Physics 150: Physics of Biomedical Instrumentation Presentation Summaries

Richard Acosta

Nanotechnology is Cancer Treatment and Detection

Nanoparticles are 20-150nm in size, roughly 100x smaller then human cells. Nanoparticles can be used as biomarkers to detect cancerous cells. Due to their rapid grown cancer cells take in a lot of folic acid, so by attaching folic acid to nanoparticles they can be concentrated in and near cancer cells. This allows for a Trojan horse approach to drug deliver, place a cytotoxic chemical in the nanoparticle and allow the cancer cells to absorb them in higher concentrations then healthy cells. Another method is photothermal ablation where light is used to excite nanoparticles that heat up cancer cells; cancer dies at 42˚C while normal cells die at 46˚C. Current limitations are in the biocompatibility of nanoparticles, the harsh chemicals used in their production and their high dependence on surface chemistry.

Omar Ahmady

MRI: Clinical Applications

Magnetic resonance imaging is a method to image tissue based on the decay of proton spins in tissue. Different tissues have different relaxation times (T1 and T2) and images can be weighted for either time depending on what needs to be imaged. MRI is used to image the brain, the spine, the heart, the musculoskeletal system and especially to find cancer. T1 images are primarily used to find cancer since it more sensitive to fat content (T2 is more sensitive to water content).

Functional Magnetic Resonance Imaging

fMRI is a specialized form of MRI used to image metabolic functions in the breain instead of anatomical structure. Both are used in conjunction with the metabolic activity layered atop the anatomical image of the brain. fMRI uses a less then 90˚ RF pulse to measure the T2* time as it gives better temporal resolution. The metabolic functions are seen since oxygenated blood has a different T2* then deoxygenated blood. However there is a few second delay between neural activity and a rise in oxygenated blood. fMRI experiments looks at levels of brain activity during certain mental tasks either repeated fixed tasks or spontaneous events like seizures. It is more controversial then standard MRI since there is not absolute baseline for brain activity (it is all normalized to each patient).

Renato Aguilera

Cell Cytometry

Cell cytometry is a technique for counting individual particles in a streaming fluid. The best are radiofrequency cytometers, these reflect a radio signal off of passing cells to detect specific cells. Cells can also be sorted by attaching a small label using a biotin-streptavidin bond, these labels along with a RF signal can be used distinguish individual cells. As they are recognized a charge is applied to the single cells and they are dropped into corresponding containers (separated by a fixed electric field). This method has the hopes of being used to harvest adult stem cells.

Alex Bae

Computed Tomography (CAT Scans)

X-rays are used to take images of patients in slices. The x-rays are made from electrons hitting a tungsten anode, electrons sling-shotting around an anode or from a heated cathode. For CAT scans higher resolution can be achieved by using higher doses of x-rays or by using a contrast dye. Harder tissue blocks the x-rays more then softer tissue. The problem with the contrast dye is that there are lot of groups at risk from using it, those with: diabetes, heart disease, asthma, allergies, kidney problems and some thyroid conditions. The procedure as a whole is not done on pregnant women.

Electrocardiograph

An EKG is a non-invasive, simple way to detect for heart abnormalities, check on pacemakers and look at how medicine is affecting the heart. EKGs attach 3-15 electrodes on the body generally placed on an arm, a leg and the midline of the chest. Millivolt voltages are detected from the beating heart and are translated into PQRST waves. These waves can be examined for abnormalities by looking for absence or abundance of characteristic waves. The huge advantage of electrocardiographs is their complete lack of risks.

Clark Beech

Protein Crystallography

Protein images are used to research how they fold and how they react to pharmaceuticals. X-ray diffraction is used to image crystallized proteins, crystallization being the hardest part of the process. There is no set way to create protein crystals, difficulty arises due to each protein being different and pH and temperature have a large effect. These crystals are millimeters on a side and only last for a few hours at room temperature, the crystal state is a energetically unfavorable one. The first analysis was done by hand and is now handled by a computer that can produce a 3D image of the protein.

Matthew Brehove

PET Scans

Positron emission tomography utilizes the decay of radioactive isotopes to image certain molecules in the body. A glucose is affixed with a radioisotope that has a positron decay product, the glucose is taken up by metabolically active regions of the body (such as cancer) in higher concentration then normal tissue. The released positrons move five micrometers into the body before annihilating and emitting two gamma rays 180˚ apart. The gamma rays are detected by scintillators and photomultiplier tubes and are reconstructed by a computer into an image. The end spatial resolution is 5mm.

Proton Therapy

Radiation therapy relies on the fact that most cancers have less of an ability to repair themselves then normal tissue. Ionizing energy is focuses onto the tissue to kill the targeted cells. Proton thereby works because incident protons release a majority of their energy right before stopping instead of x-rays which release most of it on contact with the skin. For example 200 MeV protons release almost all of their energy at a depth of 25cm. Currently there are 6 operating proton centers in the US due to the high cost, a new machine costs $160 million.

Steven Buchsbaum

Integrated Microfluidic Electrochemical DNA Sensor (IMED)

The IMED is a device that is capable of detecting single strands of DNA in low concentration. On the device the sample is exponentially replicated through a polymerase chain reaction, the resultant mixture is sent to the detector at the end of the chip. The detector works by having the complementary target strand connected to ground, when the desired DNA comes in it attaches to this strand, bending it, and changing the detected voltage. The major hurtle for this device is to find a way to create on chip mixing, as of now the laminar only flow prevents easy mixing due to turbulent flow.

Artificial Hearts

There are currently two available FDA approved artificial hearts. The Cardiowest Temporary Total Artifical Heart and the AbioCor Replacement Heart. The Cardiowest heart is a bridge heart meant to be a bridge until transplant is available; it runs off air pressure and requires a large pneumatic driver. It is successful in that those that use it have a higher survival rate once they get a replacement compared to those who don't use a bridge heart. The AbioCor is intended to be a permanent heart with no external drive system; it uses a hydraulic drive system and has 45 minutes of unassisted power. Out of 14 patients tested 2 died in surgery, 2 had device failures but the ten remaining generally reported an increase in quality of life (it has a long recovery time).

Brian Burkett

BioMEMS

BioMEMS are biological electromechanical systems, in particular (for this presentation) implantable bioMEMS for drug delivery systems. Currently there are hypodermic needles, pills and patches, MicroChips is making a device that contains hundres of nL sized reservoirs filled with the desired drug. These release due to the oxidation of the gold reservoir covers and provide very localized drug delivery. They will be implanted under the skin and the release can be triggered either wirelessly or with onboard sensors. The biggest problem currently is the body covering the device preventing the release of the drugs.

LTC (Life Tissue Connect) Bipolar Open Forceps

Open forceps are an electrosurgical system that utilize radiofrequency signals to seal blood vessels (in lieu of sutures or staples). The main surgical use for the forceps is in the removal of organs such as in a hysterectomy. The forceps are disposable ($300 to $400 each) with a twenty-four hour automatic shut-off, the connector has a programmed chip to tell the signal generator what type of forceps are being used. To close a blood vessel the forceps clamp around the area to be sealed and then a current is applied. The collagen is denatured and broken apart and then it is fused together to make a non-leaking seal. The device is FDA and EU approved for up to 8mm vessels and it works up to 7x the required FDA pressure for 2-3mm blood vessels.

Michael Hutchins

LASIK Eye Surgery

LASIK eye surgery remodels the cornea of the eye after removing the epithelia flap (by using a knife or a laser) in order to correct for astigmatism, far and near sightedness. Once the cornea is exposed an Excimer laser is used to ablate away the cornea using ultraviolet light. Ablation has the advantage that it does not heat thermally while evaporating the targeted tissue. The UV laser is produced by the creation and excitation of noble gas halide complexes which is a short lived molecule that is typically composed of a reactive and noble gas.

Bionic Eyes: The Artificial Silicon Retina

Optobionics is making an artificial implantable retina; it is used to correct macular degeneration and retinitis pigmentosa. The device is implanted underneath the retina and replaces dead or non-functioning visual receptors (rods and cones) with an array of photodiodes. It can only be placed in areas that have some remaining or nearby health cells. A clinical trial has shown improvement and quality of life for all of those who participated, the device (after 18 months) had a 100% acceptance rate by the body with no failures. It has shown some unexpected effects such as sensitivity to the infrared and restored vision in areas distant from the implant.

Justin Iveland

Gamma Knife

A high dosage of concentrated gamma radiation is used to treat brian cancer and disorders. The gamma rays are produced by the decay of cobalt-60 and are at energies of 1.17 and 1.33 MeV. Dosage and location of radiation is determined and then set by collimating the radiation through roughly 200 4-18mm dies which are oriented to a frame bolted to the skull. It is used to treat intracranial tumors, vascular malformations and potentially behavioral disorders. Of those treated for tumors 98% had no more tumor growth. Only one dosage is administered over a thirty minute period but there are many follow ups and side effects including swelling at the mounting points, nausea, headache and possible hemorrhaging.

Cochlear Implant

A cochlear implant is a device that stimulates the auditory nerve directly through electrodes placed in the cochlea. Two types are made: transcutaneous and percutaneous. Transcutaneous have internal and external components and use radiofrequency to send the audio signal through the skin to a RF pick-up coil. Percutaneous implants have a direct external connection to the electrodes. They are designed around Place Theory in that certain parts of the cochlea correspond to different frequencies of sound. Typically 4-24 electrodes are placed in the cochlea. Four companies make the implants, each with their own form of stimulation (some are digital and some are analog).

Brian Kaye

Closed Electrical Circuits for Recalcitrant Wound Healing

Recalcitrant wounds are those are not healing or are not healing in the normal time frame. By applying a constant current across a wound it starts healing again and can speed up healing in normal wounds. A 23 minutes square wave at a constant 400 nA applied for two hours is the optimal treatment to induce or speed up healing. It works because normal wounds cause breaks in cell walls, due to a voltage difference of 70mV across cell walls this creates a current which in turn attracts white blood cells and fiberblasts that start healing. The constant current device is being held back by a poor user interface and difficulty in creating a good connection to the skin.

Electronystagmography (ENG): Diagnosing Balance Problems

Electronystagmography is the process of measuring eye movement through the micro-voltages that arise from the polarity of the eyes. Four electrodes are placed to track horizontal on vertical movement. Eye movements give qualitative measures of responses to different balance tests. Balance systems include: the inner ear (angular and linear acceleration), oculomotor neurons (eye movement), optikinetic and vestibular systems (the eye-brain connection). ENG can test for disorders in all of the balance systems by using tests that isolate that system: inner ear disorders can be tested by rolling the head and watching for the eyes to react to a much greater rotation (vertigo). The ENG is better then previous tests as it gives a quantitative measurement of balance, it is non-invasive, cheap and can be used in most rooms.

Gilberto Ponce

Pacemakers

The beating of the heart is controlled by a group of cells called pacemaker cells. These can stop working by blocked electrical pathways, ion imbalance or intoxication. An artificial pacemaker is an implanted device to recreate the pulse normally produced by the cells. A lithium ion battery and pulse generator are implanted in the chest; leads connect the pulse generator to the heart walls. Placements of the leads depend on the condition being treated. Device failure can result from exposure to strong electromagnetic radiation that can induce unwanted currents in the leads.

Micro Electro Mechanical Systems (MEMS) Based Piezoelectric Pumps

Micropumps deal with volumetric forces only; weight and inertia are negligible at the microfluidic scale. The mechanical aspect of these pumps are actuating membranes that drive fluid through check valves to power devices such as insulin pumps and transdermal drug delivery. They are used in conjunction with micro needles to deliver the desired medicine 30 micrometers under the skin. The advantage to this system is that it is relatively painless and can be made into non-planar surfaces to find optimal geometries.

Chris Roberts

Mass Spectrometry: Proteomics

Mass spectrometry is used to study the post translational processing and modification of proteins. The bottom up technique breaks down the desired proteins into small segments, these are then ionized and put through a mass spectrometer. The distribution of mass/charge ratios can be compared to a database to fingerprint the proteins. Three spectrometers are used: quadrapole (detects resonant ions), time of flight (weight based on time between launch and detection) and orbitrap (induced E field from orbits). This is used to check for disease biomarkers and by inhibiting or enhancing specific proteins.

Proteomics: A Top Down Approach Using Fourier Transform Ion Cyclotron Mass Spectrometry (FTICR-MS)

Isoforms are different proteins made from the same gene sequence: 10^4 genes code for 10^5 proteins that are altered into 10^6 unique proteins. FTICR-MS is useful in that it can distinguish between isoforms as it performs mass spectrometry on the entire protein instead of breaking it up. Once isolated the proteins are charged and spun at resonance to figure out their mass/charge ratio, a Fourier transform is needed to transform the free induction decay measured into frequency space. While it can identify isoforms it is a bigger, slower, more expensive machine that can only handle small samples at a time. It also needs liquid helium to run superconducting magnets (3-11.7 Tesla).

Matt Schreiner

Electroencephalography

Firing neurons in the brain create an electrical current via ion flow which in turn creates a small voltage potential between the inside and outside of the cell. This changing potential can be read by an electroencephalograph as a 10-100 microVolt potential. In clinical uses about nineteen electrodes are used to create 30-40 minute recordings of brain activity, all of which compare the changing signal to a baseline that varies by technique. EEG's can be used to diagnose varies brain disorders such as comas, cortex damage and sub-cortical lesions. It has the advantage of high temporal resolution, cheap and adaptable, however it is a low spatial resolution, a shall depth of imaging and opposing currents can cancel their voltage out and remain undetected.

Magnetic Resonance Imaging – Physics and Math
MRI works by having a steady magnetic field align a small percentage of protons in the body, hitting them with radiofrequencies and detecting their relaxation from alignment to generate an image. Normally the patient is put into a 1.5 to 3 Tesla magnetic field (FDA has approved up to 9 Tesla), they are pulsed with 64MHz radio waves since this is the difference in energy between parallel and anti-parallel proton spins. T1 decay is the decay from excited to unexcited state and T2 is the loss of phase coherence in the transverse plain. The magnet used has a slight gradient so specific planes can be images. Dangers of MRI are mostly resultant from the strong magnet and its related cooling.

Kamal Singhrao

Applications of Medical Ultrasonography
Ultrasonography produces non-invasive images using acoustic waves in the 2-18MHz range. A piezoelectric generates the signal and receives the reflected wave, images are produces based on the timing of the reflection along with the attenuation of the wave. Brightness on ultrasonograph images is associated with the impedance of the tissue. Aside from imaging the body it can be used in conjunction with the Doppler effect to determine the direction blood is flowing.

Douglas Thor

Artificial Muscles
There are three types of artificial muscles: pneumatic, electroactive polymer and carbon nanotube. Artificial muscles may not be implanted in people but could be used for robotics and so are still considered muscles. Pneumatic muscles use pressurized air to expand/contract a membrane, they have similar force-extension relations as human skeletal muscles but are non-linear and require a compressor. Electroactive polymers are the most common and function as either squishy capacitors or by the displacement of ions (similar to a bimetallic strip). Superelastic carbon nanotube aerogel muscles are a network of carbon nanotubes which expand as a voltage is applied. At the center they expand up 220% with a length contraction less then 3%. They expand 3700%/second with a Poisson's ratio of 15.

Max Wiedmann

Transmyocardial Laser Revascularization
A laser is used to make small channels in the heart to facilitate the delivery of blood to the heart muscles. This treats angina if an angioplasty or medication does not stop the chest pain. A CO_2 laser is used to create 20-40 1 mm wide holes in the heart, the bleeding from these holes stimulates the spontaneous generation of blood vessels. The laser used is called the CO_2 Heart

Laser 2, a 1000 watt laser that is synchronized with the beating of the heart. It is fully FDA approves with an easy to use touch interface.

Digital Tomosynthesis: Advanced Breast Cancer Imaging Technique

Mammograms are the current method of breast cancer detection; they utilize a single x-ray photograph (they are slowly moving to digital). Digital Tomosynthesis takes a series of x-ray digital images in a 50˚ field then uses an inverse radon transformation to compile a 3D image. DT images are shorter, more comfortable and use less radiation then mammograms. The Mammomat Inspiration is a Sieman's Digital Tomosynthesis machine currently available in Europe (not yet FDA approved). It is fast, upgradable, user-friendly and has a 10ms-4s (large focus) to 60ms-6s (small focus) exposure times.