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BME 402 Outreach Summary

The following is a summary of an outreach event aimed at twelfth grade students at East High School in Madison WI. The primary goal of this outreach activity was to introduce and familiarize the graduating high school seniors to the various fields of biomedical engineering as a possible college track and/or career path. The presentation started with the definitions and overview of biomedical engineering in general; then, the fields of biomechanics, medical imaging, biomaterials, and tissue engineering were explained in further detail with real-life examples. Questions and answering session were reserved for the end of the PowerPoint presentation. The entire presentation lasted 35~40 minutes.

Definition and general overview of BME

Biomedical engineering can be formally defined as the development and manufacture of prostheses, medical devices, diagnostic devices, drugs and other therapies. In other words, biomedical engineering combines expertise of engineering with medical needs for the progress of health care.

At the most basic level, biomedical engineering is the integration of various engineering fields with biology. For instance, the field of bioinstrumentation is the hybrid between electrical engineering and biology to develop devices such as the pace-makers to keep the human heart pumping. Biomedical engineering include, but are not limited to the field of bioinstrumentation, biomechanics, biomolecular engineering , medical imaging, tissue engineering, biomaterials, systems physiology, and rehabilitation engineering.

Biomechanics

Biomechanics is the application of mechanical principles to the study of human body movements. The study of biomechanics frequently involves classical physics analysis, such as drawing of force profiles in different stages of a limb motion. As a biomechanist, one would study the anatomy and microstructure of various tissues including muscles, bones, tendons, and ligaments. As a career, biomechanist perform static and dynamic analyses to calculate the stress, strain, coordination, and power output of various tissues in motion.

Broken leg example. Two bones—the tibia and the fibula—makes up the bone anatomy of the lower leg. The tibia, being the larger bone, sustains about eighty-eight percent of the weight, while the fibula supports the remaining twelve percent. One feature to notice about the microstructures of bone is that it is composed of Osteon—an structural bundle arranged along the length of the bone. The arrangement of the Osteon makes the bone much stronger along the length of the bone. Governed by the anatomy and microstructures, the characteristics of bone behave much like cement: strong in compression, less strong in tension, poor in torsion. Judging from the angle of the cut in the broken leg (as seen from the X-ray film), the cutting angle of 45 degrees indicates that shear stress was the cause of failure, and it is most like brought about by the torsion of the upper body.

Medical imaging

Medical imaging creates images of body tissue and structures for diagnostic purposes (medical imaging, 1992). The main purpose of medical imaging is to study disease, anatomy or function of our internal human body. Common medical imaging technique includes Magnetic resonance imaging (MRI), ultrasound imaging, projectin radiography, x-ray computed tomography, nuclear medicine etc.

X-ray (Radiography)

X-rays are ionizing electromagnetic radiations containing high-energy photon with strong penetrating power. X-rays typically have wavelengths ranging from 0.01 to 10 nanometers. Much like regular film photography, X-ray images are produced by exposing X-ray films to the penetrating electromagnetic radiations. X-ray images depict the differences in density between various body parts. When the X-ray radiation passes though the patient, dense objects (bone) absorb more radiation than soft tissue (muscle, organs). Therefore, bones appear white while soft tissues appear gray and air black in the X-ray images (http://www.radiologyinfo.org/). Although X-rays can be use to image any parts of the body, X-rays are usually used in imagining the cardiovascular system and the skeletal system.

Ultrasonography

Ultrasounds are mechanical pressure waves. The frequency of ultrasound ranges from 1 to 10 MHz in clinical use. Ultrasonography is typically used to image soft tissues, such as muscle and obsteric. Due to difference in density, echoes are produced when the transmitted ultrasound hits the boundary between various tissues/organs. The delay in time of the echo signals allows us to determine the numerous boundary layers within the human body. Safety is the main advantage of ultrasound but the method suffers from low resolution.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is an imaging modality that allows imaging of internal organs and structures without any inherent risk to the patient. In MRI, a magnet first polarizes the atoms like the spins of a top. How we get information is by disrupting, or "throwing off", a slice of spins and measuring the resulting energy given off as the atoms regain their polarization. Both the disruption of atom spin and the reading of emitted energy are done by using magnetic/electronic coupling in a radio frequency coil. The emitted energy correlates to hydrogen density in soft tissues and it maps out the water concentrations in various parts of our body, usually outlining the area or organ of interest. For example, an image of the thoracic cavity taken with MRI will show different organs at different levels of brightness depending on their water concentration. A high variability of signal between similar tissues can be accomplished by the use of a contrast agent. A contrast is something added to the object being imaged that produced a known and definite signal level that can easily be picked up and distinguished from other sources of signal. MRI images can also be combined with CT image data to produce a detailed mapping of a region of the body. This combination of imaging techniques can include details that are usually only evident from one or the other modality.

Computed Tomography

Computed tomography (CT) operates by taking various X-rays of a section of the body, and putting the two-dimensional images together into a three-dimensional image using projections and filters. Many properties of CT are similar to those of X-ray, especially for each respective projection. One powerful aspect of CT imaging is the flexibility to obtain fairly rapid images of large portions of the body. With spiral CT, the imaging time can be further reduced and missing slices can be interpolated from nearby data. This allows for three-dimensional images of organs such as the heart (as well as the vasculature surrounding it). In some CT images, there may be very subtle changes in signal between two areas of interest. The small difference can make it very hard to detect on a usual grayscale. For this reason, specialized color-maps may be developed and applied to the image data to provide for sharp distinctions between tissue types.

Biomaterials/project detail

Biomaterials can be basically defined as any material that comes into contact with a biological system. The field of biomaterial encompasses many advanced areas of research such as cancer drug delivery, tissue engineering, and cell implantation.

The biological problem that our project aims to resolve is the testosterone hormone imbalance typically observed in elderly men. One way to address this problem is through cell implantation. We plan to restore testosterone level by inserting functional testosterone-producing cells back into the body; however, the cells cannot simply be placed into the body because of the immune response. Thus our engineering design problem: how to construct a shield for the cells that can effectively block out the host's immune system while allowing for the production and diffusion of testosterone. Cell encapsulation with Polyethylene glycol (PEG) is a way to shield the cells from the host's immune system. Properties such as gel porosity, bioinertness, and durability make PEG an ideal material for cell encapsulation. Of these properties, gel porosity is the only one that varies; the others are set due to the chemical nature of PEG. Gel porosity varies with the molecular weight of the PEG and an optimum molecular weight was chosen such that the pores allowed the cells to communicate with the Extra Cellular Matrix (ECM) while preventing contact with antibodies.

The engineering parameters that need to be optimized for maximum cell viability and function are capsule thickness, UV exposure, and RGD incorporation. The capsule must not be too thick, or the cells will not be able to receive nutrients and oxygen due to the overly great diffusion distance. Next, photopolymerization of the PEG is required to create the capsule, and the UV light used in this process may harm the cells. It must be determined what are the effects of UV on the cells during the photopolymerization process. Lastly, most cells need to be anchored to its surrounding in order to survive. Due to the bioinert property of the PEG, PEG does not offer binding sites for the encapsulated cells to anchor to, and the lack of anchoring may affecting cell viability and function. Therefore, a cell binding peptide such as RGD can be incorporated into the PEG mesh network to promote cell anchorage and increase cell viability and testosterone production function. Optimizing these three parameters is currently the subject of our research.

Tissue engineering (TE)

Tissue Engineering or TE for short is the development of biological substitutes to maintain, restore, or replace lost tissue function (Langer and Vacanti, 1993).

The motivation for TE is the increasing deviation between the supply and demand for organ/tissue replacements. Current methods of addressing this problem are complete or partial organ replacements, tissue grafts, bioprosthetic constructs, and artificial devices. However, the main challenge with these options is the inability for the replacements to regenerate naturally, remodel, and grow with the patient. Thus, the field of TE seeks to develop biological tissues that can regenerate and grow and/or introduce constructs than can help to restore native tissues. Additionally, TE hopes to address the issue of low organ/tissue supply. Other goals include the use of engineered tissues to test pharmaceutical drugs in lieu of animal and human subjects and to better understand tissue development, physiology, and pathology.

Several approaches are utilized in TE, namely cells + scaffold, cells + scaffold + bioreactor, growth factors + scaffold. For the cell-based approaches, the cells must first be harvested (extracted and isolated) and expanded (allowed to proliferate in culture). The cells may then be seeded in a biomaterial scaffold and subsequently conditioned and developed in a bioreactor. Depending upon the nature and function of the tissue, the bioreactor may be an external device used to fully develop the tissue prior to implantation or the body may be used as an *in vivo* bioreactor.

TE applications range from metabolic functions (i.e., liver and pancreas) to structural functions (i.e., bone and cartilage) with many tissues lying in between these extremes. During the presentation, we displayed four examples of specific TE applications, namely a heart valve (cardiac), encapsulated cell system (metabolic), bone microenvironment (musculoskeletal), and a nerve guidance channel (neural).

Conclusion

One attractive feature of biomedical engineering is that BME encompasses all disciplines of engineering. Collective expertise in mechanical, electrical, biological, and chemical is often required in order to complete a BME project. Well rounded education is the reason for the success of biomedical engineers in UW-Madison. The BME students are offered the opportunities to take a wide variety of classes that help the student to excel in his/her area of interest.

Due to its diverse nature, students in the biomedical engineering department, upon graduation, are well equipped to take on various job markets. Many of our BME graduates go on to medical school and become doctors. Biomedical engineering, mechanical engineering, electrical engineering, chemical engineering, business school, medical school, navy—are all but a small portion of viable options for a student with a biomedical engineering degree.

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Medical imaging. (1992). In *Academic Press Dictionary of Science and Technology*. Retrieved April 25, 2007, from http://www.xreferplus.com/entry/3128256