conductivity/resistance from step 2, a wire grid can be set up to produce a sensor network interlaced within a design that was determined to be the best for body conductivity/resistance from part 1.

b. A controller chip and power production center will also be produced for the best design so that the sensor chip will simply lie against the skin and then transmit to a smart phone app a constant low level transmission of the amount of conductivity/resistivity currently being produced.

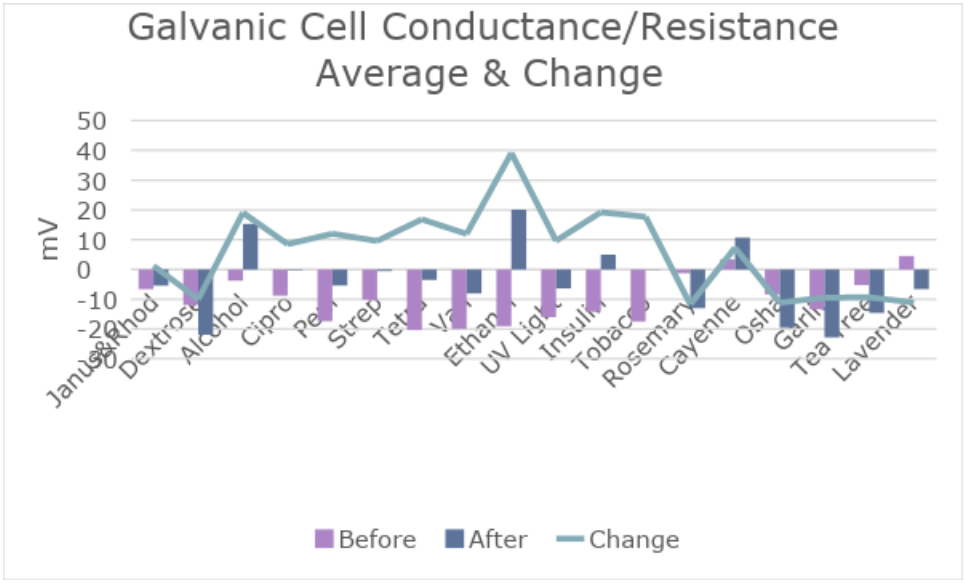
The following is data we collected over the years:



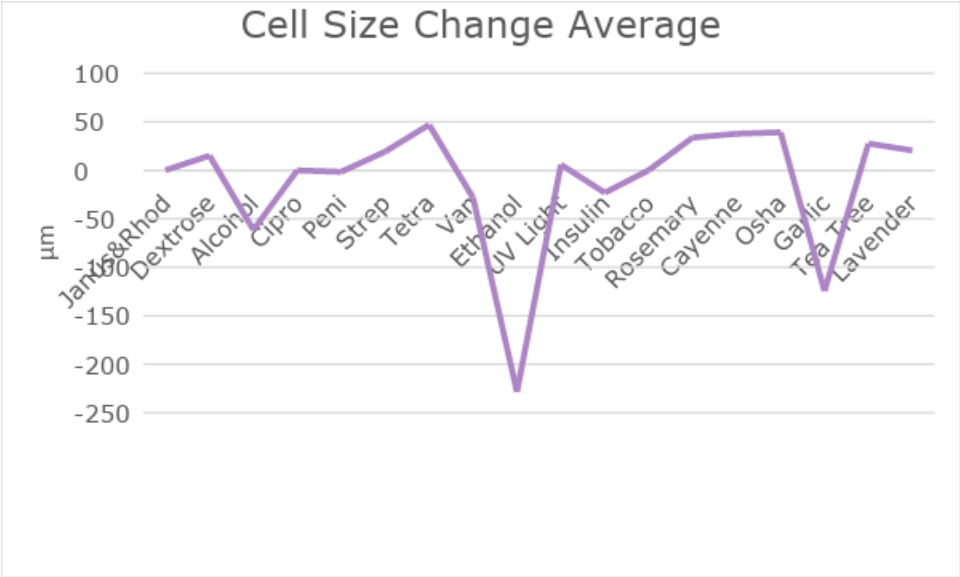
Cellular mortality indicates if the cell survived or not, and in the presence of some of the synthetically produced antibiotics and the tea tree oil solution, the cells had a high level of mortality.



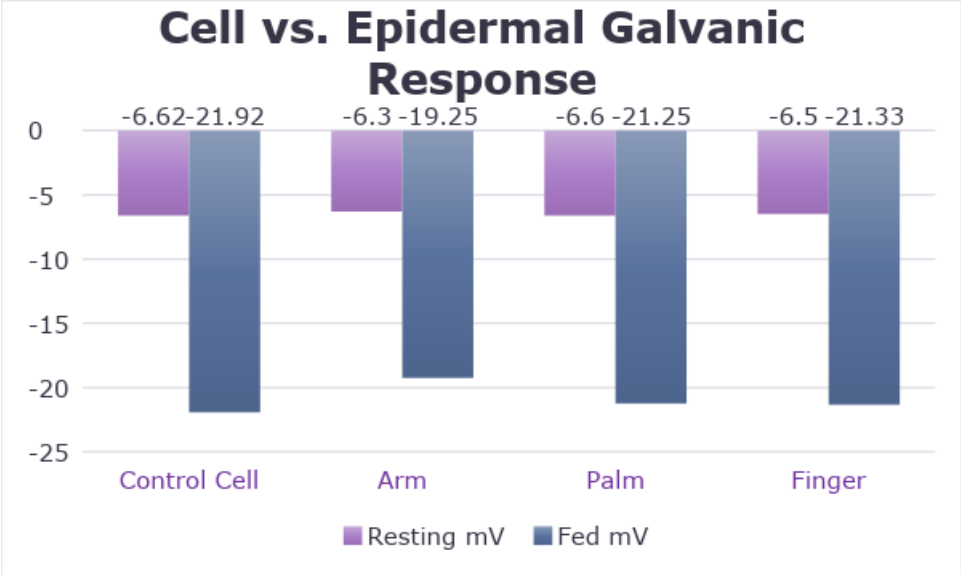
Mitochondrial change was observed through the Janus Green B illumination process, when the mitochondria winked out or turned pink, it was considered no longer viable and dysfunctional. There was a correlation to the dysfunction of the mitochondria and the conductivity level of the cells, once again most noticeable in the presence of the antibiotics and the tea tree oil.



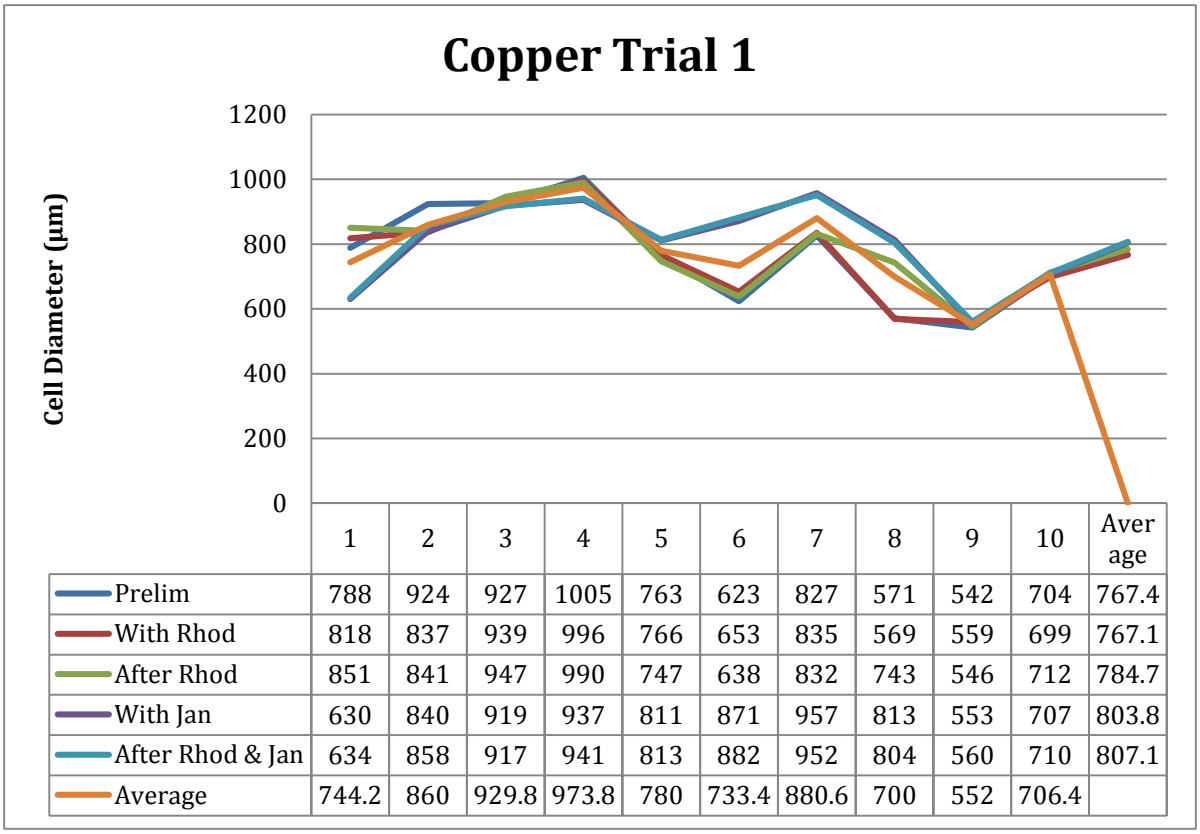
The galvanic cell conductance and resistance was indicated by tapping each cell with the multimeter electrodes in the most sensitive mV reading. The voltage was taken before and after exposure to the solutions. Conductivity is a negative result, while resistivity is a positive result indicating a closer status to homeostasis.



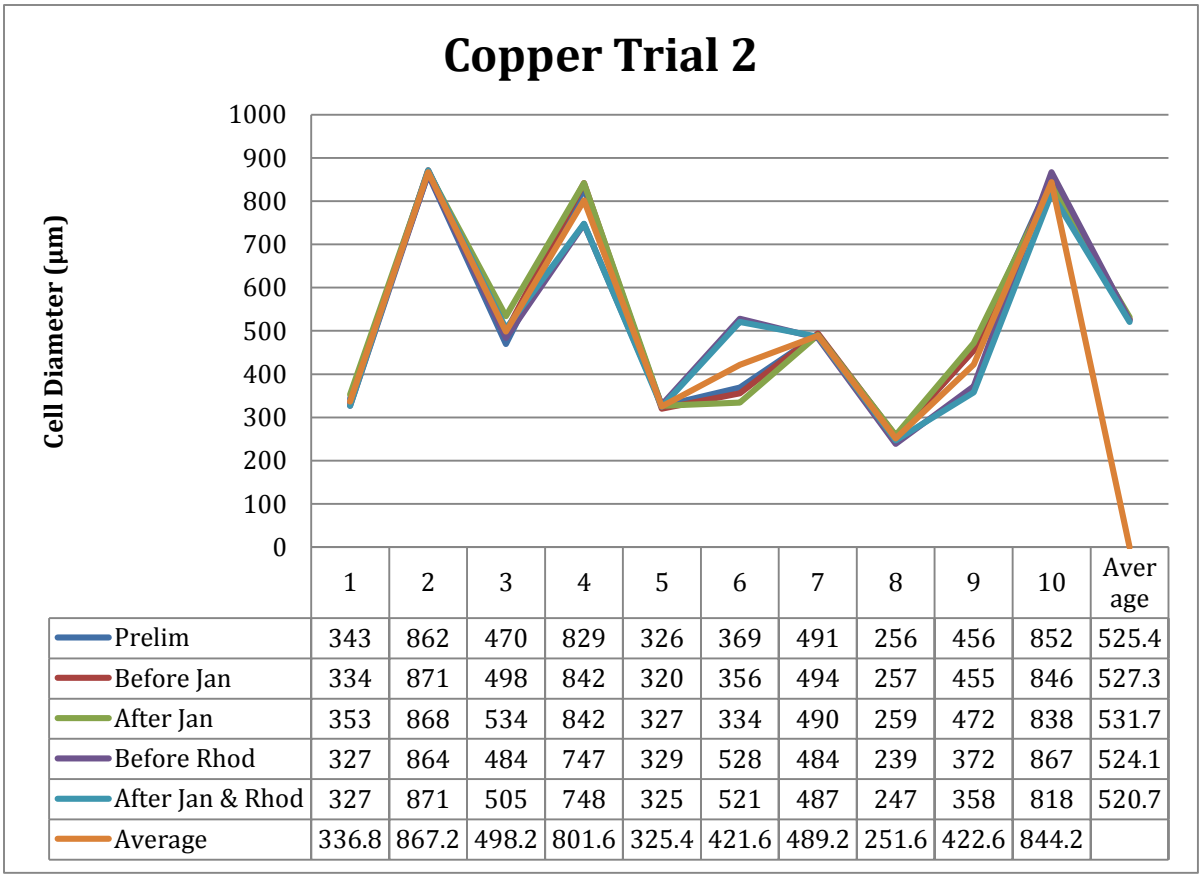
Cell sizes were recorded before and after exposure to the different solutions and dyes, many of the solutions caused blebbing, which is the swelling or shrinking of a cell in tune with stimuli. If a cell shrinks or expands too far, it can lyse and destroy itself. Homeostasis is near zero.



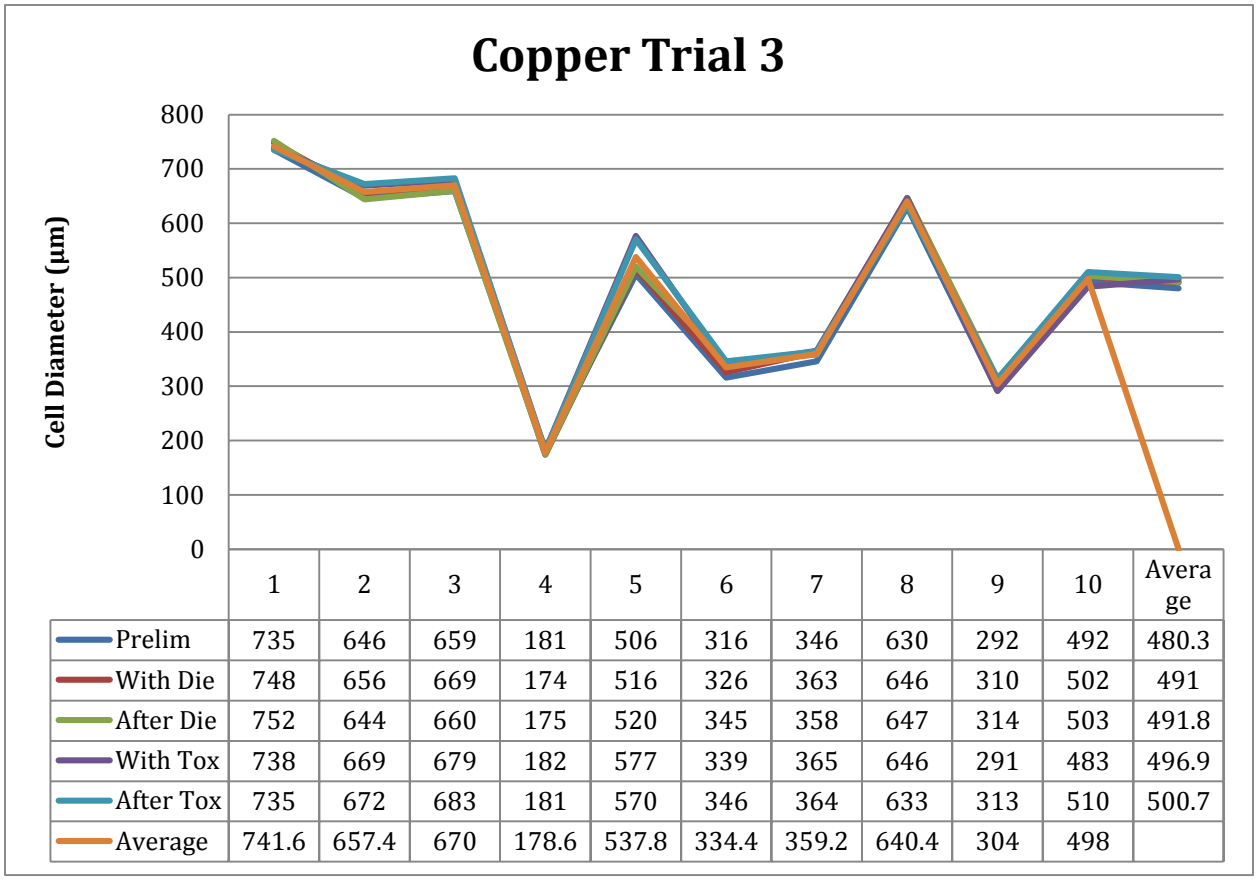
The micro-voltmeter was tested on the cells, and then against the adult volunteer's arm, palm and finger tips by gently touching it to the arm. This was done before eating and 30 minutes after the subject consumed food, the results were comparable indicating a correlation between not the sweat produced, but the mitochondrial ATP function for galvanic response.



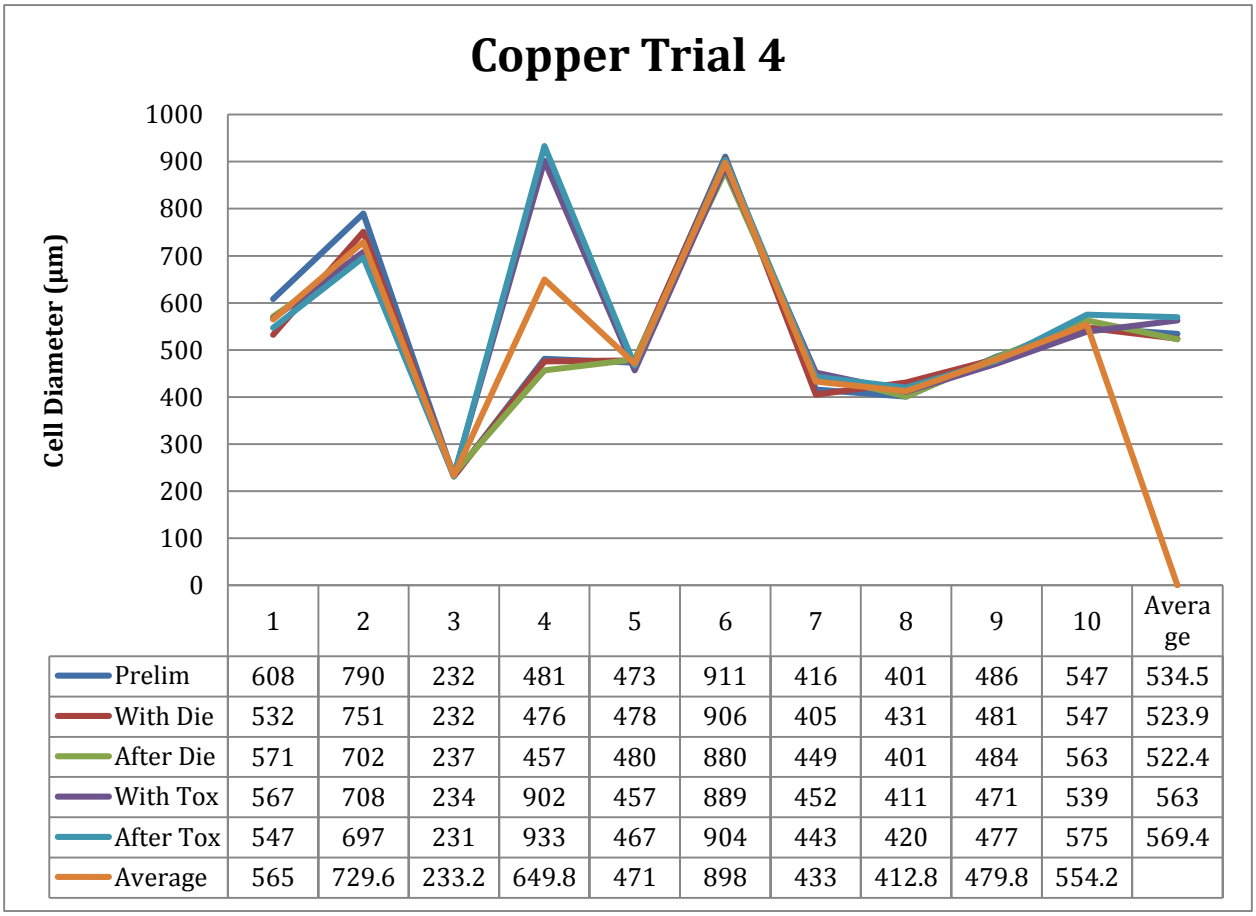
	1	2	3	4	5	6	7	8	9	10	Average
Prelim	788	924	927	1005	763	623	827	571	542	704	767.4
With Rhod	818	837	939	996	766	653	835	569	559	699	767.1
After Rhod	851	841	947	990	747	638	832	743	546	712	784.7
With Jan	630	840	919	937	811	871	957	813	553	707	803.8
After Rhod & Jan	634	858	917	941	813	882	952	804	560	710	807.1
Average	744.2	860	929.8	973.8	780	733.4	880.6	700	552	706.4	



	1	2	3	4	5	6	7	8	9	10	Average
Prelim	343	862	470	829	326	369	491	256	456	852	525.4
Before Jan	334	871	498	842	320	356	494	257	455	846	527.3
After Jan	353	868	534	842	327	334	490	259	472	838	531.7
Before Rhod	327	864	484	747	329	528	484	239	372	867	524.1
After Jan & Rhod	327	871	505	748	325	521	487	247	358	818	520.7
Average	336.8	867.2	498.2	801.6	325.4	421.6	489.2	251.6	422.6	844.2	

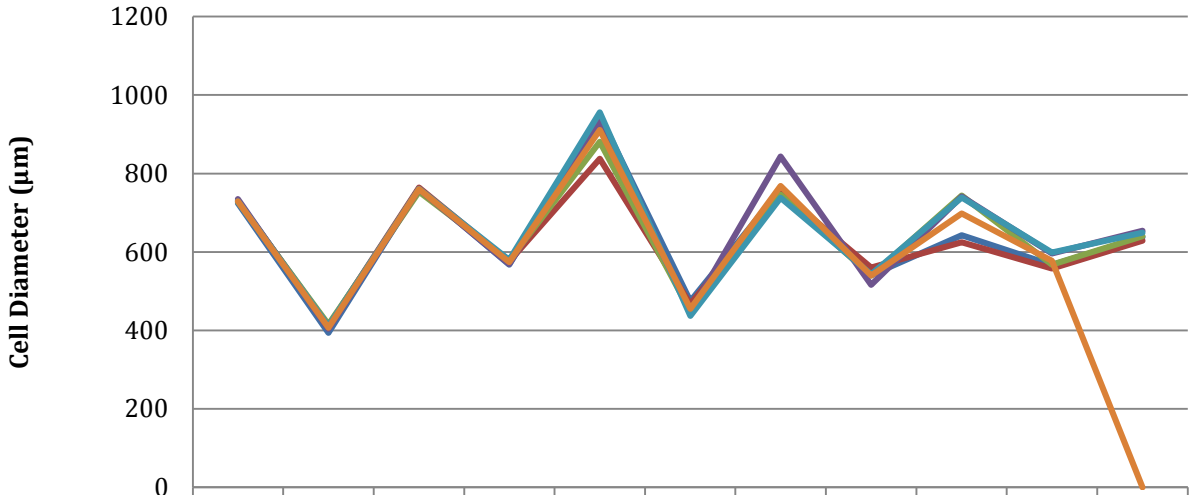


	1	2	3	4	5	6	7	8	9	10	Average
Prelim	735	646	659	181	506	316	346	630	292	492	480.3
With Die	748	656	669	174	516	326	363	646	310	502	491
After Die	752	644	660	175	520	345	358	647	314	503	491.8
With Tox	738	669	679	182	577	339	365	646	291	483	496.9
After Tox	735	672	683	181	570	346	364	633	313	510	500.7
Average	741.6	657.4	670	178.6	537.8	334.4	359.2	640.4	304	498	



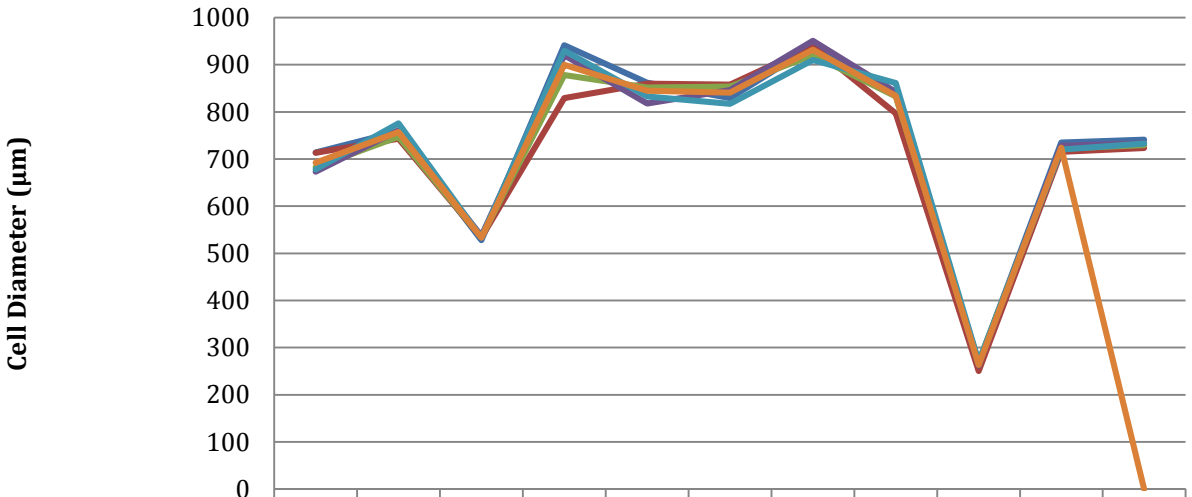
	1	2	3	4	5	6	7	8	9	10	Average
Prelim	608	790	232	481	473	911	416	401	486	547	534.5
With Die	532	751	232	476	478	906	405	431	481	547	523.9
After Die	571	702	237	457	480	880	449	401	484	563	522.4
With Tox	567	708	234	902	457	889	452	411	471	539	563
After Tox	547	697	231	933	467	904	443	420	477	575	569.4
Average	565	729.6	233.2	649.8	471	898	433	412.8	479.8	554.2	

Copper Trial 5

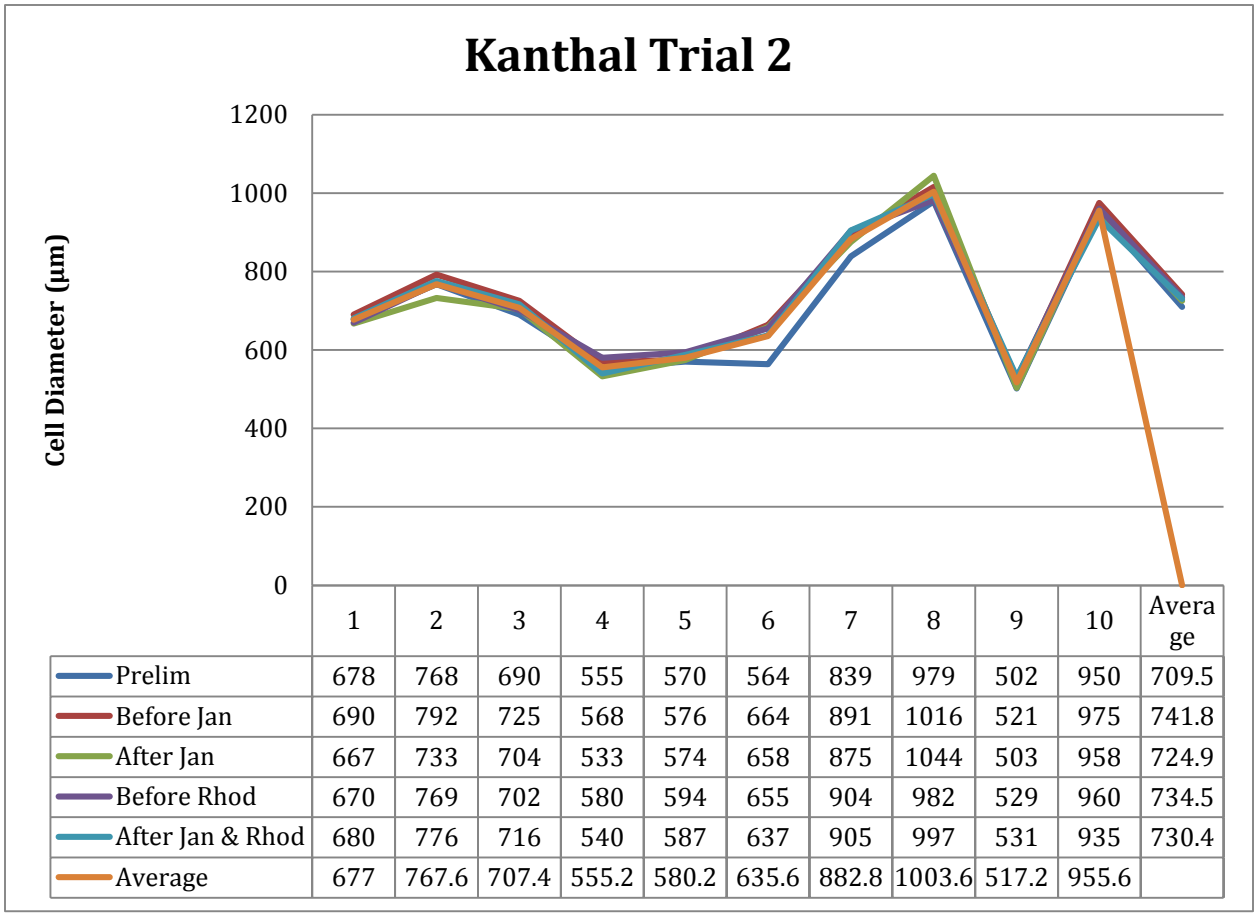


	1	2	3	4	5	6	7	8	9	10	Average
Prelim	724	394	762	568	947	475	759	541	643	567	638
With Die	731	411	764	576	838	467	754	560	625	558	628.4
After Die	728	415	754	578	881	448	746	540	744	568	640.2
With Tox	735	404	760	569	932	447	843	516	741	596	654.3
After Tox	729	411	761	580	956	437	738	543	739	599	649.3
Average	729.4	407	760.2	574.2	910.8	454.8	768	540	698.4	577.6	

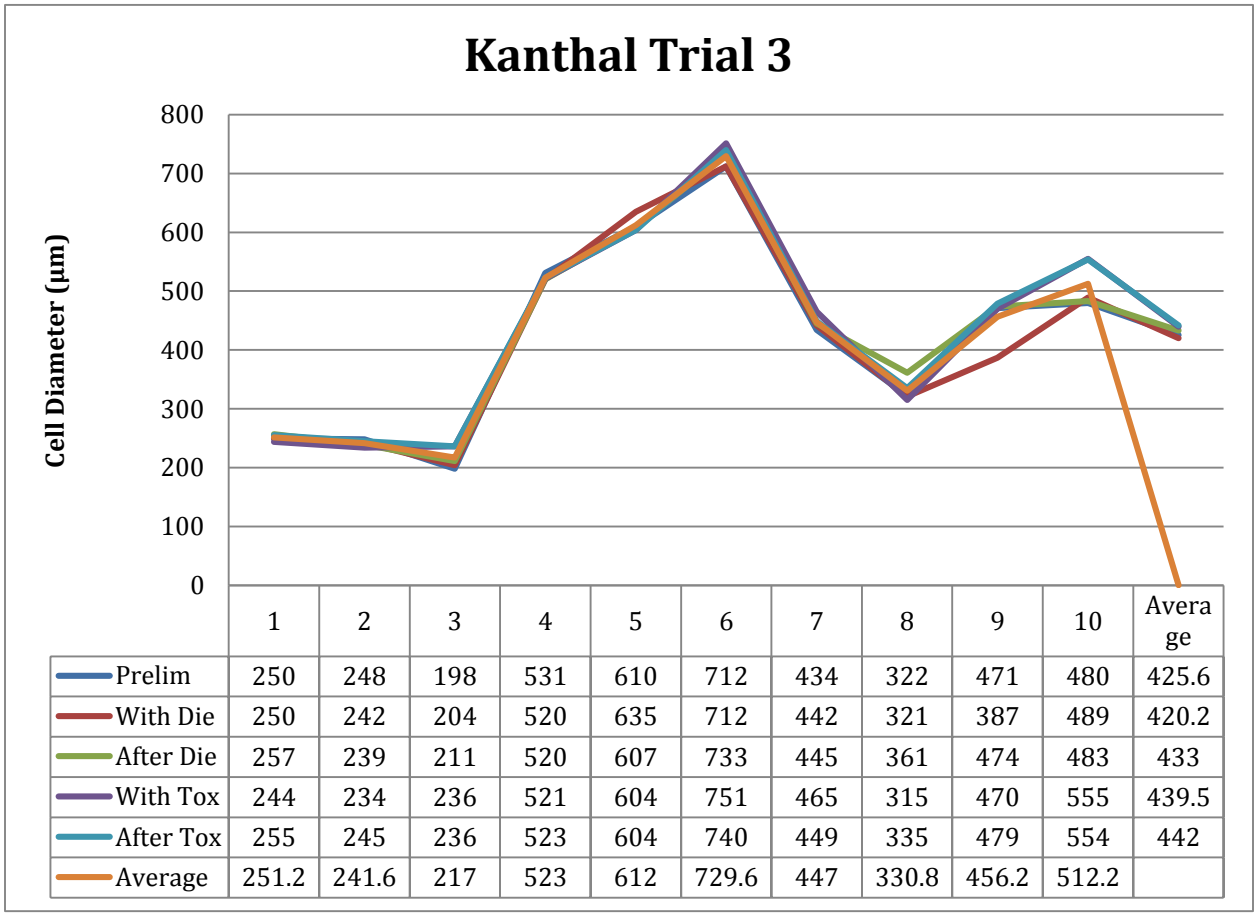
Kanthal Trial 1



	1	2	3	4	5	6	7	8	9	10	Average
Prelim	714	759	528	941	862	829	939	838	267	735	741.2
With Rhod	713	743	533	829	860	858	939	797	250	715	723.7
After Rhod	683	747	534	878	852	854	920	833	269	722	729.2
With Jan	673	761	537	920	818	846	951	842	262	728	733.8
After Rhod & Jan	678	776	533	930	833	817	910	861	269	720	732.7
Average	692.2	757.2	533	899.6	845	840.8	931.8	834.2	263.4	724	

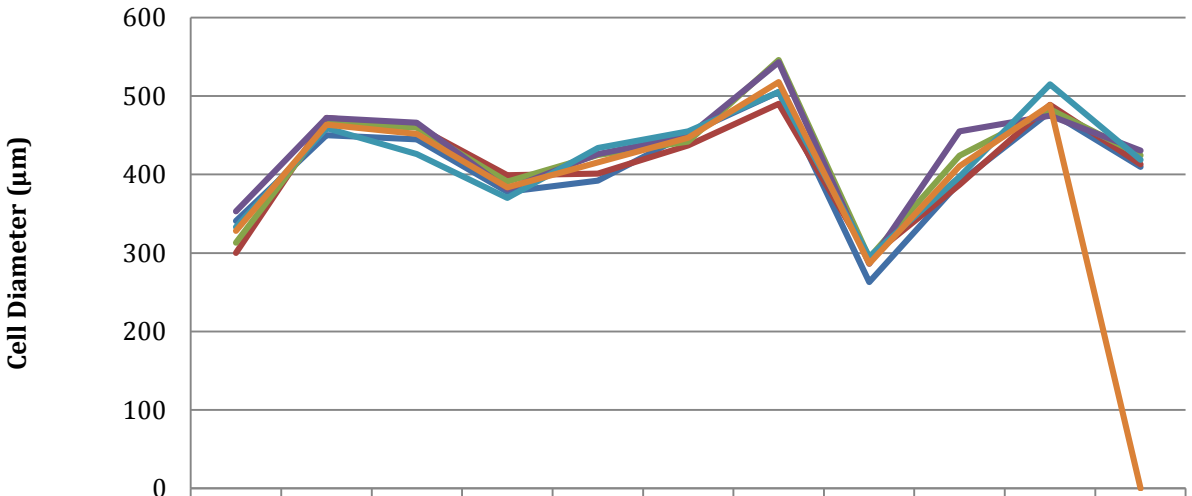


	1	2	3	4	5	6	7	8	9	10	Average
Prelim	678	768	690	555	570	564	839	979	502	950	709.5
Before Jan	690	792	725	568	576	664	891	1016	521	975	741.8
After Jan	667	733	704	533	574	658	875	1044	503	958	724.9
Before Rhod	670	769	702	580	594	655	904	982	529	960	734.5
After Jan & Rhod	680	776	716	540	587	637	905	997	531	935	730.4
Average	677	767.6	707.4	555.2	580.2	635.6	882.8	1003.6	517.2	955.6	



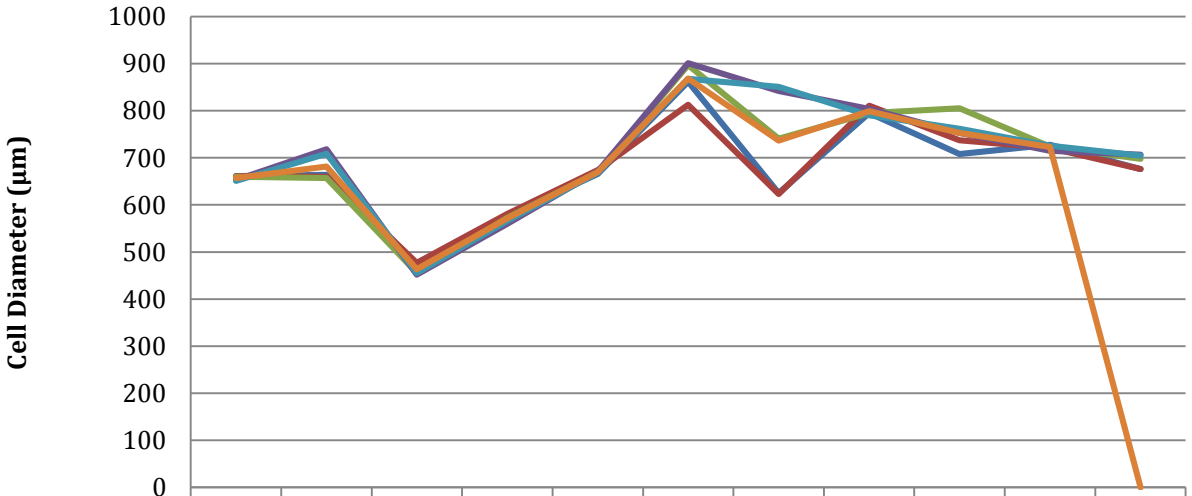
	1	2	3	4	5	6	7	8	9	10	Average
Prelim	250	248	198	531	610	712	434	322	471	480	425.6
With Die	250	242	204	520	635	712	442	321	387	489	420.2
After Die	257	239	211	520	607	733	445	361	474	483	433
With Tox	244	234	236	521	604	751	465	315	470	555	439.5
After Tox	255	245	236	523	604	740	449	335	479	554	442
Average	251.2	241.6	217	523	612	729.6	447	330.8	456.2	512.2	

Kanthal Trial 4



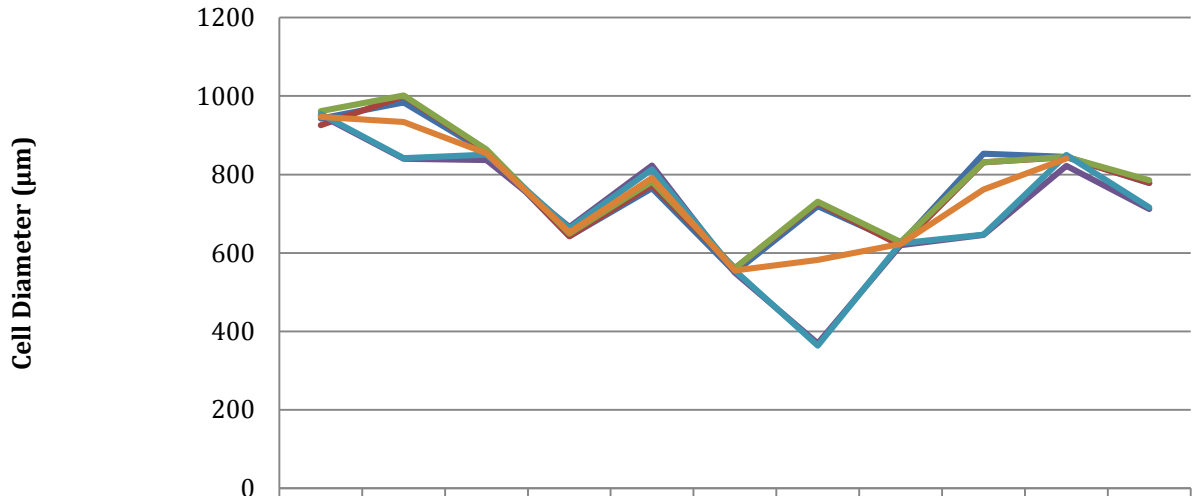
	1	2	3	4	5	6	7	8	9	10	Average
Prelim	341	450	445	378	392	452	505	263	390	480	409.6
With Die	300	472	461	399	401	437	490	294	387	489	413
After Die	313	465	460	391	425	442	546	294	424	483	424.3
With Tox	353	472	466	381	426	449	543	286	455	475	430.6
After Tox	333	459	426	370	434	455	505	295	397	515	418.9
Average	328	463.6	451.6	383.8	415.6	447	517.8	286.4	410.6	488.4	

Kanthal Trial 5



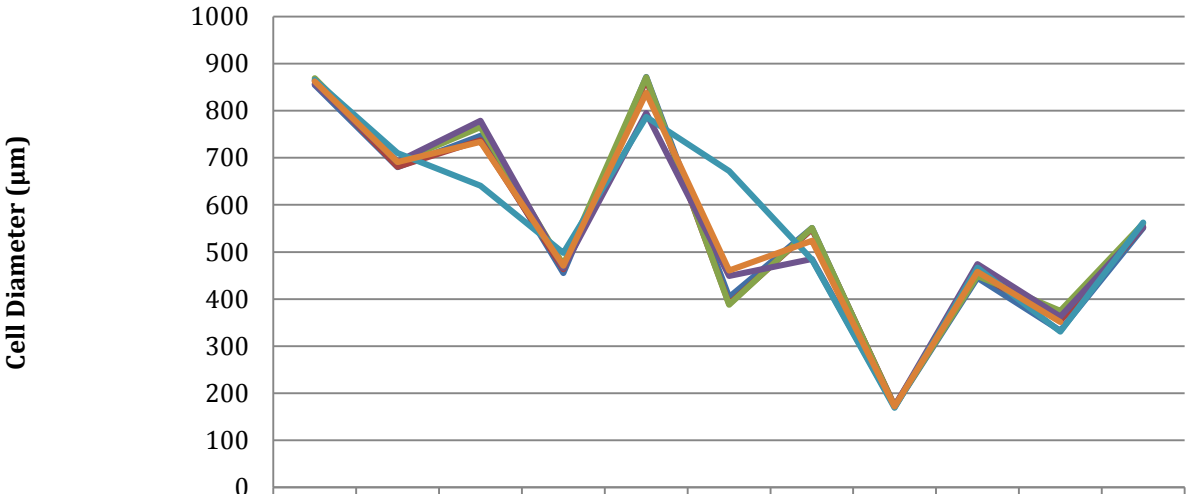
	1	2	3	4	5	6	7	8	9	10	Average
Prelim	661	664	475	576	666	862	625	795	708	728	676
With Die	661	660	477	581	674	813	623	811	737	721	675.8
After Die	660	657	456	573	669	897	741	795	805	724	697.7
With Tox	653	718	452	560	671	901	842	804	753	715	706.9
After Tox	651	709	455	566	669	868	851	790	762	726	704.7
Average	657.2	681.6	463	571.2	669.8	868.2	736.4	799	753	722.8	

Nichrome Trial 1



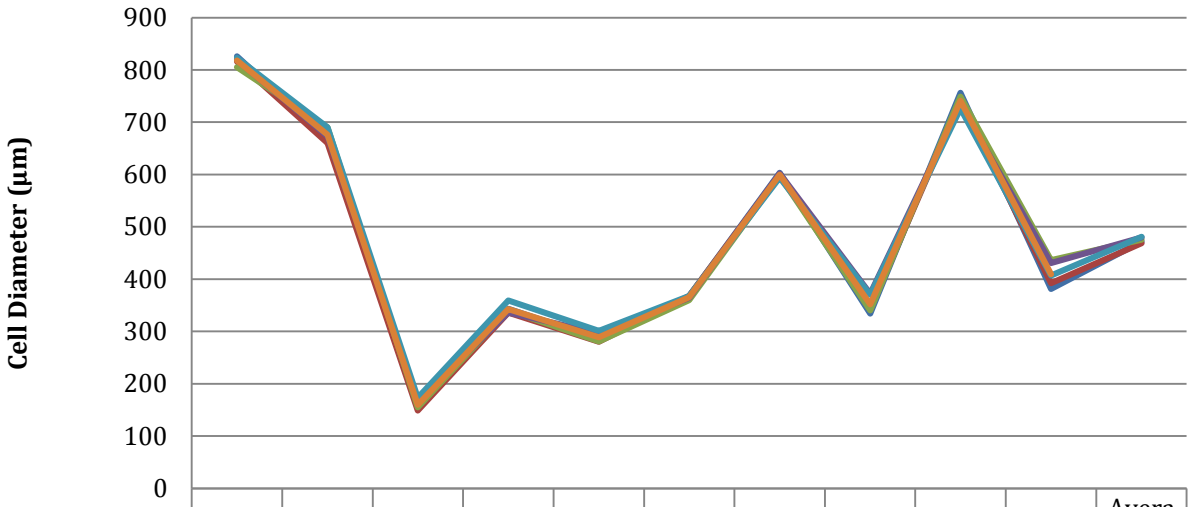
	1	2	3	4	5	6	7	8	9	10	Average
Prelim	943	984	857	643	765	551	719	624	853	845	778.4
With Rhod	926	1000	861	643	773	561	728	619	831	844	778.6
After Rhod	962	1002	864	649	782	561	731	628	831	845	785.5
With Jan	951	840	837	666	823	550	369	620	646	822	712.4
After Rhod & Jan	954	842	851	663	813	555	364	625	647	850	716.4
Average	947.2	933.6	854	652.8	791.2	555.6	582.2	623.2	761.6	841.2	

Nichrome Trial 2



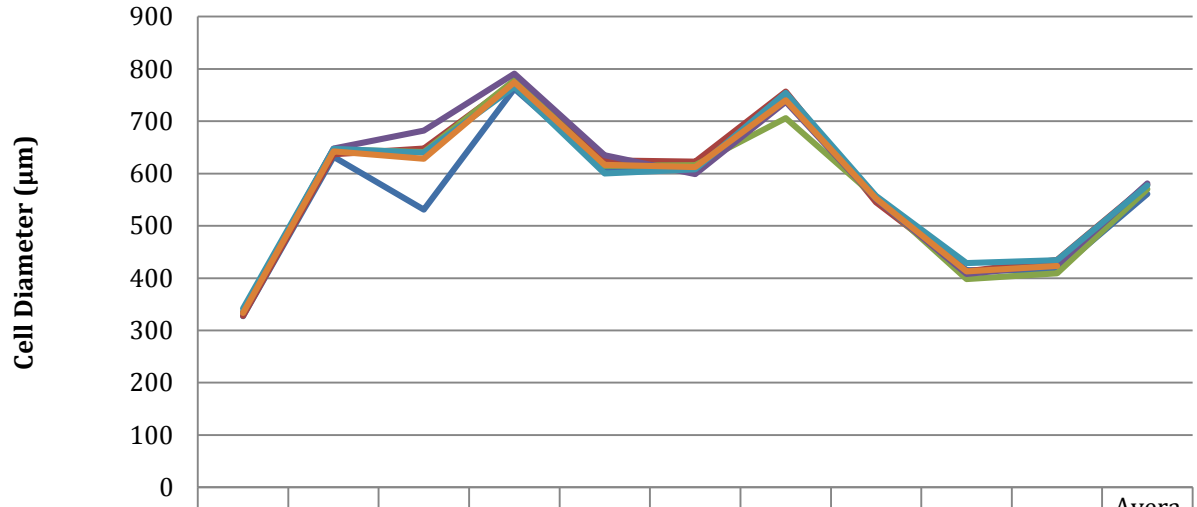
	1	2	3	4	5	6	7	8	9	10	Average
Prelim	855	680	747	455	872	404	551	171	445	333	551.3
Before Jan	864	681	737	463	866	390	548	174	454	354	553.1
After Jan	869	691	765	473	871	388	551	172	449	375	560.4
Before Rhod	857	692	779	466	795	449	485	172	474	363	553.2
After Jan & Rhod	866	710	641	498	787	672	484	169	467	331	562.5
Average	862.2	690.8	733.8	471	838.2	460.6	523.8	171.6	457.8	351.2	

Nichrome Trial 3

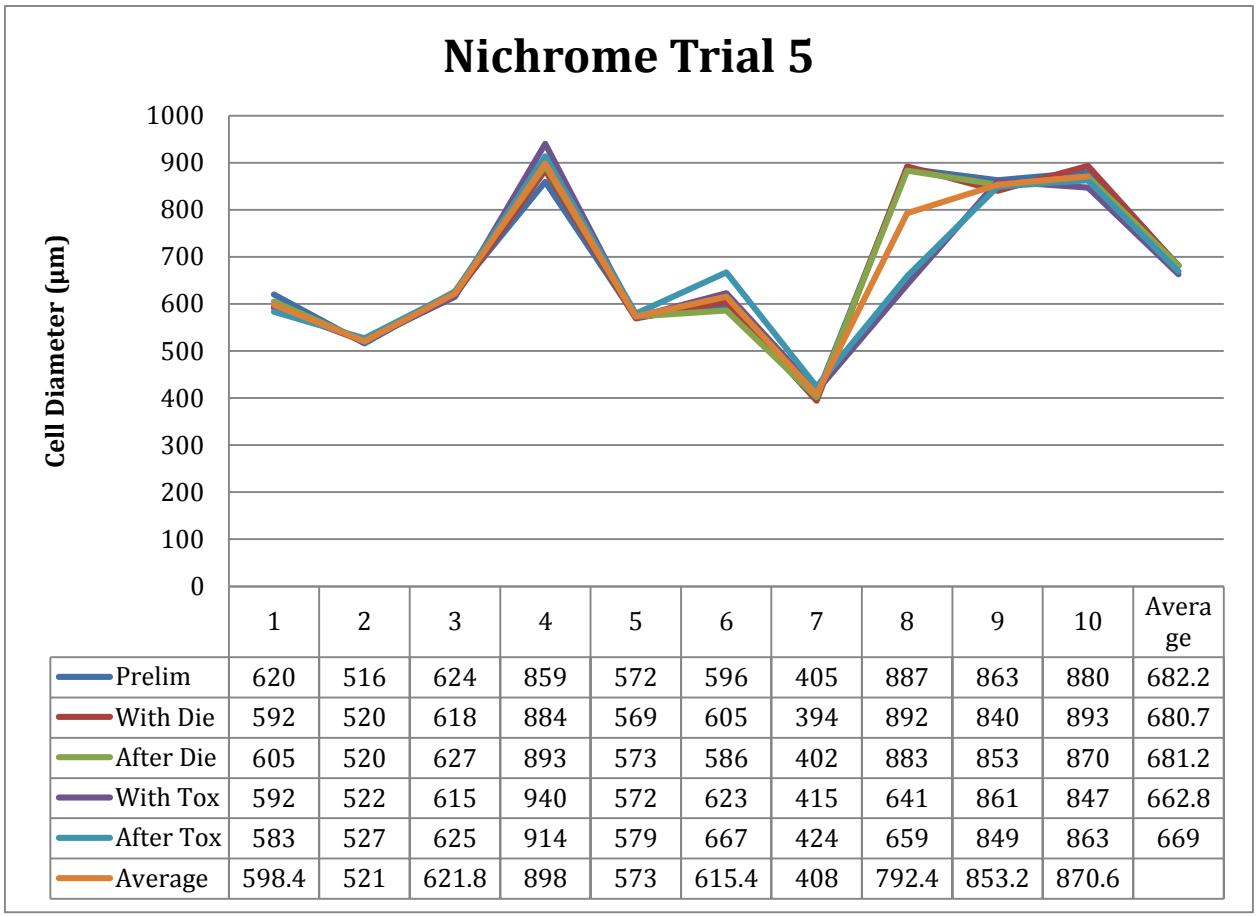


	1	2	3	4	5	6	7	8	9	10	Average
Prelim	826	668	155	343	286	367	603	334	756	381	471.9
With Die	816	660	149	336	280	368	600	343	741	392	468.5
After Die	805	690	155	340	281	360	598	340	749	436	475.4
With Tox	819	673	168	336	297	364	602	372	733	431	479.5
After Tox	823	690	173	359	301	368	594	370	726	407	481.1
Average	817.8	676.2	160	342.8	289	365.4	599.4	351.8	741	409.4	

Nichrome Trial 4



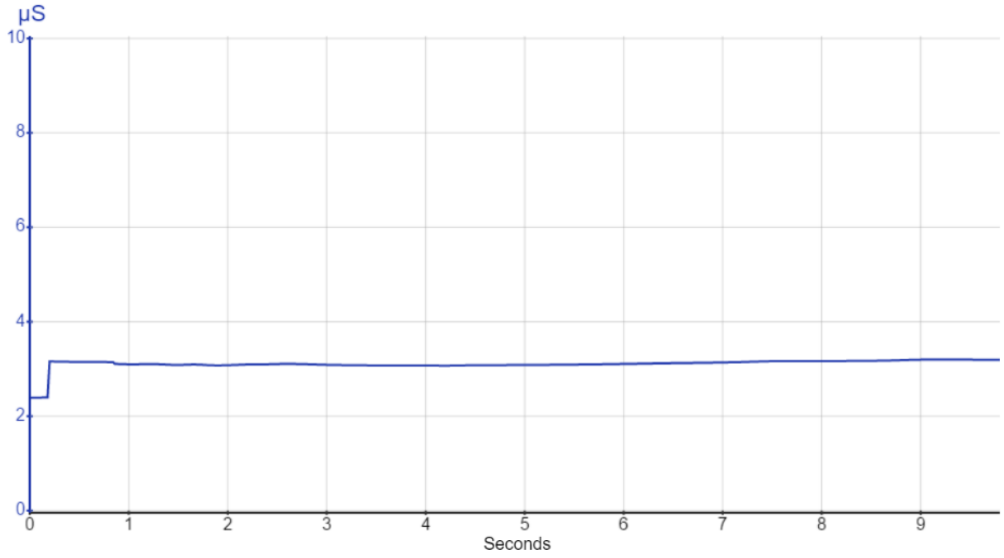
	1	2	3	4	5	6	7	8	9	10	Average
Prelim	327	632	531	762	609	616	746	556	415	414	560.8
With Die	328	637	648	775	625	623	757	545	413	435	578.6
After Die	336	646	641	779	615	616	706	554	398	409	570
With Tox	334	648	682	791	635	599	737	551	408	425	581
After Tox	342	647	640	766	600	608	754	557	429	434	577.7
Average	333.4	642	628.4	774.6	616.8	612.4	740	552.6	412.6	423.4	



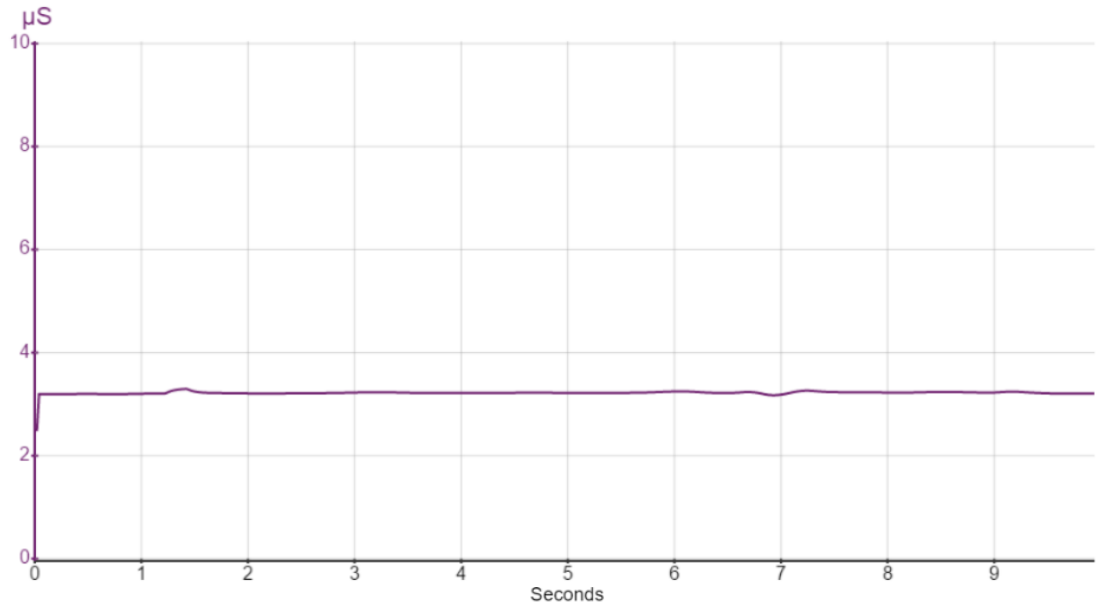
	1	2	3	4	5	6	7	8	9	10	Average
Prelim	620	516	624	859	572	596	405	887	863	880	682.2
With Die	592	520	618	884	569	605	394	892	840	893	680.7
After Die	605	520	627	893	573	586	402	883	853	870	681.2
With Tox	592	522	615	940	572	623	415	641	861	847	662.8
After Tox	583	527	625	914	579	667	424	659	849	863	669
Average	598.4	521	621.8	898	573	615.4	408	792.4	853.2	870.6	

The following are graphs from our database of cellular reactions towards stimulation/toxicity.

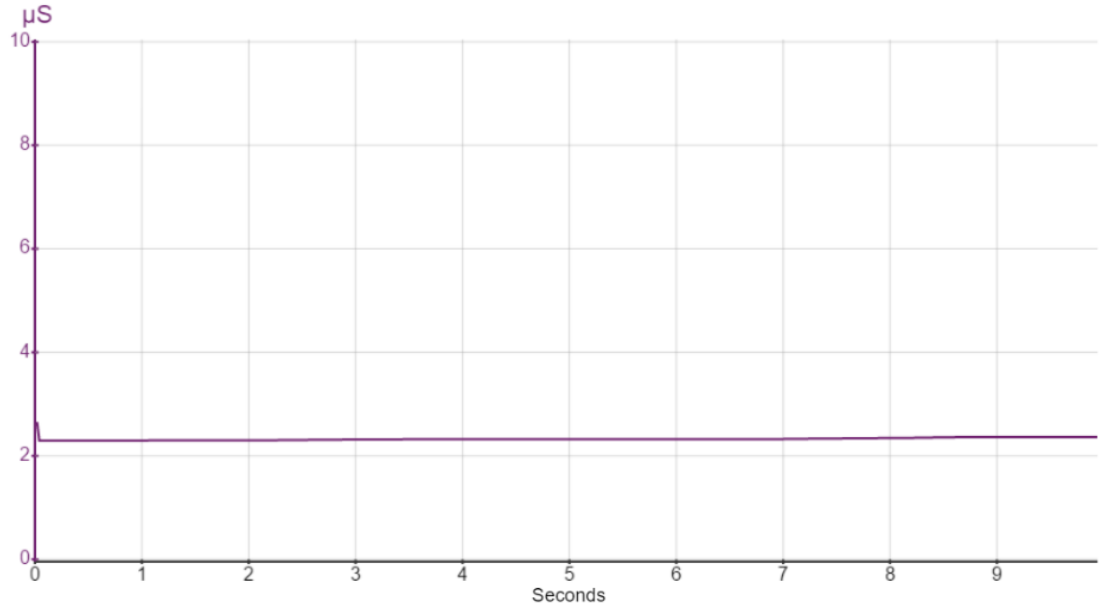
For these, we used a Galvanic Skin Sensor to gather baseline data from a healthy subject, subject with Diabetes and a subject with an Autoimmune Deficiency. Each subject took a control reading, a reading while holding their breath, drinking water and eating. They took these readings on the regular sensor and on the sensor after we made modifications to it based off of our experimentation.



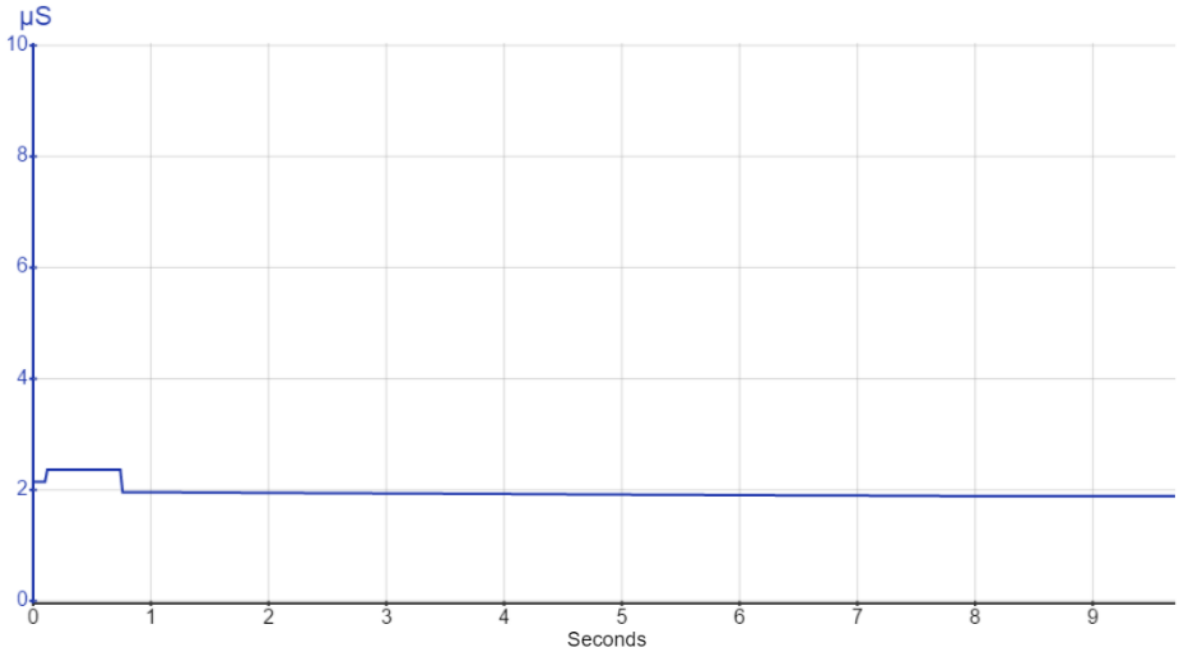
Control Healthy Baseline



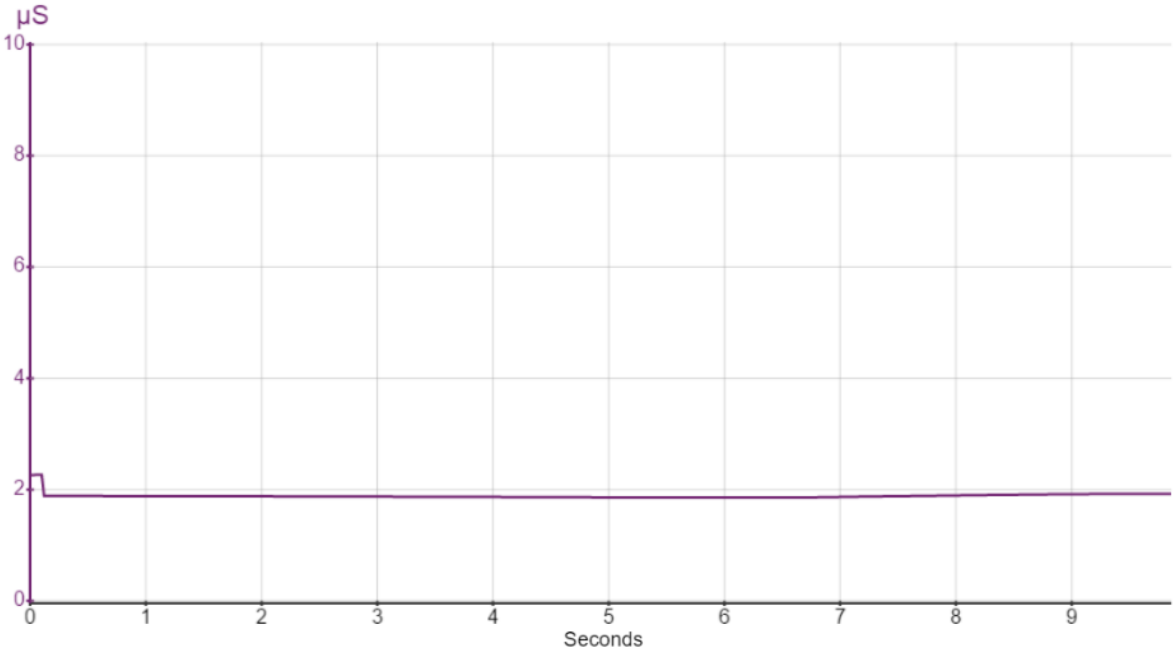
Control Healthy Breath



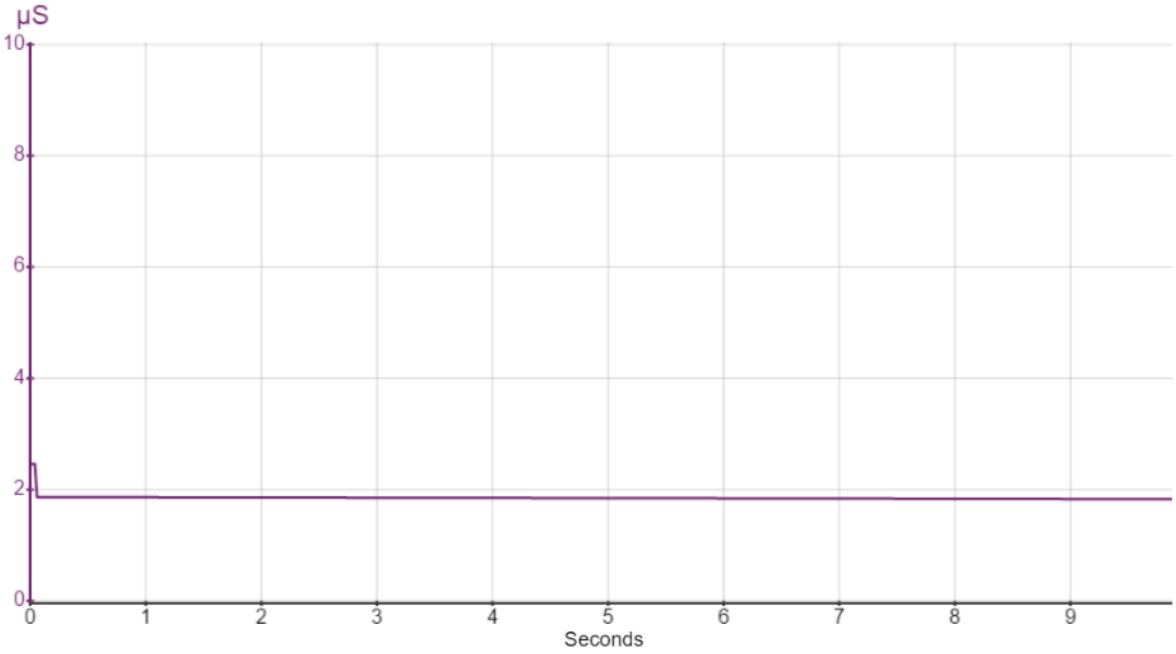
Control Healthy Water



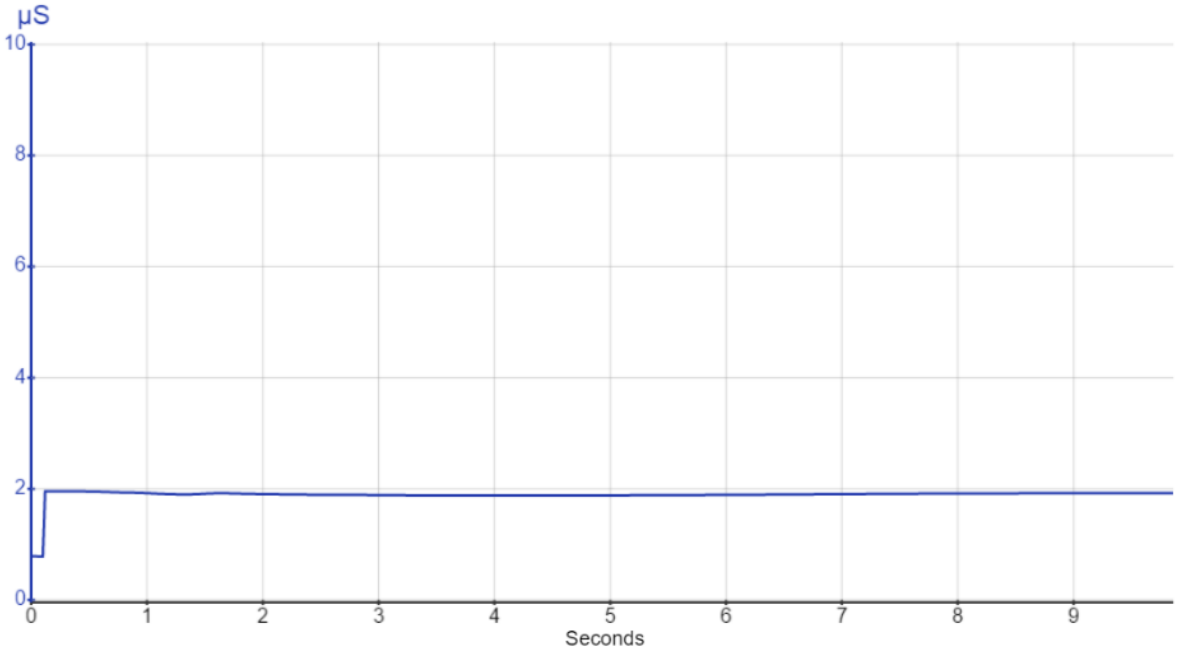
Altered Healthy Baseline



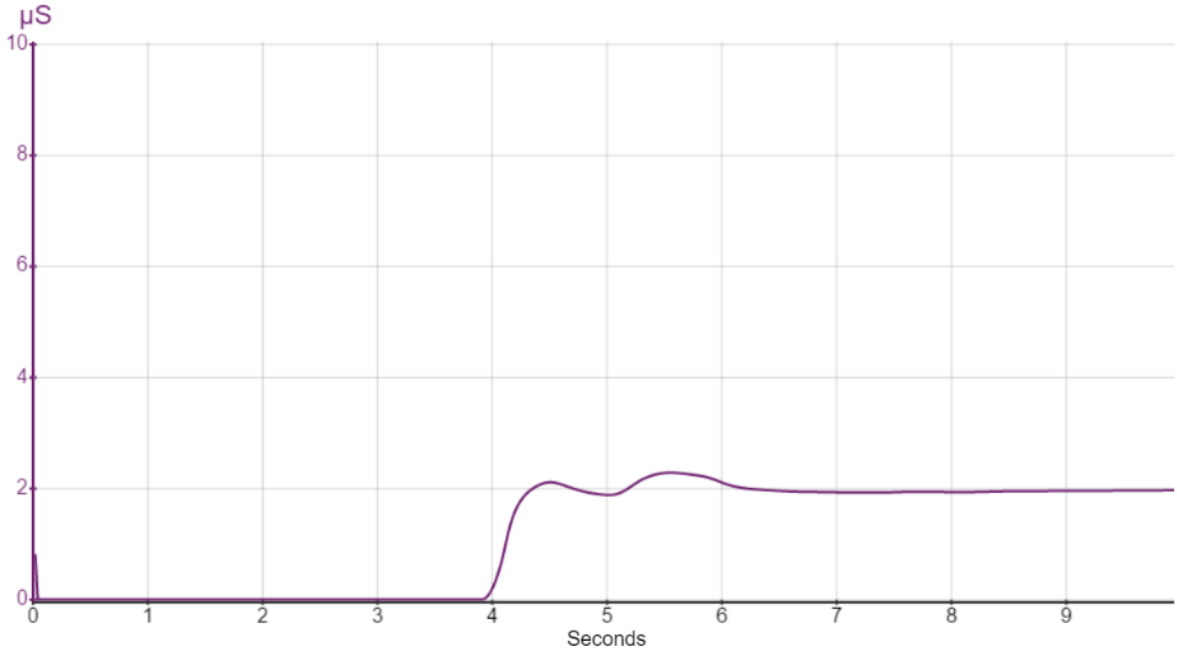
Altered Healthy Breath



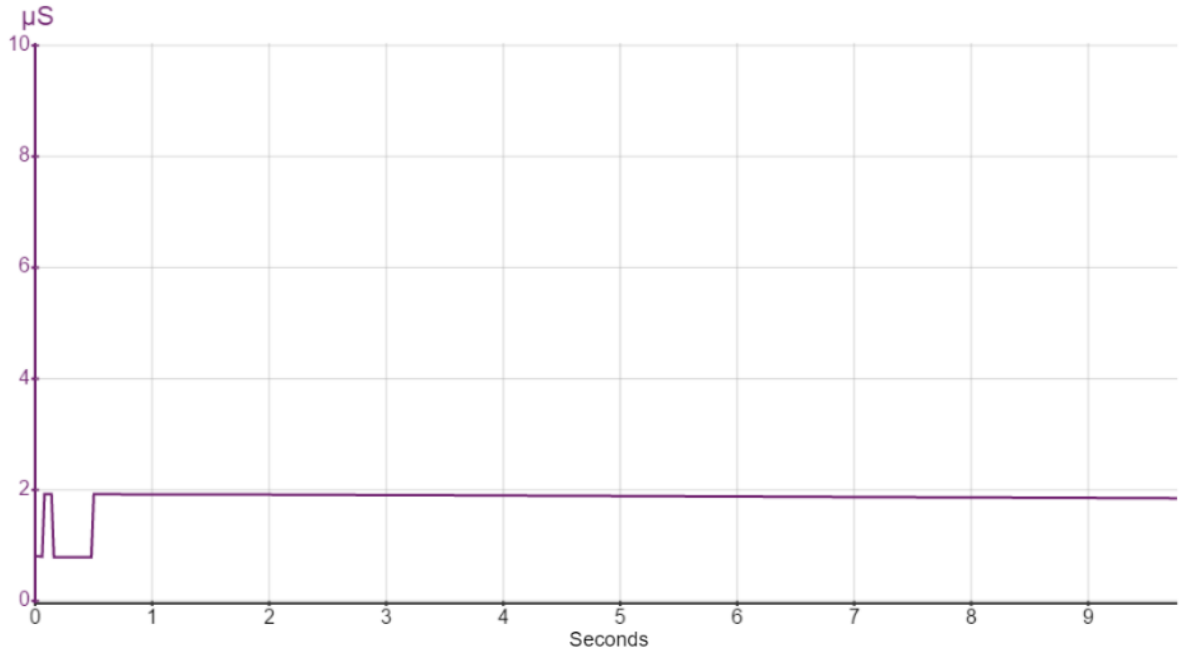
Altered Healthy Water



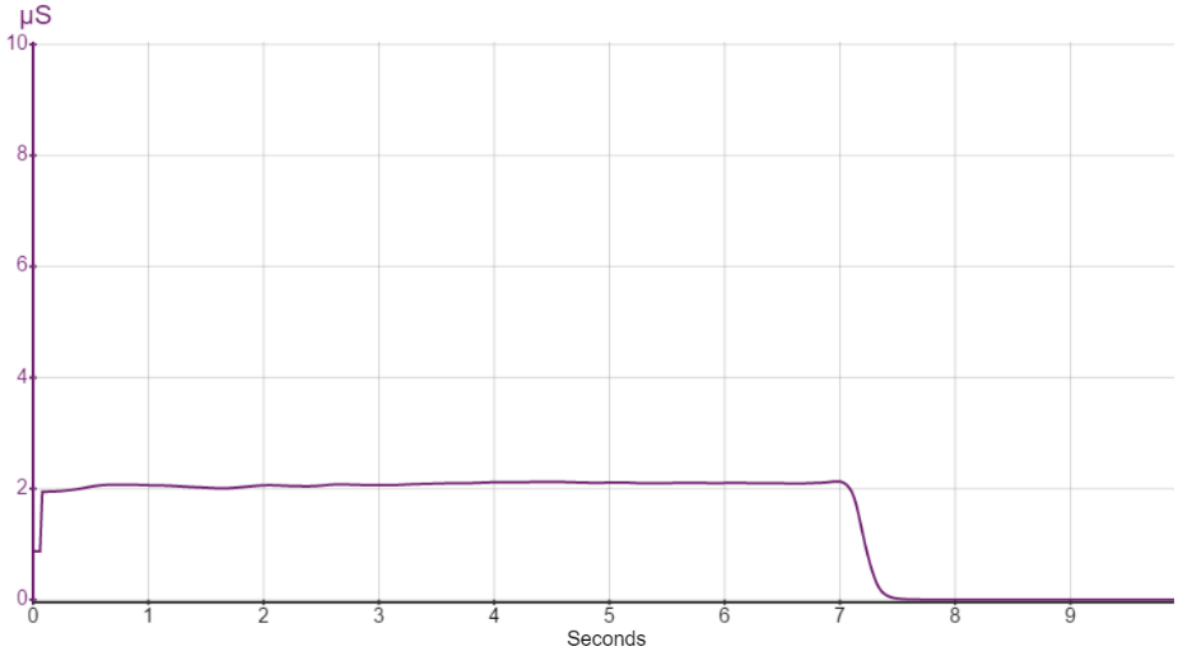
Control Diabetic Baseline



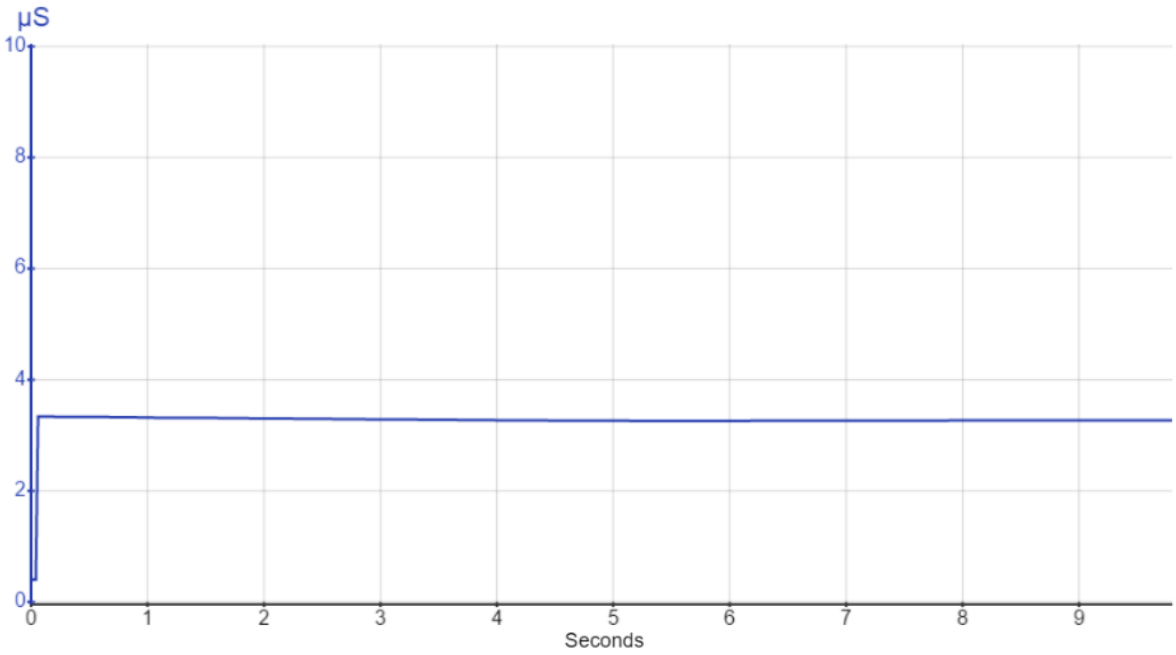
Control Diabetic Breath



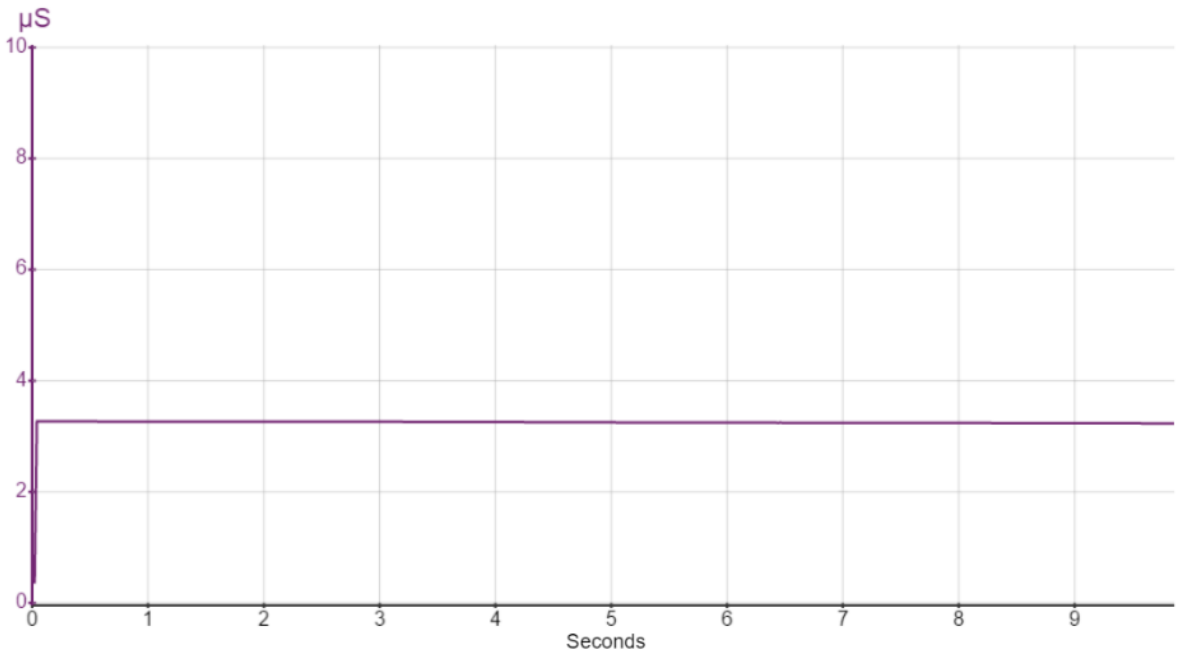
Control Diabetic Eat



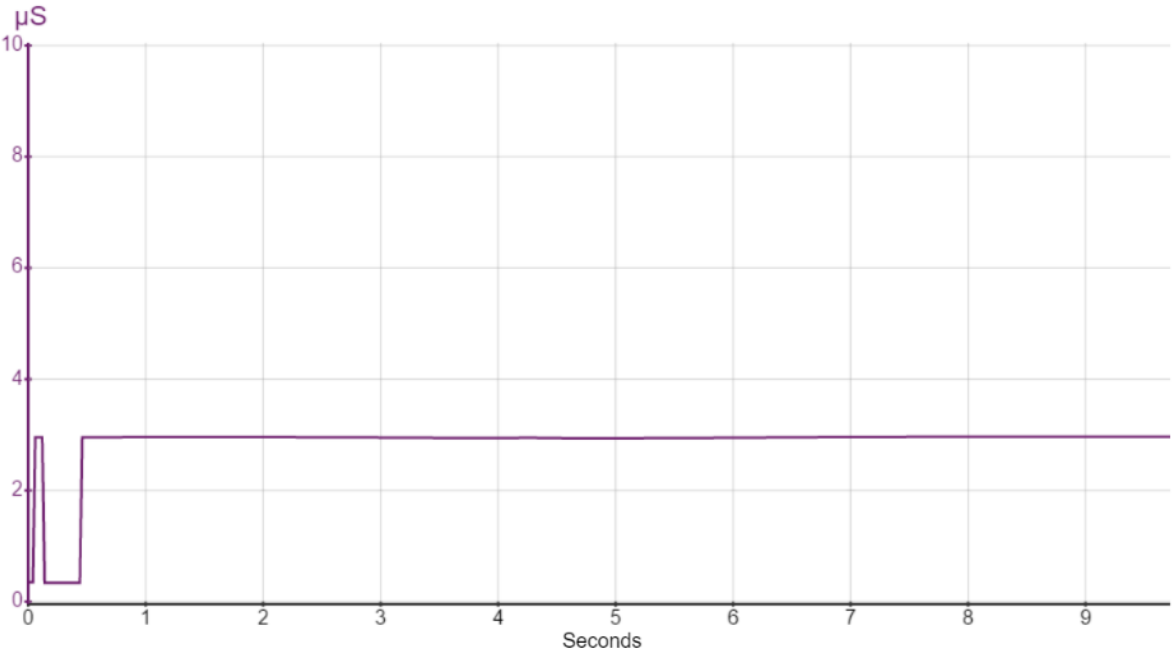
Control Diabetic Water



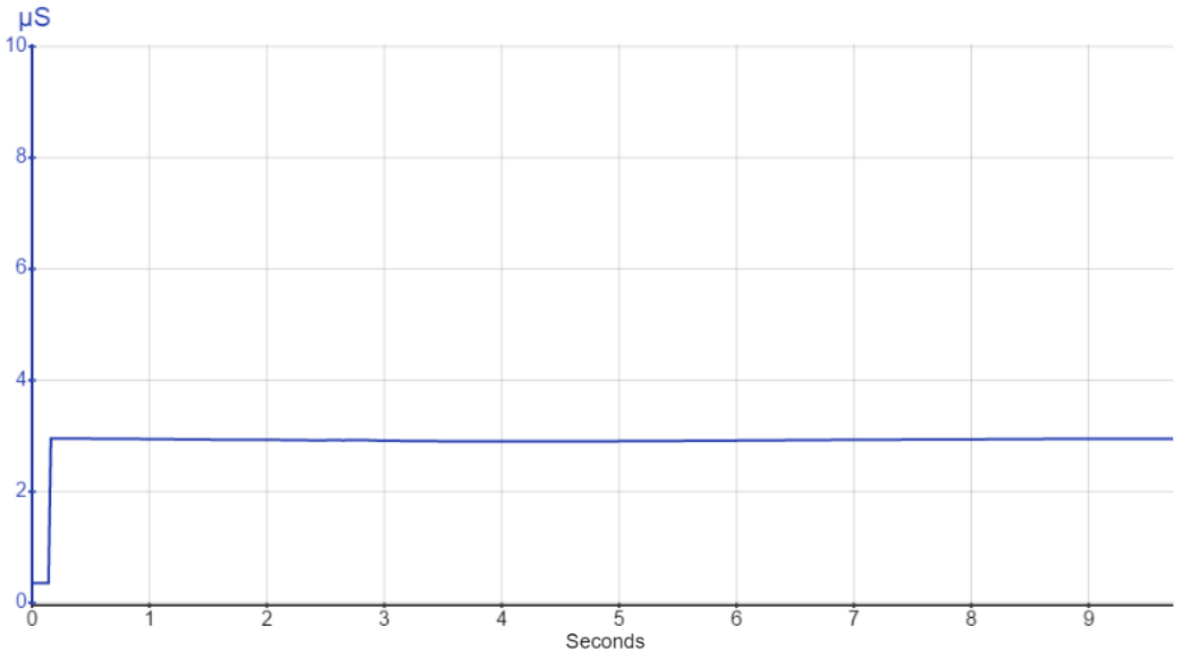
Altered Diabetic Baseline



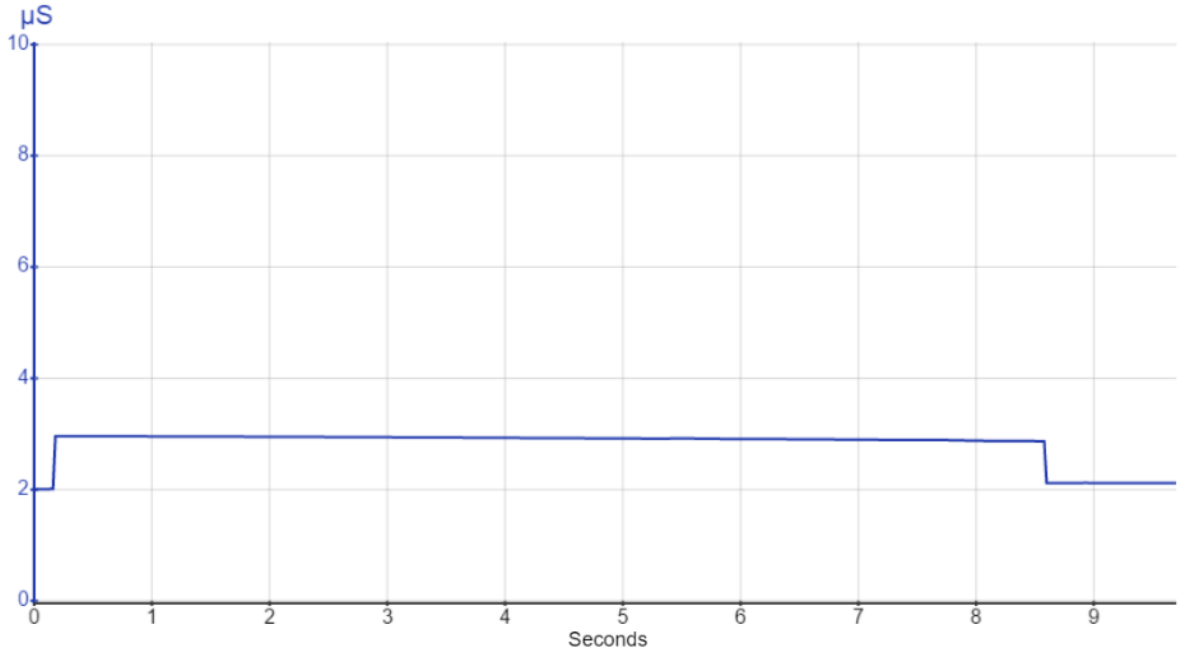
Altered Diabetic Breath



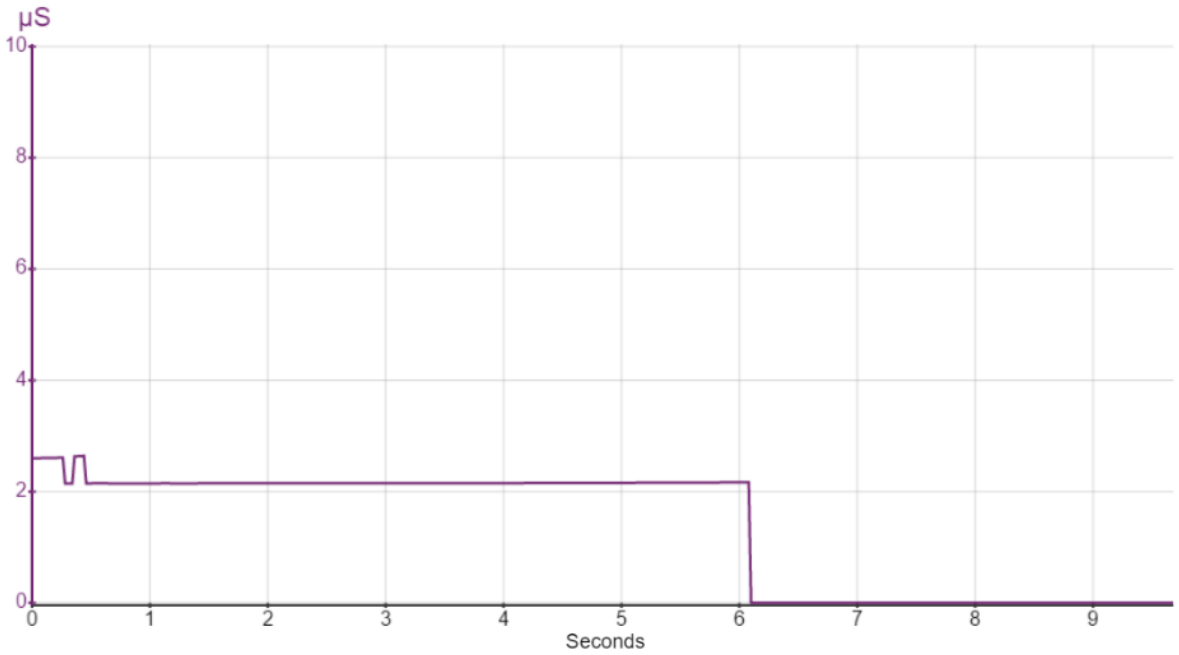
Altered Diabetic Eat



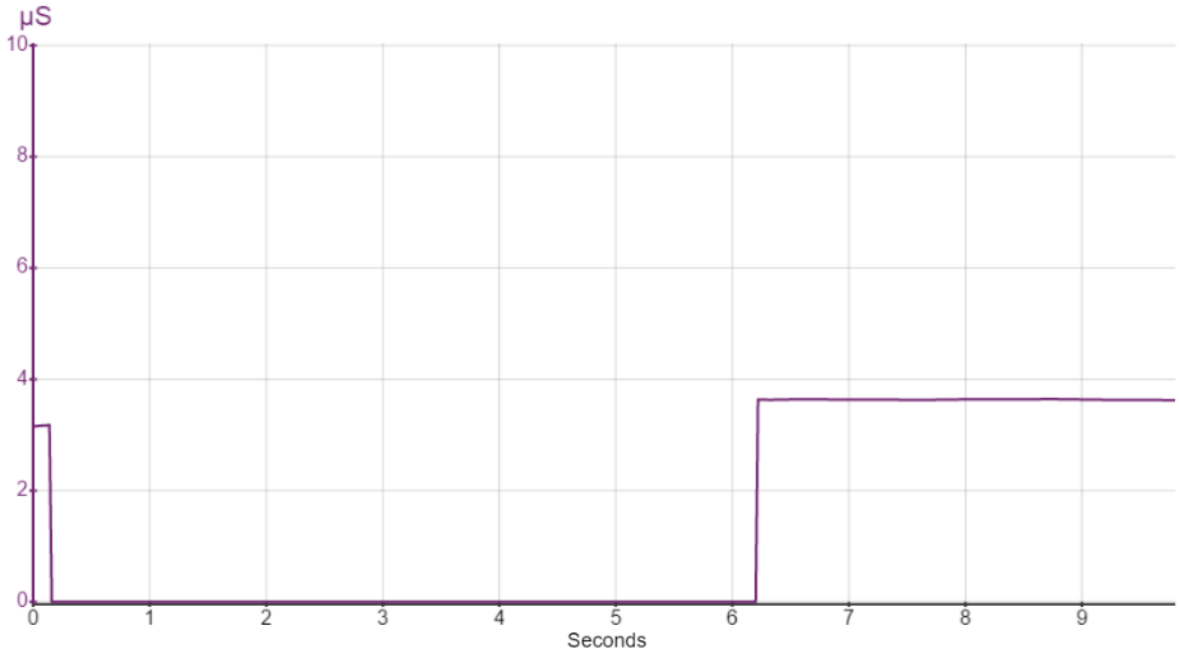
Altered Diabetic Water



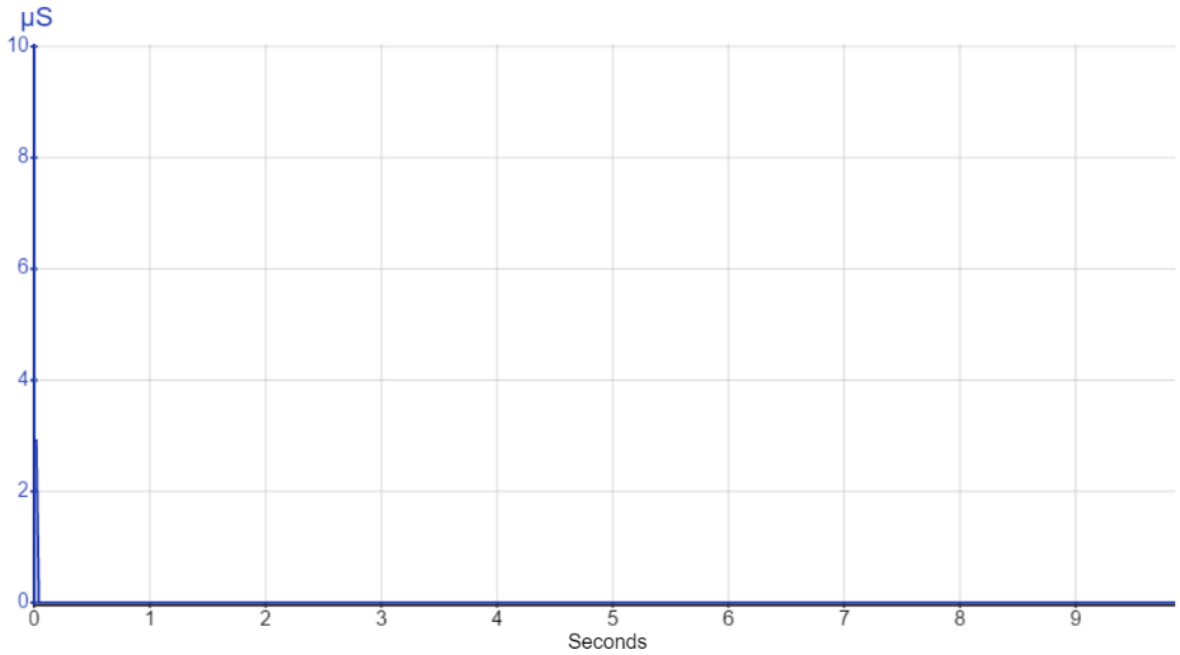
Control Autoimmune Baseline



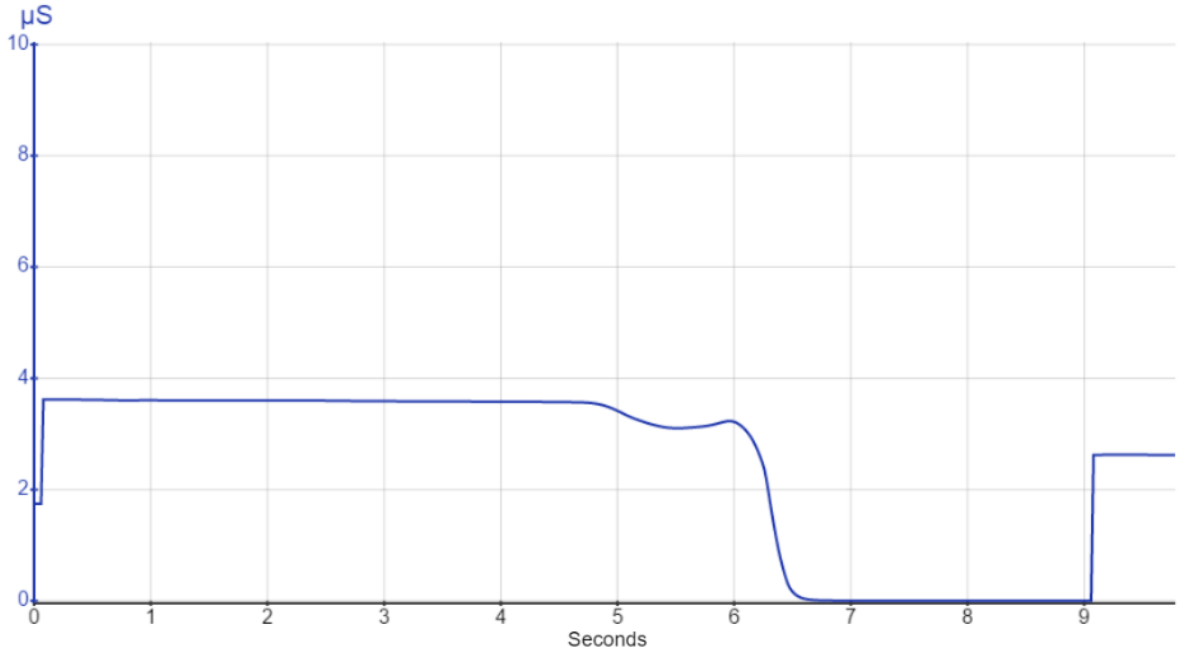
Control Autoimmune Breath



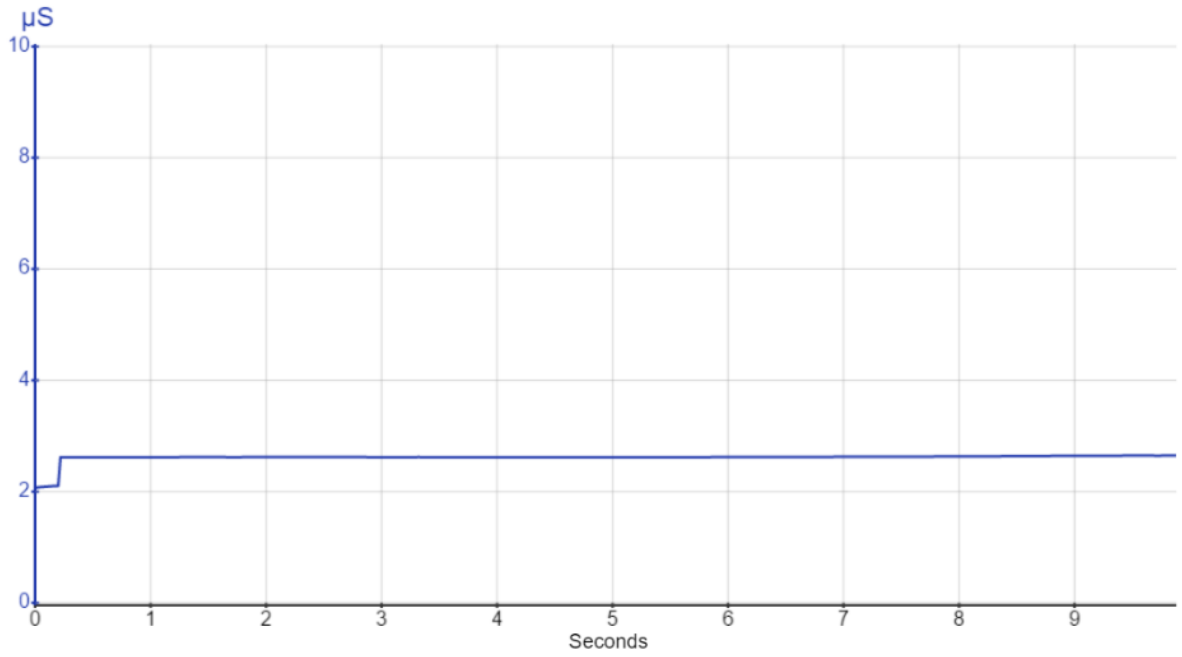
Control Autoimmune Eat



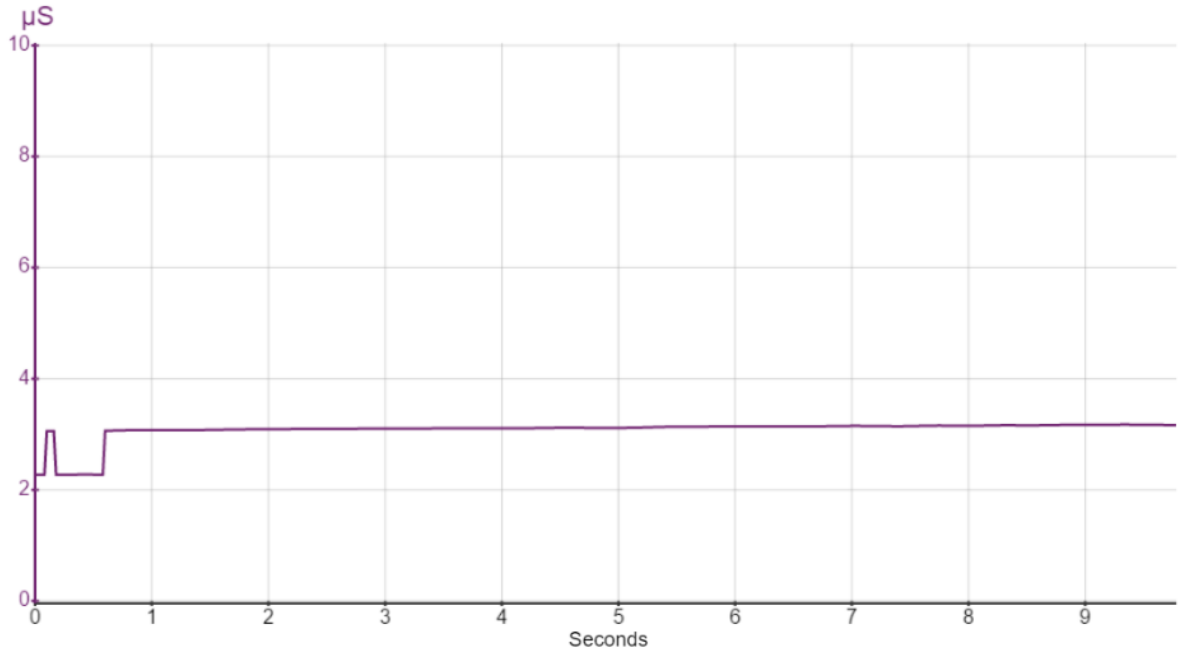
Control Autoimmune Water



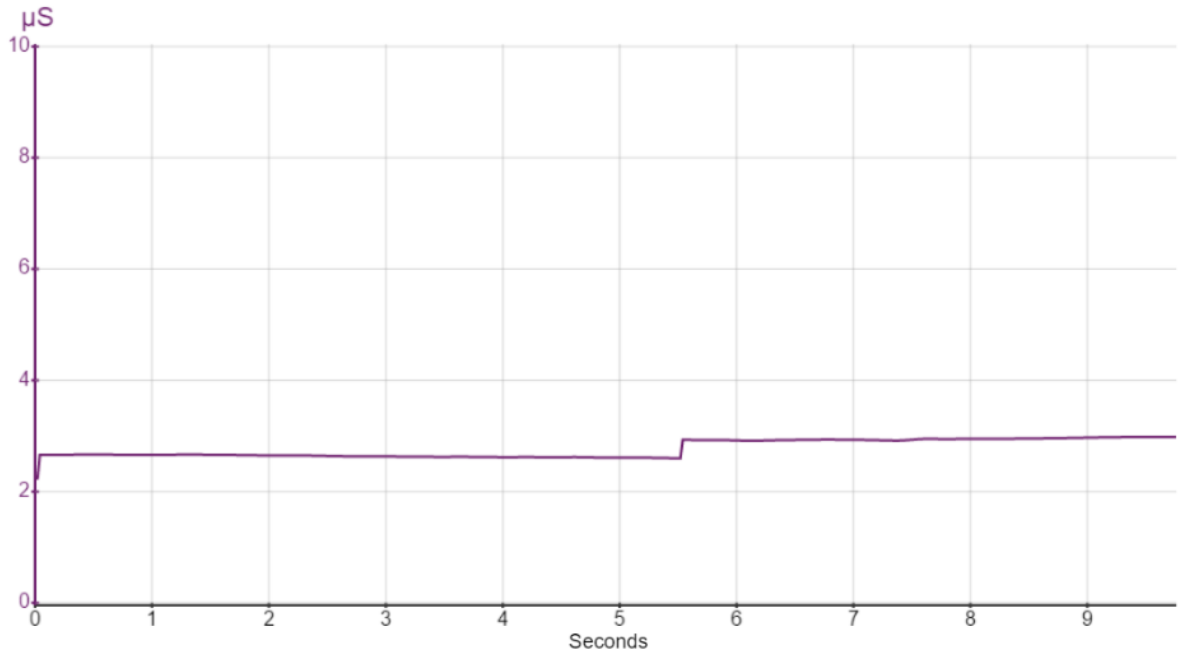
Altered Autoimmune Baseline



Altered Autoimmune Breath



Altered Autoimmune Eat



Altered Autoimmune Water

Phase 1 Conclusion:

Upon conducting the experiment and analyzing the data, it can be concluded that galvanic cell response correlates to galvanic skin response, as well as cellular response and mitochondrial response as a whole. Upon introduction of the varying solutions, the epidermal cell cultures had a notable reaction in mitochondrial function and mortality, and in some cases, cellular mortality. The cells reacted by blebbing within a matter of minutes of the exposure to the varying solutions, and the mitochondria began to change function and tone. As natural solutions were introduced to the cells, their resistivity increased, and as toxins and synthetically produced substances were introduced, their conductivity increased which correlates to galvanic skin response, with the only true exception being tea tree oil, which is a natural toxin. Tests were conducted with the epidermal cell subject by having them touch the multimeter on the arm, palm and fingertips, which indicated a very close correlation with cellular galvanic response and epidermal galvanic response. These experiments indicate a true correlation towards galvanic response at the cellular level in the face of potential medicines and toxins.

The hypothesis that stated that as the cells were stressed by toxins the conductivity will increase due to an immune response and the viable cells' attempt to work harder against the toxin, while the positive stimuli such as dextrose feeding will increase resistivity as the cell does not have to work as hard to maintain homeostasis is supported by the data. The second hypothesis which stated that copper and silver will be more sensitive to detecting these changes than other conductive materials is not supported as the copper and silver electrodes for the multimeter were not as sensitive as the gold and broke. The final hypothesis of as exposure to toxins increase, the more the conductivity will increase until the cell enters apoptosis or necrosis when the ATP function ceases. Cells that are not viable will not produce conductivity or resistance is fully supported by the data obtained. Future experimentation will include expanding

the test database with more medications and then to develop a full library for a testing strip to determine what toxins may be potentially causing cellular dysfunction at the mitochondrial level, which could lead to a paper testing strip or a simple galvanic test to determine the source of a disease.

Phase 2 Conclusion:

Upon conducting the experiment and analyzing the data, it can be concluded that the copper, then the Kanthal, and finally the Nichrome increased the conductivity/resistivity ability of the micromultimeter in detecting subtle changes in cell viability and function, and proved to be a more viable indicator of electrodermal and electrocellular activity than the silver electrodes used for galvanic skin response. A combination of the copper and Kanthal produces a galvanic cell sensor that is accurate to the cell reaction to stimuli within a matter of milliseconds. The sensor wires were capable of detecting resistance in healthy and functional cells, particularly those that were being fed with dextrose, and conductance in cells that were under stress from substances that are deemed toxins such as tobacco and alcohol. Measurements at the fingertips, between the fingers, at the wrist, and behind the ears were the most accurate in mV resistance and conductance in comparison to the cellular response resistance and conductance.

It was initially hypothesized that copper and silver would be sensitive enough to detect the changes in cellular conductivity and resistivity in accordance to stressors and normal stimuli, this was partially supported, as Kanthal does include silver oxide, and the copper was very accurate, moreso than the existing silver sensor included with a galvanic skin meter. Areas between the fingers and behind the ear should be most sensitive to conductivity/resistivity measurements. This hypothesis was partially supported, as the measurements behind the ear were

less accurate than the measuring points on the hands. The cells did show resistance the more healthy and homeostatic they were, because the cells were not having to work as hard to maintain homeostasis, while in the presence of stressors the conductance did increase because the cells were working harder to maintain homeostasis. Finally, the most conductive wires, copper and Kanthal can be integrated with small relays to translate the conductivity/resistivity readings to an application that will indicate cellular stress or dysfunction, this was also supported because the two wire types increased the sensitivity of a galvanic skin response sensor, therefore producing a galvanic cell response sensor. This data allows for the acceptance of the hypotheses as stated. Future experimentation will continue to test individuals who have known diagnosed ailments with the sensor apparatus, to program a separate app to measure in mV, and to downsize the sensor apparatus so that it is more portable and convenient, and can use a cell phone as a remote power source and processor.

The cost of experimentation is as follows:

Item/Consumables	Purpose	Cost
Distilled Water	Solutions	$.97
Petri Dishes w/Nutrient Agar	Culturing of cells	$50.00
Dextrose	Feeding of cell cultures	$8.07
Beral Pipettes	Feeding of cell cultures	$7.25
Nutrient Broth	Feeding of cell cultures	$4.06
70% Isopropyl Alcohol	Chemical sterility of all equipment and area	$4.56
Hypodermic Needles	Application of dyes and solutions	$5.56
Janus Green	Mitochondrial dye	$40.00
Rhodamine B	Cell viability dye	$10.45
Toxin Solutions	Test items	$20.00

Copper Electrodes	Test items	$10.22
Multimeter w/Gold Electrodes	Tester	$21.97
Kanthal Wire	Test items	$20.00
Nichrome Wire	Test items	$6.95
Galvanic Skin Sensor w/Silver Electrodes	Tester	$97.00
	Total	$307.06

Problem Definition

Mitochondria are the powerhouses of the cell, but when something goes wrong, the mitochondria is responsible for cellular dysfunction. When the dysfunction is caused by outside sources, it is called mitochondrial toxicity, when it is caused by genetic sources, it is called mitochondrial dysfunction. The glycolytic and ATP progression in mitochondria produces electrical impulses, known as conductivity and resistivity, which in turn can be used as a signals for a wearable testing device to determine changes in body health. This has been experimented by our team for several years. The final product we are hoping to produce would be a lightweight, wearable sensor that is sensitive enough to detect cell signaling, galvanic cell response, and mitochondrial toxicity/dysfunction and relay this in real-time to a phone app to indicate immediate cellular impact, which would enable the user to take action to reverse the toxicity at the cellular level to avoid disease progression. The overall goal is to produce a fully functioning 3D model that shows how this sensor would work at the cellular level, as well as other important biological processes.

Problem Solution

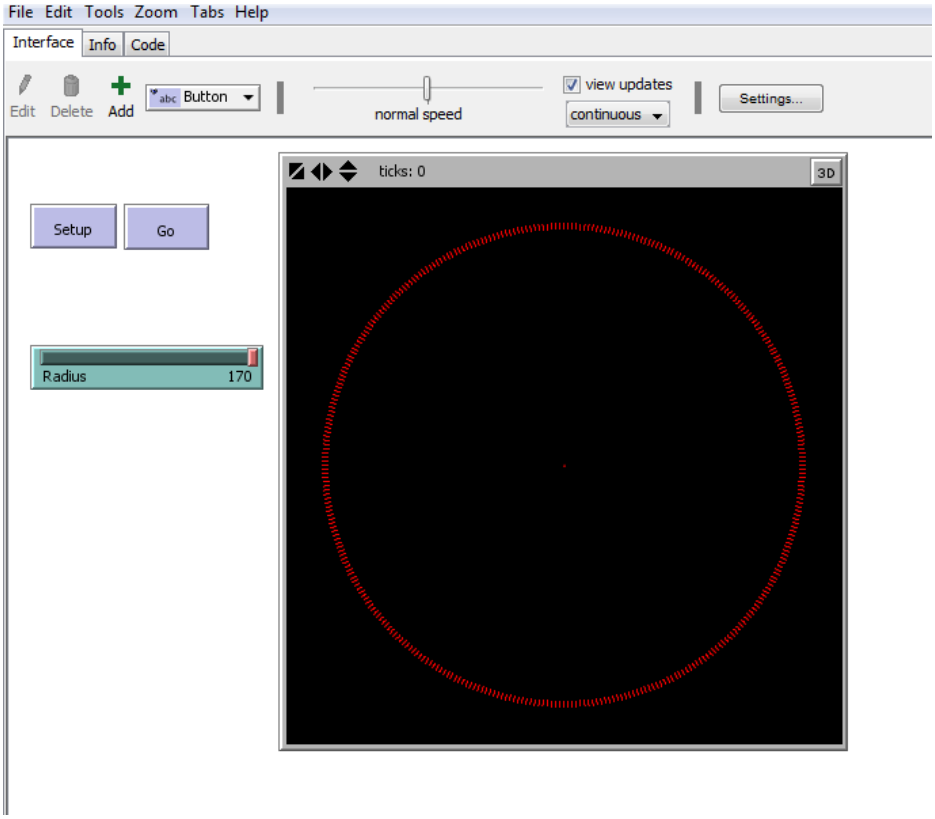
From this experimentation and data, our team attempted to see if we could produce a database of cellar/mitochondrial reactions as indicators of disease/toxicity via mitochondria dysfunction from our scientific findings and enter it into a 3D model. Initially, we had hoped that

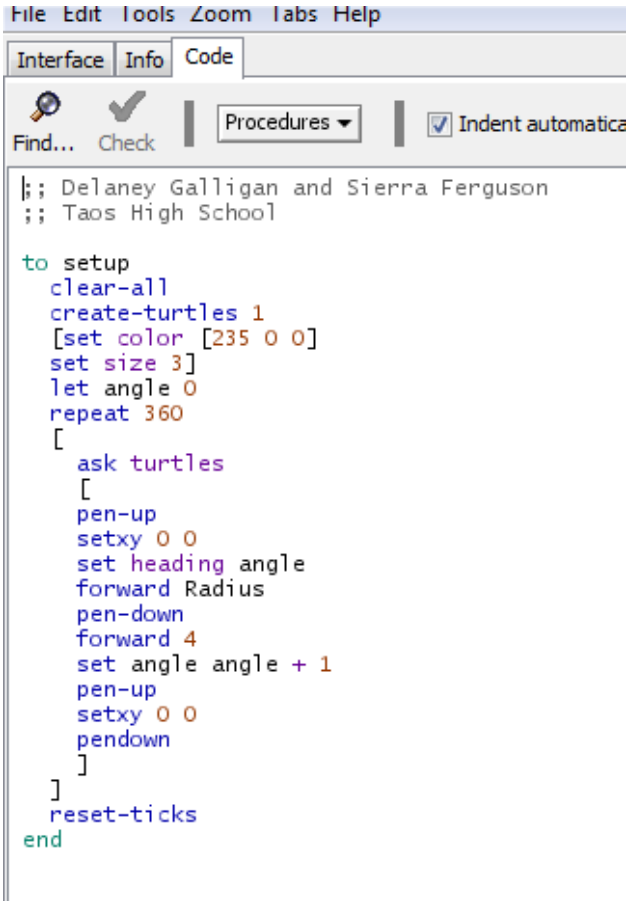
the model would provide a quicker way of gaining data and seeing if the sensor works. In doing this, our model needed to have a full library of ATP/electro activity that occurs within the mitochondria and cells during homeostasis and different diseases. This model would also help with reducing the confusion between electrodermal and electrocellular feedback.

However, after political battles and decisions made in our school district, our science fair program was shut down. This ended our team's experimentation and data gathering that we needed to complete the model. Because of this, we had to alter our problem solution. Instead, we just decided to model what happens during mitochondrial toxicity/dysfunction and how that can be measured through a sensor. We also wanted to highlight major biological processes that supported our findings from the updated model.

Software and Code

This is the code and interface for the first version of our model. Version 1 only had the cell membrane.






```
;; Delaney Galligan and Sierra Ferguson
;; Taos High School

to setup
  clear-all
  create-turtles 1
  [set color [235 0 0]
  set size 3]
  let angle 0
  repeat 360
  [
    ask turtles
    [
    pen-up
    setxy 0 0
    set heading angle
    forward Radius
    pen-down
    forward 4
    set angle angle + 1
    pen-up
    setxy 0 0
    pendown
    ]
  ]
  reset-ticks
end
```

File Edit Tools Zoom Tabs Help

Interface | Info | Code

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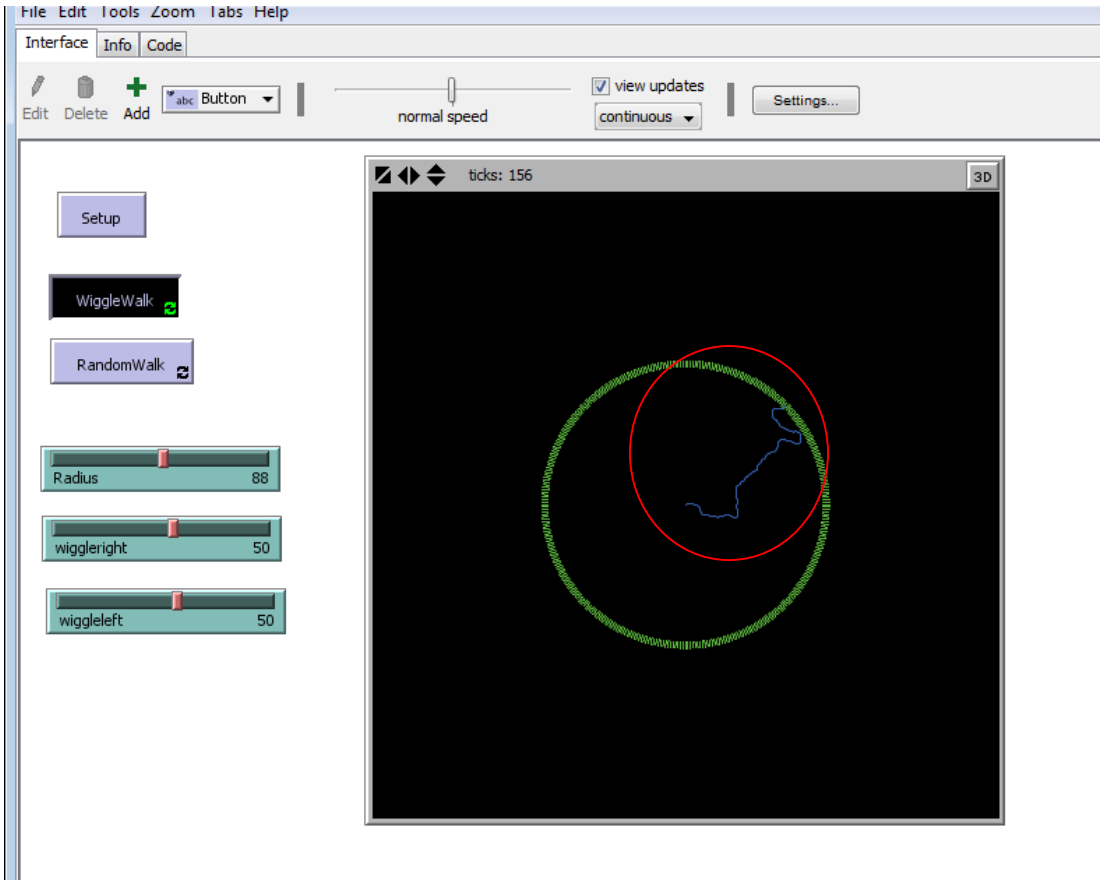
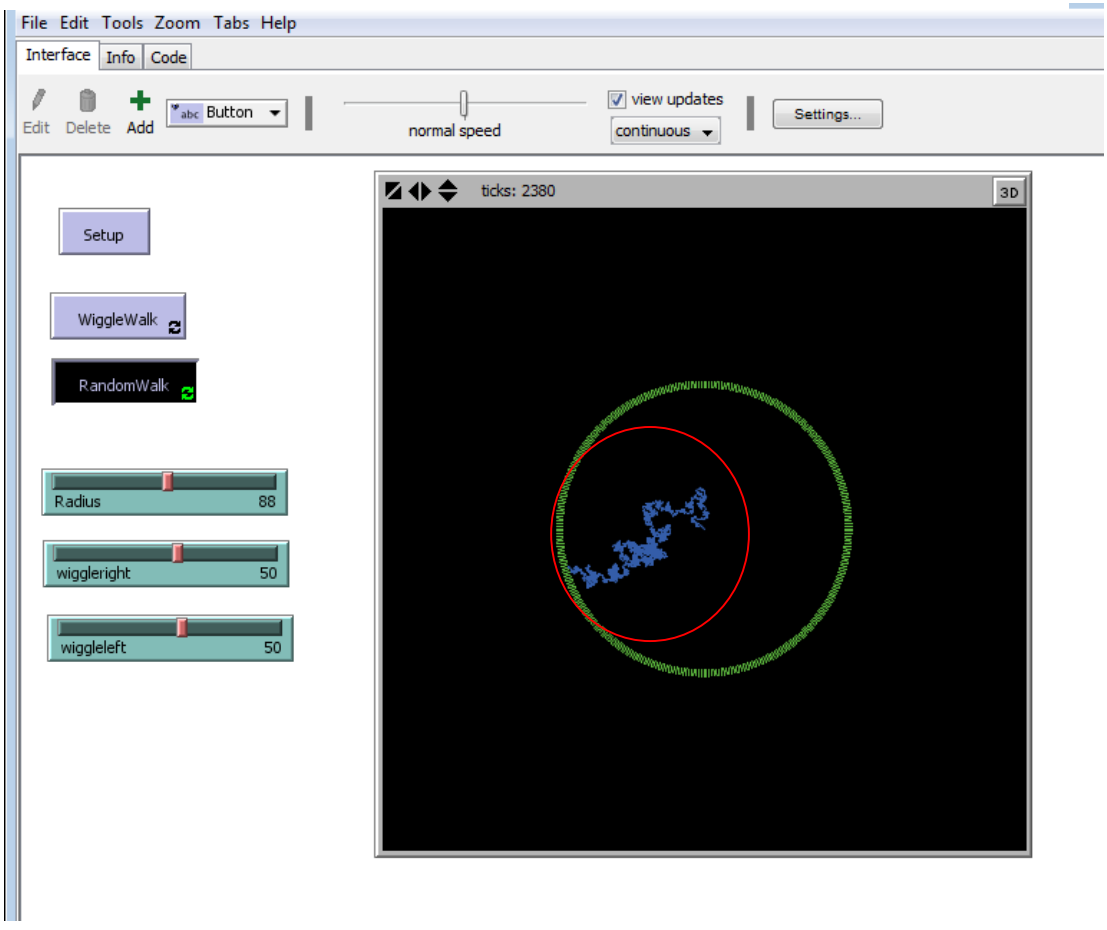
```
globals [stopp]
to setup
  ca
  set stopp false
  create-turtles 1
  [
    set color green
  ]
  let angle 0
  repeat 360
  [
    ask turtles
    [
      pu setxy 0 0
      set heading angle
      fd radius
      pd
      fd 4
      set angle angle + 1
    ]
  ]
  reset-ticks
  ct
  create-turtles 1
  [
    pd
    set color blue
  ]
end

to RandomWalk
  if (stopp = false)
  [
    ask turtles
    [
      if (distancexy 0 0 > radius)
      [
        set stopp true
      ]
      set heading (random 360)
      fd 1
    ]
    tick
  ]
end

to WiggleWalk
  while [stopp = false]
  [
    ask turtles
    [
      if (distancexy 0 0 > radius)
      [
        set stopp true
      ]
      rt (random (wiggleright + 1))
    lt (random (wiggleleft + 1))
    fd 1
    ]
    tick
  ]
  print ticks
end
```

This is the code for Version 2. This version had the membrane and a two types of random variables.



Version 2 served to establish the best type of motion (which seems more natural) for the variables to be added. We compared WiggleWalk vs. RandomWalk



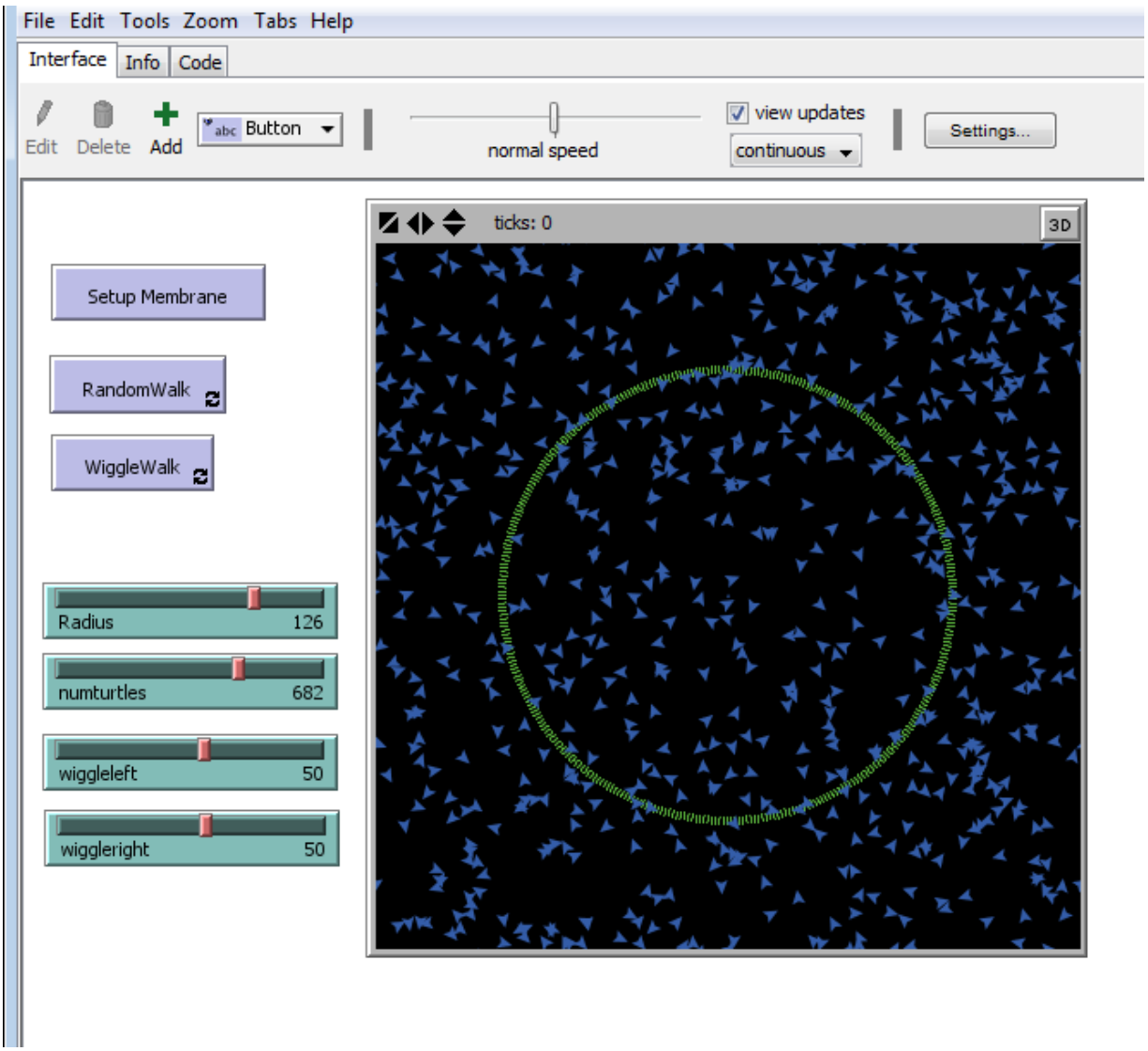
File Edit Tools Zoom Tabs Help

Interface | Info | Code

Find... Check | Procedures | Indent automatically

```
;; Delaney Galligan and Sierra Ferguson
;; Taos High School


turtles-own [sick? sicktime]
globals [stopp]

to setup_membrane
  clear-all
  set stopp false
  create-turtles 1
  [set color green
  set size 3]
  let angle 0
  repeat 360
  [
    ask turtles
    [
    pen-up
    setxy 0 0
    set heading angle
    forward Radius
    pen-down
    forward 4
    set angle angle + 1
    pen-up
    setxy 0 0
    pendown
    pen-up
    ]
  ]
  crt numturtles
  [
    set color blue
    set size 10]
  ask turtles
  [
    if who = 0 ;; patient 0
    [
      set sick? true
      set color blue ;; healthy turtles will be represented by the color blue
    ]
    if who > 0
    [
    set sicktime 0
    setxy random-xcor random-ycor
    ]
  ]
  reset-ticks
end

to RandomWalk
  if (stopp = false)
  [
    ask turtles
    [
      if (distancexy 0 0 > radius)
      [
        set stopp true
      ]
      set heading (random 360)
      fd 1
    ]
  ]
end

to WiggleWalk
  while [stopp = false]
  [
    ask turtles
    [
      if (distancexy 0 0 > radius)
      [
        set stopp true
      ]
      rt (random (wiggleright + 1))
    lt (random (wiggleleft + 1))
    fd 1
    ]
    tick
  ]
```

This is the code for Version 3. This version had the membrane and variables introduced with WiggleWalk and RandomWalk. However, this version yielded complications with the movement and only moved for one tick.



This is the interface for Version 3. Variables are scattered but not moving.

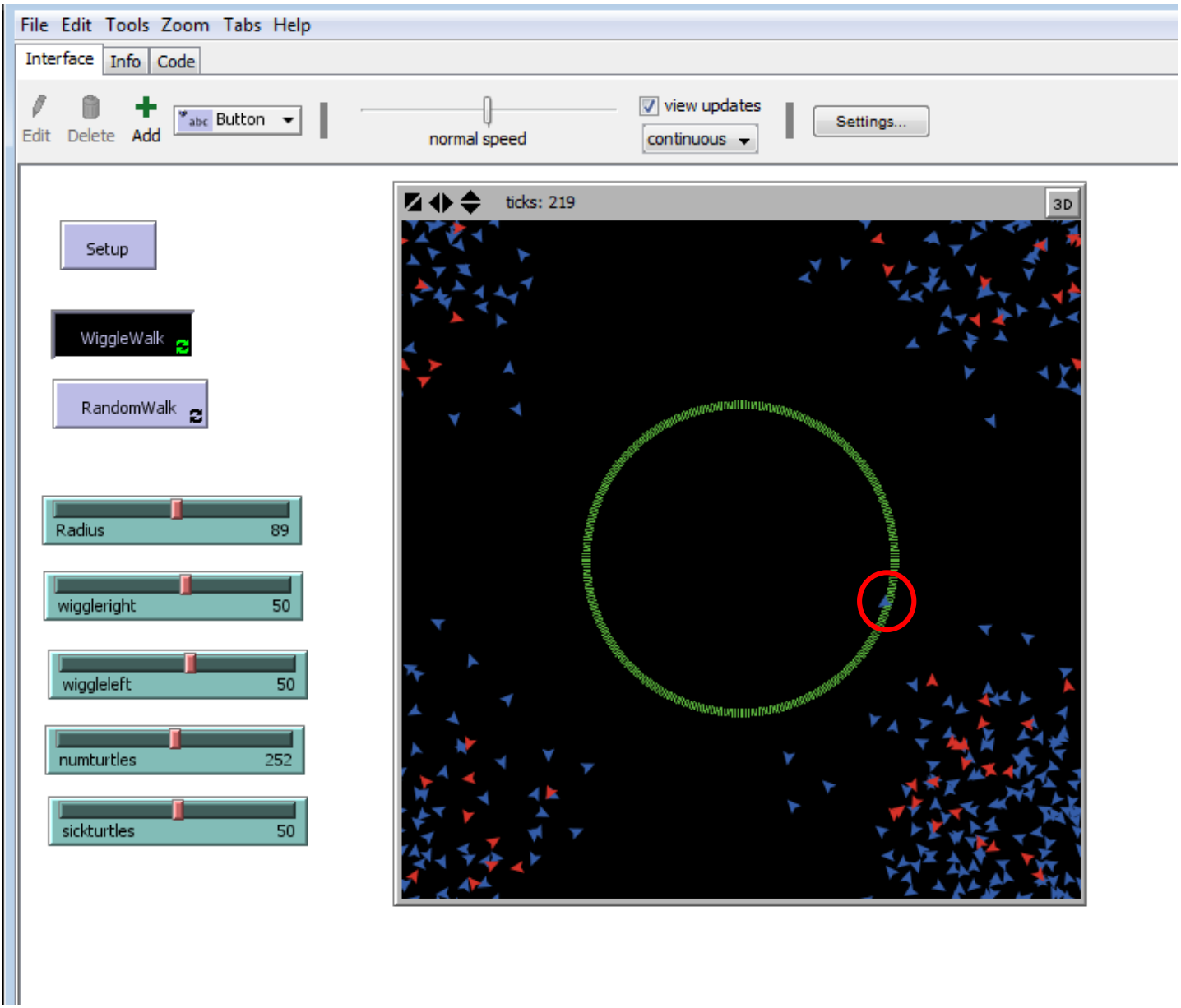
File Edit Tools Zoom Tabs Help

Interface | Info | Code

Find... Check | Procedures | Indent a

```
globals [stopp]
to setup
  ca
  set stopp false
  create-turtles 1
  [
    set color green
  ]
  let angle 0
  repeat 360
  [
    ask turtles
    [
      pu setxy 0 0
      set heading angle
      fd radius
      pd
      fd 4
      set angle angle + 1
    ]
  ]
  reset-ticks
  ct
  create-turtles numturtles
  [
    pu
    set size 10
    set color blue
    setxy 175 -175
  ]
   create-turtles sickturtles
   [
     pu
     set size 10
     set color red
     setxy 175 -175
   ]
end

to RandomWalk
  if (stopp = false)
  [
    ask turtles
    [
      if (distancexy 0 0 < radius)
      [
        set stopp true
      ]
      set heading (random 360)
      fd 1
    ]
    tick
  ]
end

to WiggleWalk
  while [stopp = false]
  [
    ask turtles
    [
      if (distancexy 0 0 < radius)
      [
        set stopp true
      ]
      rt (random (wiggleright + 1))
    lt (random (wiggleleft + 1))
    fd 1
    ]
    tick
  ]
  print ticks
end
```

This is the code for Version 4. This version has red and blue variables (good and bad) which both move. However, this version has the variables stop as soon as they touch the radius of the cell membrane.



This is the interface for Version 4. You can see that since the first variable hit the radius, all agents stopped.

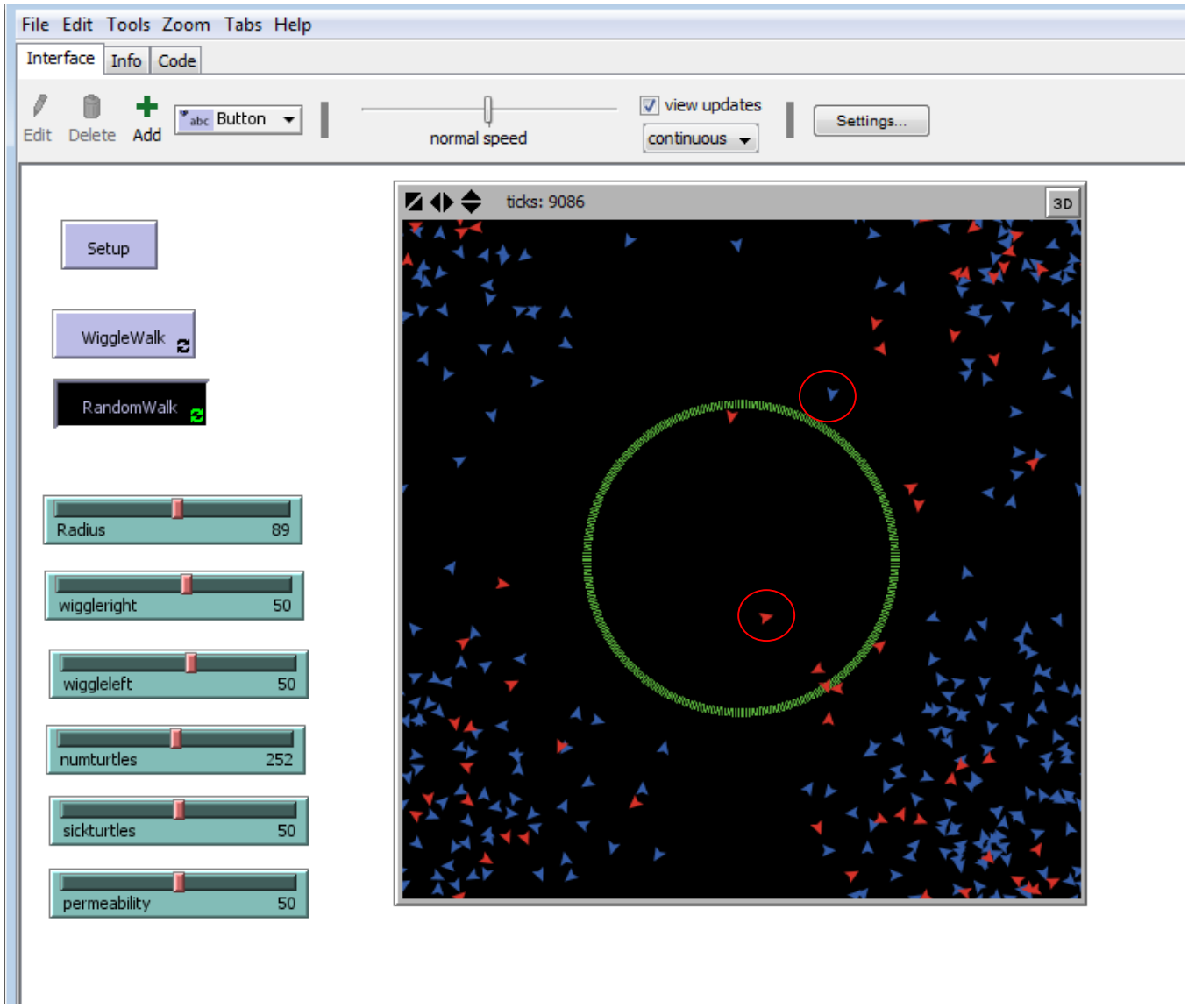
File Edit Tools Zoom Tabs Help

Interface | Info | Code

Find... Check Procedures Indent

```
globals [stopp sick]

to setup
  ca
  set stopp false
  create-turtles 1
  [
    set color green
  ]
  let angle 0
  repeat 360
  [
    ask turtles
    [
      pu setxy 0 0
      set heading angle
      fd radius
      pd
      fd 4
      set angle angle + 1
    ]
  ]
  reset-ticks
  ct
  create-turtles numturtles
  [
    pu
    set size 10
    set color blue
    setxy 175 -175
  ]
  create-turtles sickturtles
    [
      pu
      set size 10
      set color red
      setxy 175 -175
      set sick true
    ]
end

to Randomwalk
  if (stopp = false)
  [
    ask turtles
    [
      if (distancexy 0 0 = radius) and (sick = true)
      [


        if (random 100 > permeability)
        [
          set heading heading + 180

        ]
      ]
      set heading (random 360)
      fd 1
    ]
    tick
    if (sick = true)
    [
      ask turtles
      [
        if (distancexy 0 0 < radius)
        [
          set color red
        ]
      ]
    ]
  ]
end

to wigglewalk
  while [stopp = false]
  [
    ask turtles
    [
      if (distancexy 0 0 < radius)
      [
        set stopp true
      ]
      rt (random (wiggleright + 1))
      lt (random (wiggleleft + 1))
      fd 1
    ]
    tick
  ]
  print ticks
end
```

This is the code for version 5. This version had the variables moving into the membrane, but when they did, they turned red.



This is the interface for version 5. The blue variable circled will turn red once it enters the green membrane. This happened to the red variable which is circled.

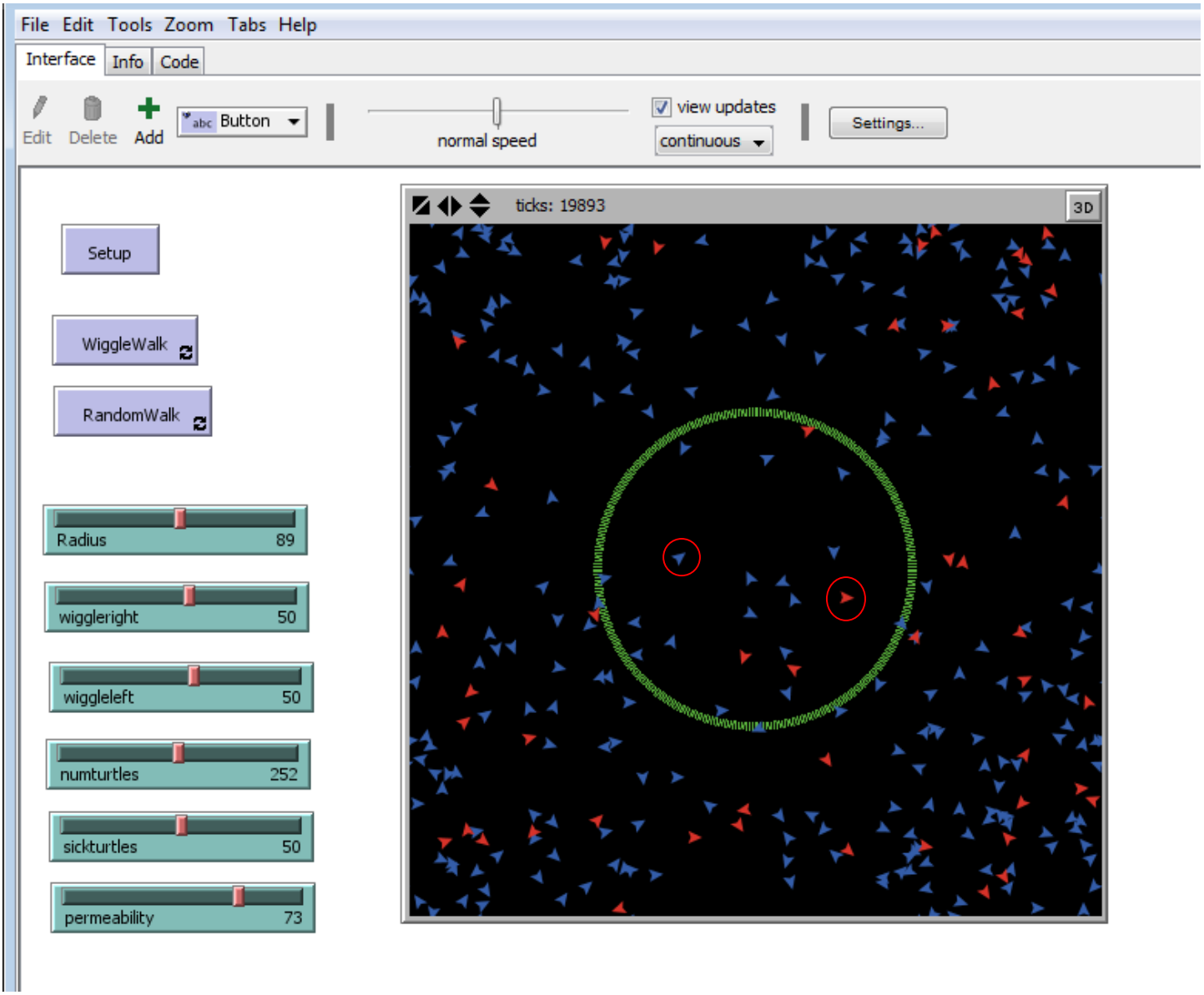
File Edit Tools Zoom Tabs Help

Interface | Info | Code

Find... | Check | Procedures | Indent automatically

```
globals [stopp sick]
breed [alerts alert]

to setup
  ca
  set stopp false
  set sick false
  create-turtles 1
  [
    set color green
  ]
  let angle 0
  repeat 360
  [
    ask turtles
    [
      pu setxy 0 0
      set heading angle
      fd radius
      pd
      fd 4
      set angle angle + 1
    ]
  ]
  reset-ticks
  ct
  create-turtles numturtles
  [
    pu
    set size 10
    set color blue
    setxy 175 -175
  ]
  create-turtles sickturtles
    [
      pu
      set size 10
      set color red
      setxy 175 -175
      set sick true
    ]
end

to Randomwalk
  if (stopp = false)
  [
    ask turtles
    [
      if (distancexy 0 0 = radius) and (sick = true)
      [

        if (random 100 > permeability)
        [
          set heading heading + 180

        ]
      ]
      set heading (random 360)
      fd 1
    ]
    tick
    ask alerts
    [
      set color white
    ]
  ]
end

to wigglewalk
  while [stopp = false]
  [
    ask turtles
    [
      if (distancexy 0 0 < radius)
      [
        set stopp true
      ]
      rt (random (wiggleright + 1))
      lt (random (wiggleleft + 1))
      fd 1
    ]
    tick
  ]
  print ticks
end
```

This is the code for version 6. This code allows for both blue and red variables to move freely throughout the membrane.



This is the interface for version 6. As you can see, both red and blue variables can enter the membrane. This version got us closer to our goal, but we were having a difficult time spawning the agent that would represent the electrical signal given off by the mitochondria when affected by a toxin (red variable).

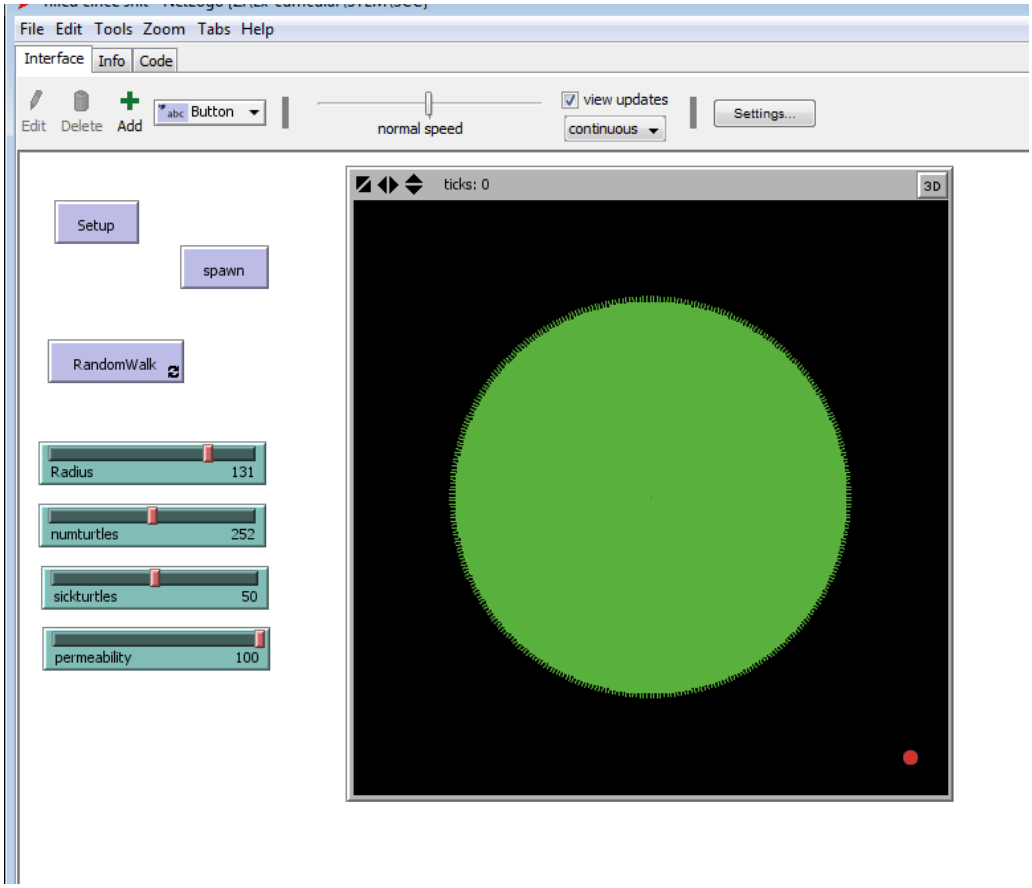
File Edit Tools Zoom Tabs Help

Interface | Info | Code

Find... | Check | Procedures | Indent automatically

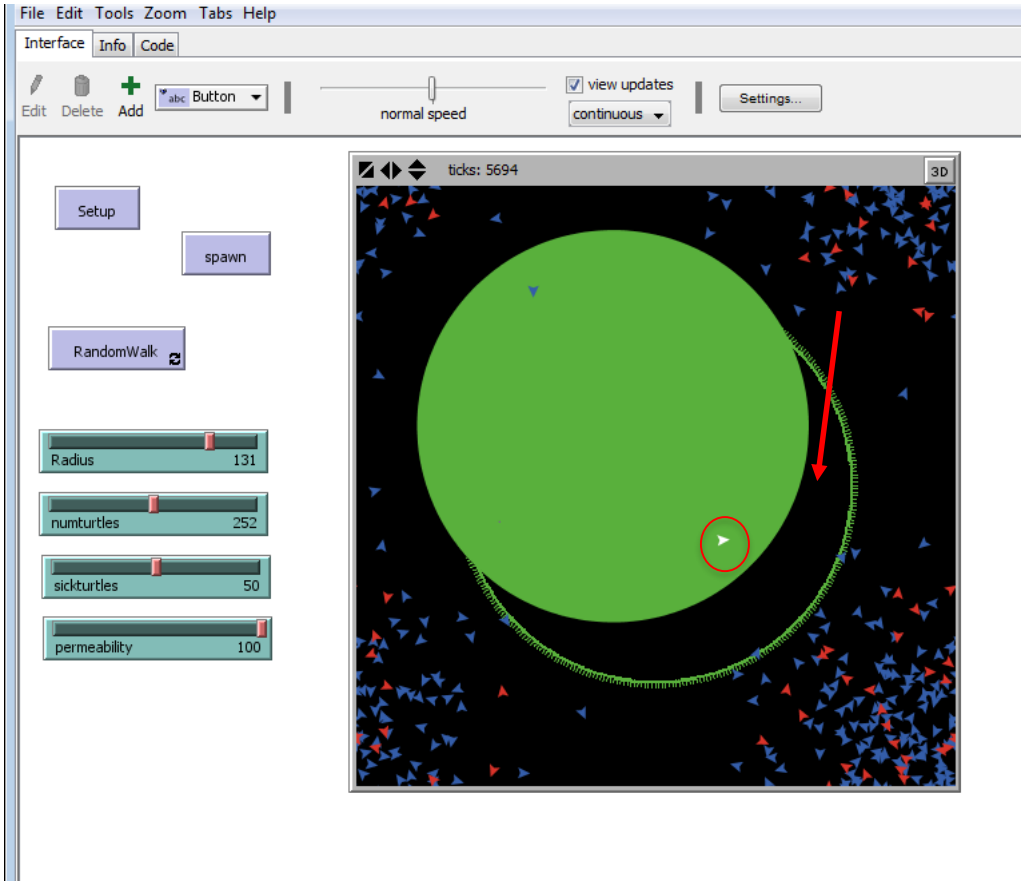
```
globals [stopp sick sickalerted]
breed [alerts alert]

to setup
  ca
  set stopp false
  set sick false
  create-turtles 1
  [
    set color green
  ]
  let angle 0
  repeat 360
  [
    ask turtles
    [
      pu setxy 0 0
      set heading angle
      fd radius
      pd
      fd 4
      set angle angle + 1
    ]
  ]
  reset-ticks
  ct
  create-turtles numturtles
  [
    pu
    set size 10
    set color blue
    setxy 175 -175
  ]
  create-turtles sickturtles
    [
      pu
      set size 10
      set color red
      setxy 175 -175
      set sick true
      set sickalerted false
    ]
  ask patches
  [
    if (distancexy 0 0 > Radius - 1) and (distancexy 0 0 < Radius + 1)
    [
      set pcolor green
    ]
  ]
end

to spawn-turtle
  crt 1
  [
    ask turtle 0
    [ setxy 0 0
      set size radius * 2
      set shape "circle"
      set color green
    ]
  ]
end

to RandomWalk

    ask turtles
    [
      if (pcolor = green) and (sick = true) and (sickalerted = false)
      [
        hatch 1 [set color white]
        set sickalerted true
      ]
      if (distancexy 0 0 = radius) and (sick = true)
      [

        if (random 100 > permeability)
        [
          set heading heading + 180

        ]
      ]
      set heading (random 360)
      fd 1
    ]
    tick

  end

to spawn
  ask turtles
  [
    if (distancexy 0 0 = radius) and (sick = true)
    [
      hatch 1 ]
    set color white
    set size 10
  ]
end
```

This is the code for version 7. After having difficulties with creating the electrical signal (spawn of red variable) we tried a different approach. We tried to have it spawn when it reached a patch color instead of when it reached the radius point. This caused additional difficulties.



Above: Setup for Version 7

Below: RandomWalk for Version 7. Although allowing for successful spawning of electrical signals, our mitochondria was now moving without its membrane.



File Edit Tools Zoom Tabs Help

Interface | Info | Code

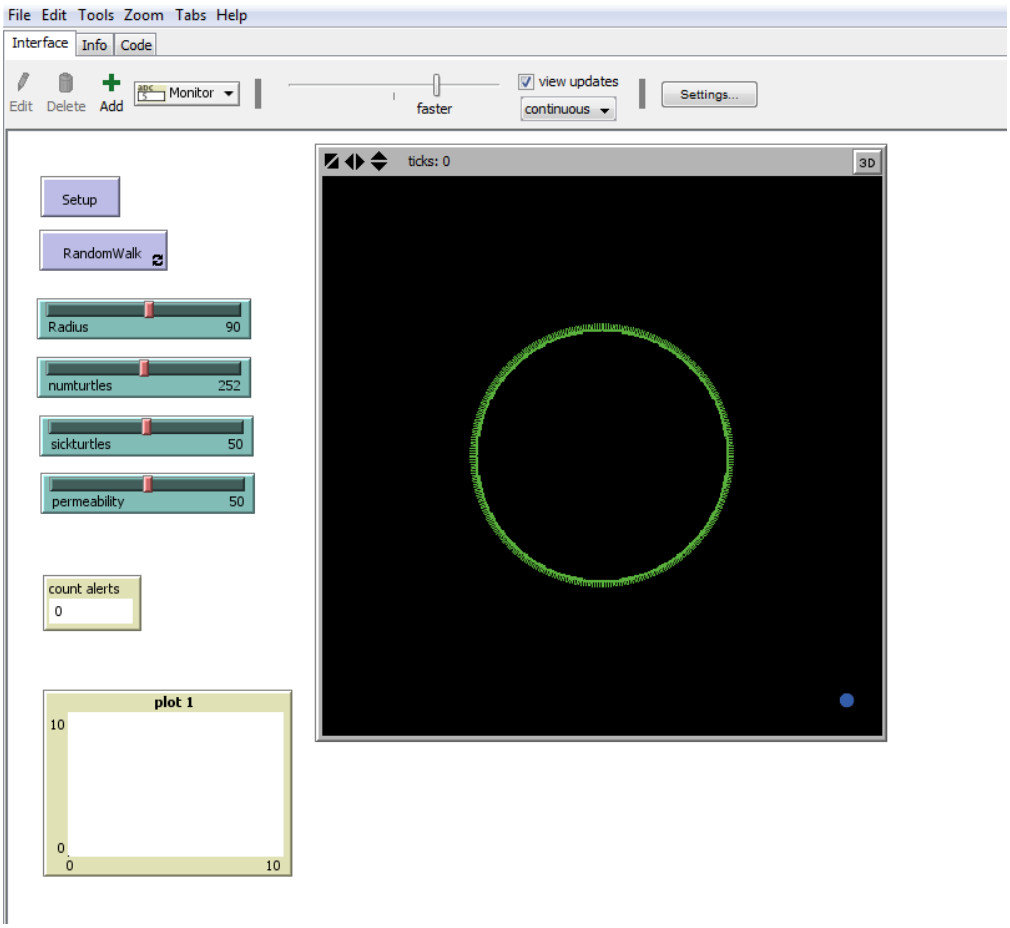
Find... | Check | Procedures | Indent automatically

```
;; THS159
;; Sierra Ferguson and Delaney Galligan
;; version 8



globals [stopp]
breed [alerts alert]
breed [sick sicker]
breed [sickalerted sickalerteder]

to setup ;; setups up membrane and starting point of variables
  ca
  set stopp false
  create-turtles 1
  [
    set color green ;; sets color of membrane to green
  ]
  let angle 0
  repeat 360
  [
    ask turtles
    [
      pu setxy 0 0
      set heading angle
      fd radius
      pd
      fd 4
      set angle angle + 1
    ]
  ]
  reset-ticks
  ct
  create-turtles numturtles ;; creates good variables
  [
    pu
    set size 10
    set color blue
    setxy 175 -175
  ]
  create-sick sickturtles ;; creates bad vaqriables
    [
      pu
      set size 10
      set color red
      setxy 175 -175
    ]
  ask patches
  [
    if (distancexy 0 0 > Radius - 1) and (distancexy 0 0 < Radius + 1)
    [
      set pcolor green
    ]
  ]
end
```

This is the code for Version 8 of our code (the most accurate version). See comments for explanations.

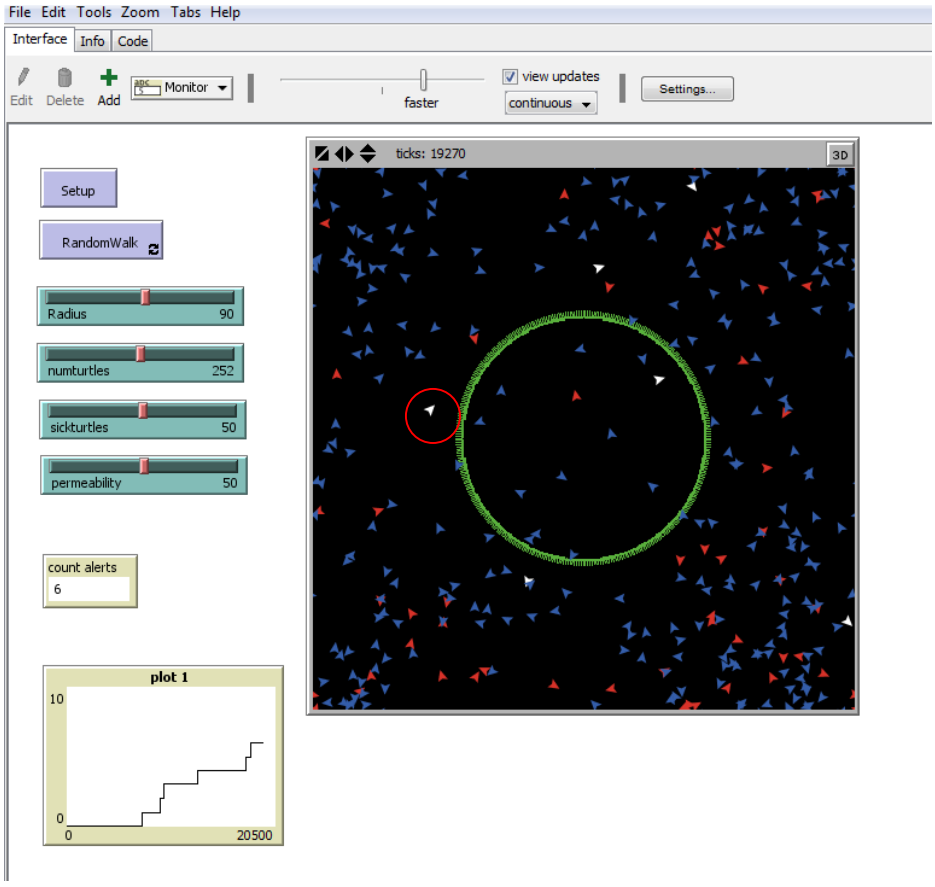
```
to RandomWalk ;; sets up movement of variables

    ask sick
    [
      if (pcolor = green)
      [
        set breed sickalerted ;; tells the variables to change to an electrical signal if entered into the cell membrane
        hatch-alerts 1 [set color white]
      ]
      if (distancexy 0 0 = radius) and (sick = true)
      [

        ifelse (random 100 > permeability) ;; allows for the permeability slider
        [
          set heading heading + 180
          fd 1
        ]
        [
          set heading random 360
          fd 1
        ]

      ]
    ]
    ask turtles
    [
      set heading random 360
          fd 1
    ]
    tick

  end

to spawn ;; creates the conductive signals produced from introduction of toxins or "bad variables"
  ask turtles
  [
    if (distancexy 0 0 = radius) and (sick = true)
    [
      hatch 1 ]
    set color white
    set size 10
  ]
end
```

This is the code for Version 8 of our code (the most accurate version). See comments for explanations.



Above: Setup screen for Version 8 of our code (the most accurate version)

Below: RandomWalk for Version 8



Data and End Results

Most of our data from these models are observational. However, in Version 8 we can get statistical data based off of the changes in permeability of the radius, amount of toxins introduced, the size of the radius of the membrane, and the number of good turtles/variables. From this, we can observe the amount of electrical signals that result from these changes.

Verification and Validation of Code

Our code is validated by the prior years of experimentation and data collection from our science fair project. We also validated the code through trial-and-error to ensure that it was working correctly and modeling what actually happens at the cellular level. This trial-and-error can be seen through the 8 different versions of code we have provided. For further validation please see the section of the report titled "Experimentation." This section outlines what we did in the laboratory prior to modeling this and the conclusions we reached from it.

Conclusion

Through this model, we have established that a sensor used for the reasons we have put forth can theoretically work. Our model shows exactly what happens during mitochondrial toxicity and puts a visual aspect to the theory behind this project. We hope to continue work on this model to make it more realistic and add more variables. We would like to add variables such as other organelles, other cells, and organic molecules (CO2, glucose, Oxygen, etc.). We would like to model the entire cell in relation to toxins, homeostasis (and disruption of homeostasis) within the cell and mitochondria, and disease of the cell. If we accomplish this, we feel that there will be even more supporting evidence for our scientific research/experimentation and we can

continue until a prototype of the sensor is made and we can distribute it. Ultimately, we want to finish the project and reach the goal we originally set at the beginning of the year.

Achievements

This year, the biggest achievement we have accomplished is being able to say that we have completed the challenge, as it was definitely challenging. As it was our junior year this year, we struggled managing our time between honors and AP classes, college classes, jobs, scholarships and activities like the Challenge. On top of this, our school shut down our beloved science fair program. This made our supercomputing project much harder, as we could no longer get data that we needed for our model.

Despite the struggles, we were able to learn and comprehend a lot about NetLogo. Since it was Sierra's first year in the Challenge, she learned about how the challenge works and what it's like to computer model real life experimentation. In doing so, we've learned more about my project and the components of it. Finally, we can say that we've achieved pride in what we have produced this year with the model, PowerPoint presentation, and presentation board. We hope to do very well at the Supercomputing Expo in April and bring some satisfaction and congratulations to a rather challenging year.

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