ChE 125

Principles of Bioengineering

ChE 125

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Grades

Home work (50%): ~ Starting from Next Week

Project (50%): ~ Due at the end of the quarter

Bioengineering

- Bioengineering is defined as the application of engineering principles to understand, modify, or control living systems.

- Bioengineers need to have a solid education in engineering and a working knowledge of biology, physiology, and medicine.

Bioengineering

Bioengineering is like any engineering discipline

- Engineers collect knowledge and develop an understanding of how things work.
- Engineers make practical use of their knowledge.
- Engineers convert scientific theories into useful products.

What do Bioengineers do?

- Understand and model physiological and biological functions
  - -gain a comprehensive and integrated understanding of the function of living organisms.
  - -Develop mathematical descriptions of physiological events
- Improve existing devices/processes
  - -Diagnostics
  - -Surgical Instruments
  - -Imaging
- Develop new Materials/methods
  - -Drug Delivery
  - -Biosensors
  - -Tissue Engineering
  - -Macromolecular Engineering (Protein/DNA)

Understand and model physiological and biological functions

- Applications of Engineering Fundamentals to Biological Systems

  -Transport Processes
  -Thermodynamics
  -Kinetics

  -Basics of Solid Mechanics
  -Basic of Electricity
  -Knowledge of Basic Mathematical Methods

Bioengineers need to have a solid education in engineering

-Transport Processes

Macroscopic Mass, Momentum, and Energy Balances

Navier-Stokes Equation

Laminar/Turbulent Flows

Shear Stress/Shear Rate Analysis

Diffusion Analysis (mass, momentum, and heat)

Solutions to Basic Differential Equations

Solid education in engineering..continued

-Thermodynamics

First and second laws of thermodynamics

Equilibrium and non-equilibrium processes

Equations of states

Thermodynamic relationships

Solid education in engineering..continued

-Kinetics

First and second order chemical reactions

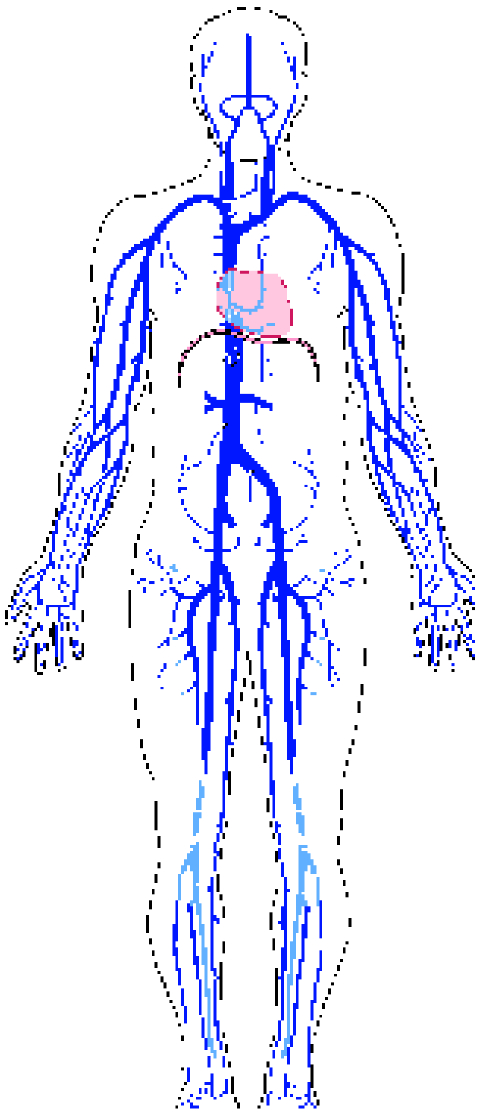
Rate constants

Reversible and Irreversible Reactions

Analysis of Physiological Functions

- Macroscopic Systems (Whole Body Level Functions)
  - -Blood Circulation
  - -Nervous System
- Mesoscopic Systems (Tissue Level Functions)
  - -Oxygen Transport in Tissues (muscles etc.)
  - -Transport across Barriers (intestinal lining, skin etc.)
- Microscopic Systems (Cell Level Functions)
  - -Cell-Cell Communication
- Sub-microscopic Systems (Molecule Level)
  - -Protein Folding

Macroscopic Systems: Circulatory System



Length Scale ~10-100 cm

Heart as a pump; blood vessels as a multi-level piping

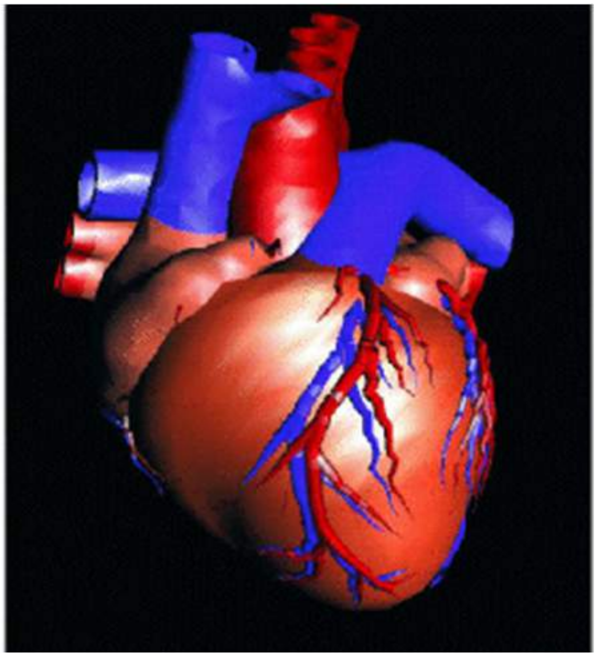
Total length of all our body's blood vessels if they were placed in a straight line = 60,000 miles

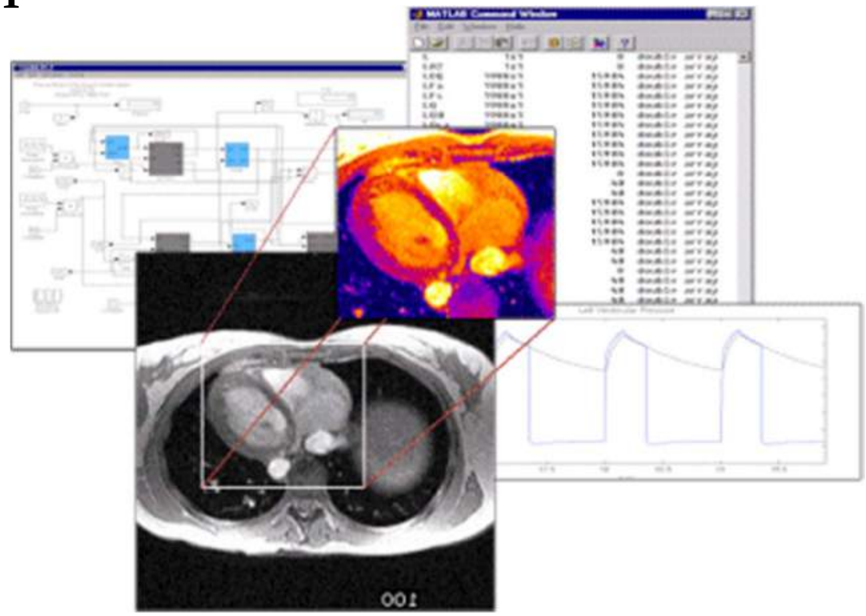
Heart beats about 100,000 times a day

Analysis of blood flow and nutrient transport

Circulatory System

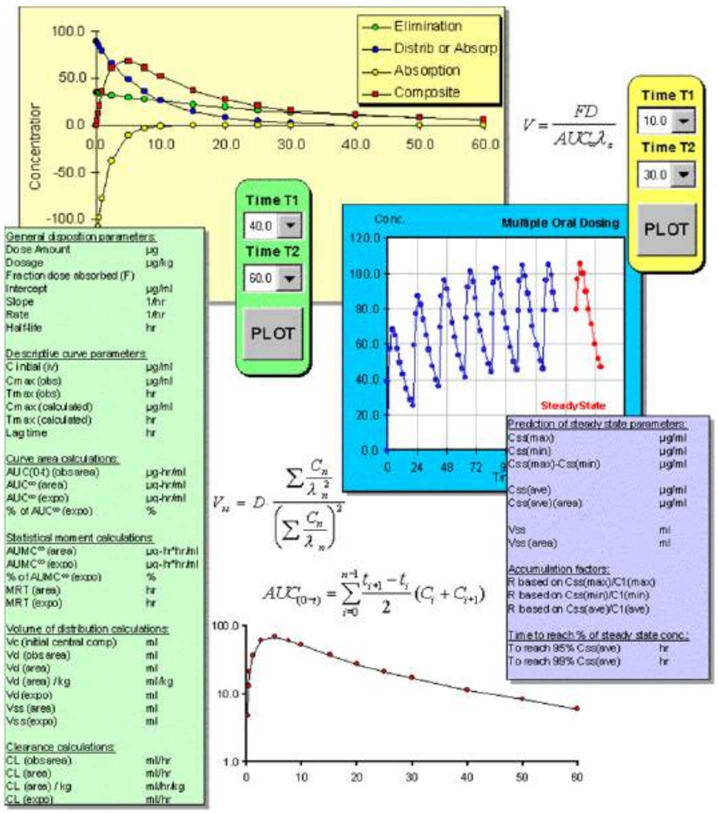
- Modeling of heart function





- Prediction of heart disease

Macroscopic Systems: Drug Metabolism

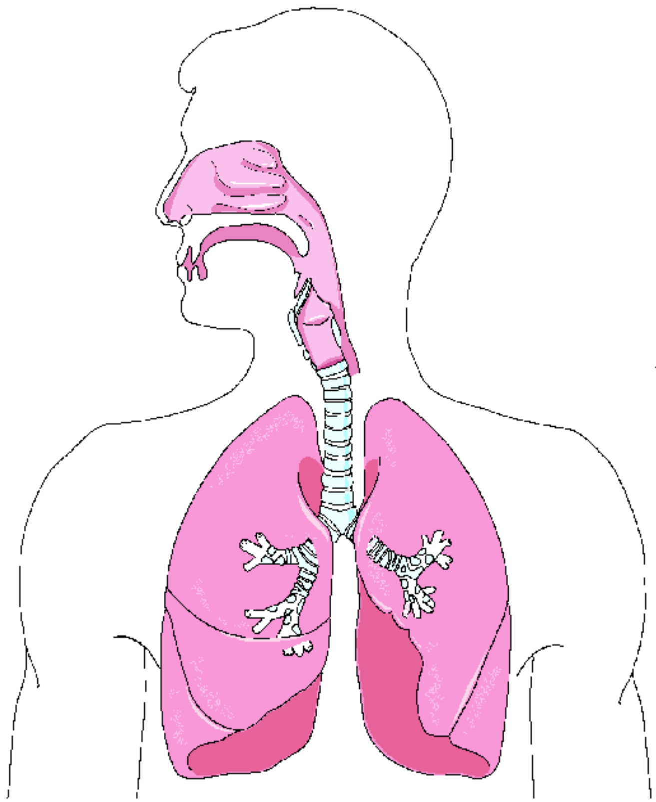


Modeling of drug transport, distribution, and clearance

Determine doses and dose frequency

Pharmacokinetics and Pharmacodynhamics

Macroscopic Systems: Respiratory System



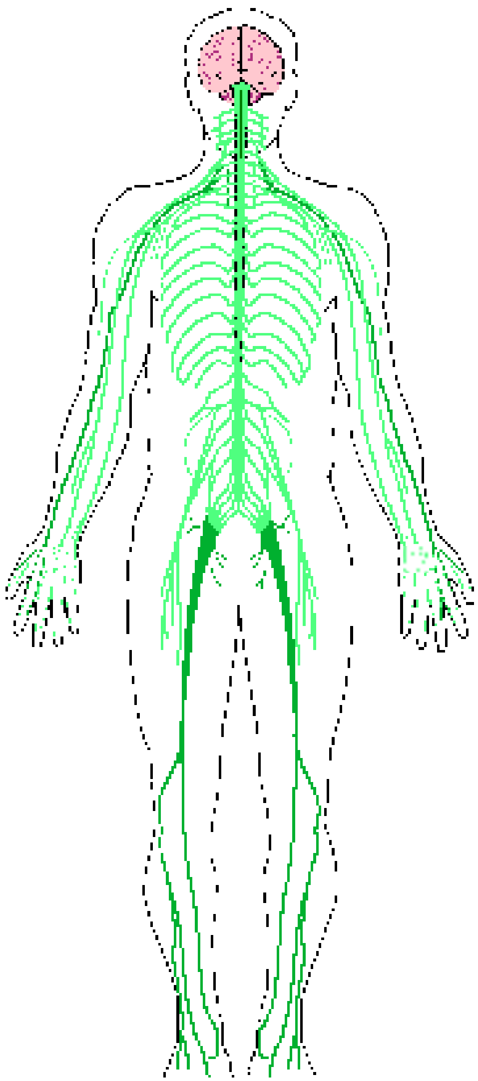
Air is taken into lungs where oxygen is absorbed into blood

Average human has 700 million air sacs In lungs

Average human breathes about 20,000 times a day

Bioengineers analyze air flow in lungs and rates of oxygen transfer across lung capillaries

Macroscopic System: Nervous System



Human brain has 10 billion cells

Communication between nerve
Cells is complex

Signals travel fast through nerves

- strong pain travels at ~100 miles/hour
- mild pain travel at ~2miles/hour

Bioengineers analyze signal
transmission in the nervous system

Mesoscopic Systems (Tissue Level Functions)

Length Scale: 1-10 cm

- Oxygen Transport in Tissues
- Kidney Function: Filtration and removal of waste products
- Pancreas: Blood glucose control and hormonal regulation
- Intestine: Nutrient Uptake

Other Examples of Complex Mesoscopic Functions

Bones: Support body weight, some bones support up to 20-times body weight

Nose: 10 million cells able to identify thousands of different smells

Tongue: About 10,000 taste buds capable of identifying thousands of tastes

Skin: Capable of identifying hundreds of touches

Eye: Capable of recognizing millions of objects

Microscopic Systems (Cell Level Functions)

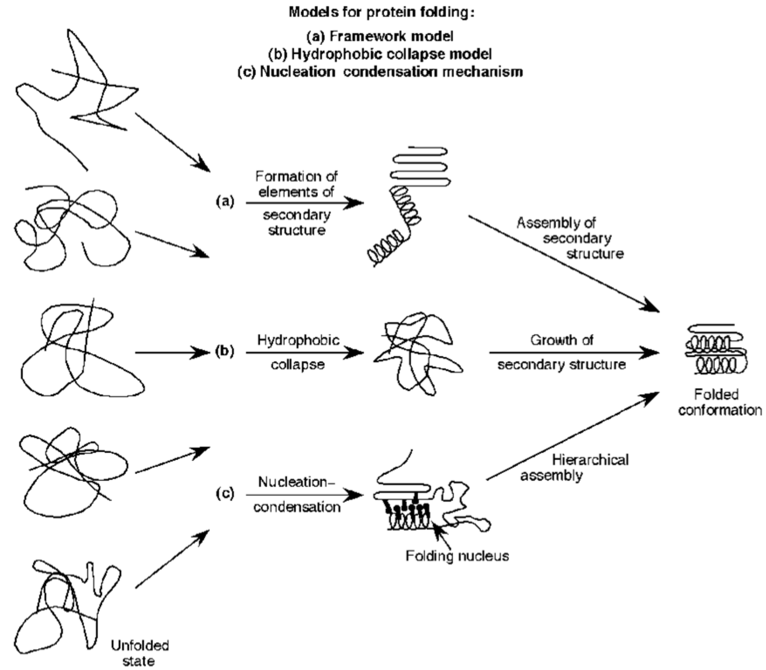
Length Scale: 10-1000 μm

- Phagocytosis
- Trans-membrane particle permeation
- Cell-cell interactions
- Membrane Fusion

Sub-microscopic Systems (Molecule Level Functions)

Length Scale: 1-100 nm

- Protein folding
- Transport across nuclear pores
- Viral transport
  Gene therapy

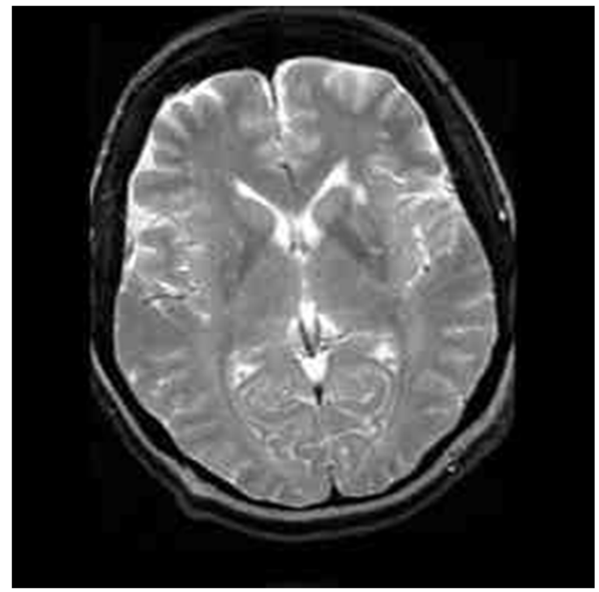


Bioengineering

Improvement of Existing Devices/Processes

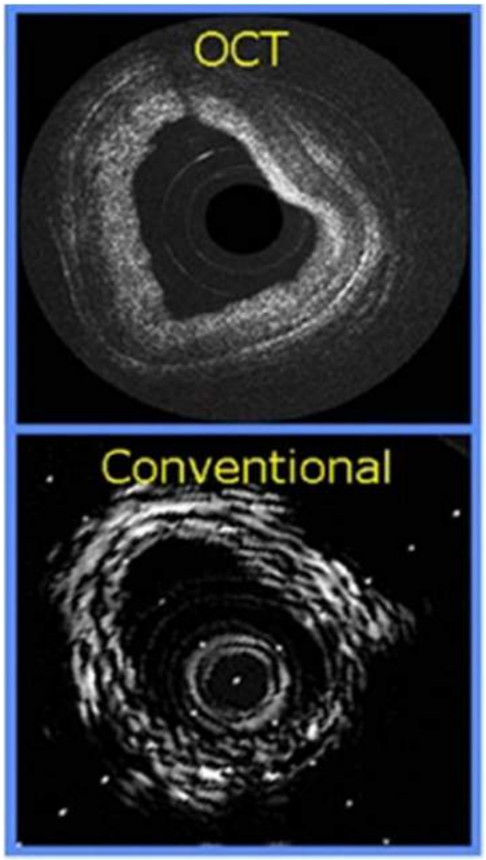
Biomedical Imaging

Ultrasound Imaging



Magnetic Resonance Imaging

Recent Developments in Biomedical Imaging

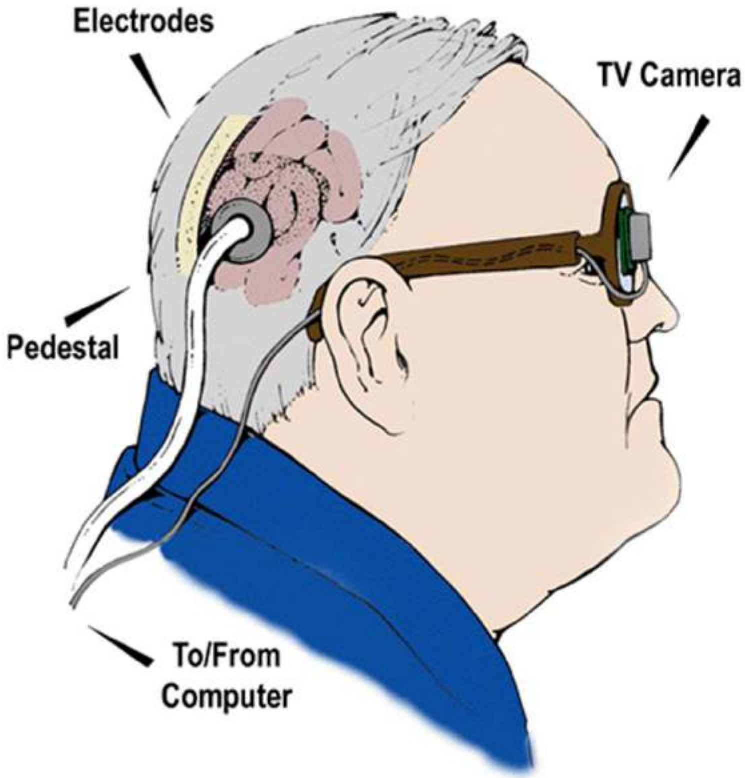


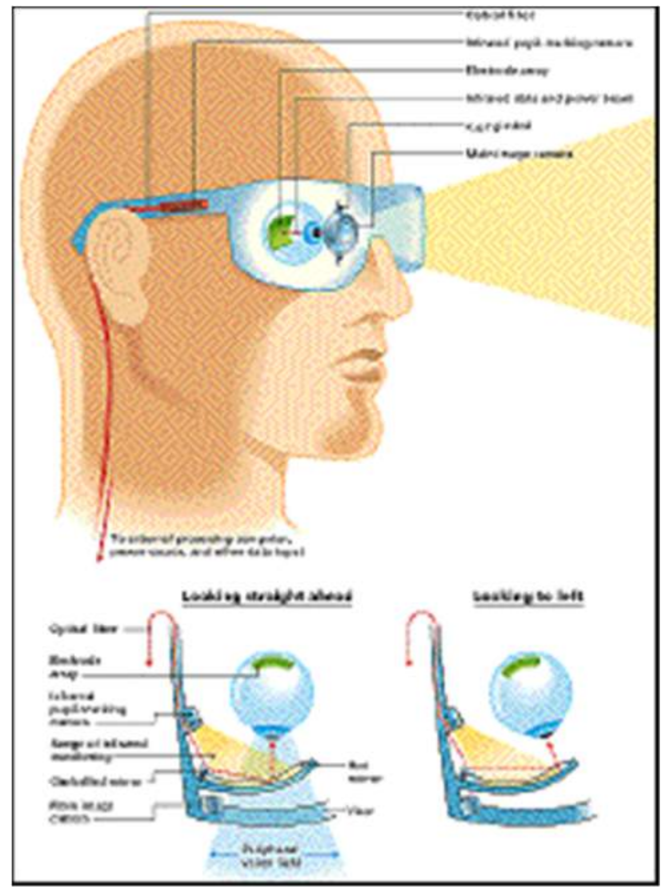
Better view of a blood vessel

Camera in a capsule

Design of Prosthetics

Prosthetics: Artificial Eye





Existing Extracorporeal Devices

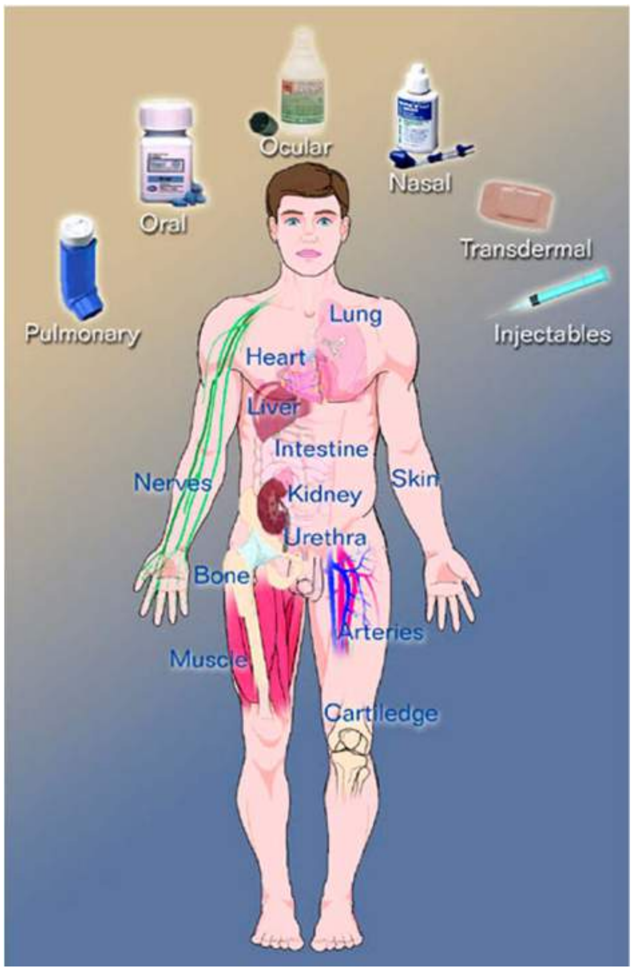
- Kidney Dialyzer
- Artificial Liver
- Blood Oxygenator
- Insulin Pump

Bioengineers try to improve these devices

Bioengineering

Development of New Materials/methods

Bioengineering: Design of Novel Biomaterials



New Methods of Drug Delivery

Tissue Engineering

Biosensors

Macromolecular Engineering (proteins and DNA)

New Methods of Drug Delivery

- Many of the Existing Drug Delivery Systems (injections and pills) are not optimal

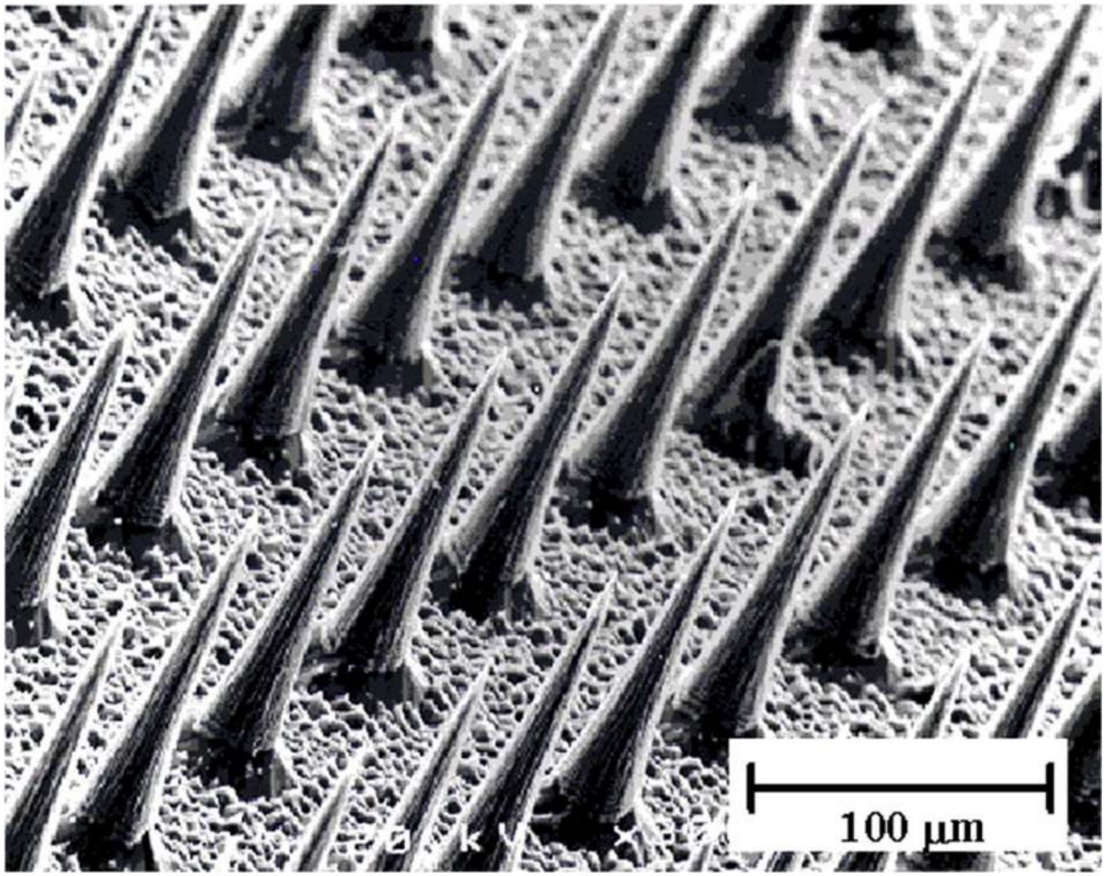
  -Pain, Infection, Frequent Doses, Interference with Patient’s Routine

- Consequence: Non-Compliance Rate of > 50%
- Causes Long-Term Complications

- Develop Novel Drug Delivery Systems and Biomaterials

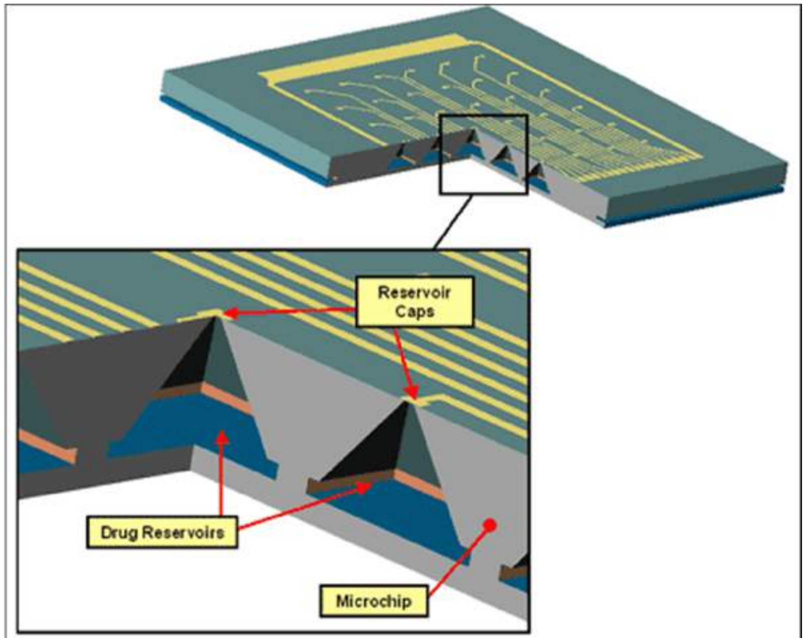
  Intelligent, Task Specific, Patient Friendly, Easy-to-Use

Microscopic needles reduce pain of Injections

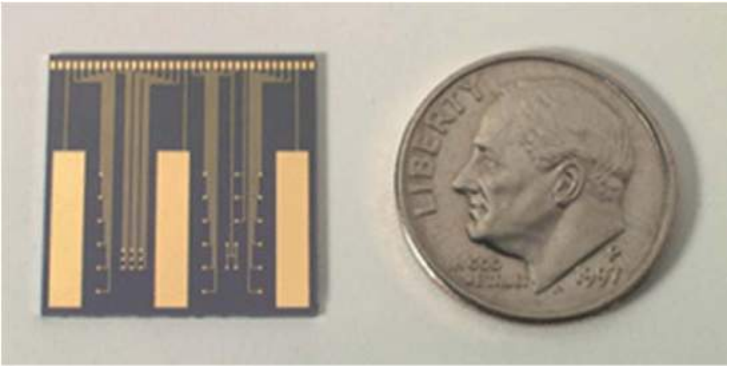


Needles thinner than a human hair

"Pharmacy-on-a-chip" pills for drug delivery



Schematic diagram of a prototype microchip delivery device with a portion cut away to reveal the micro-reservoirs. *(Figure by J. Brady)*



Silicon chips containing drugs

Tissue Engineering: Making Tissues in the Lab

- Hundreds of thousands of people need organ transplants each year
  - -liver
  - -kidney
  - -heart valves
  - -cartilage
  - -skin

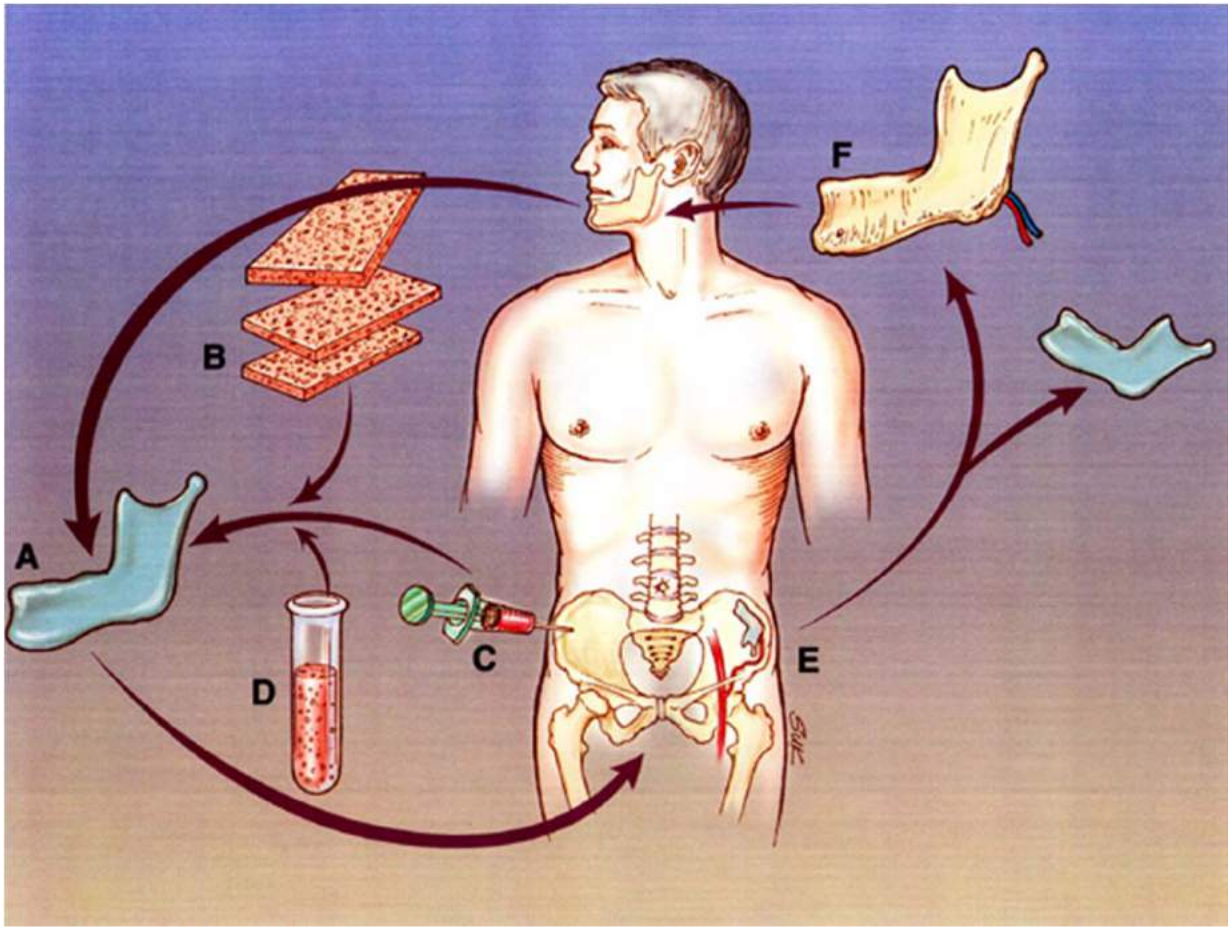
- Tremendous organ shortage

- Grow tissues in the lab

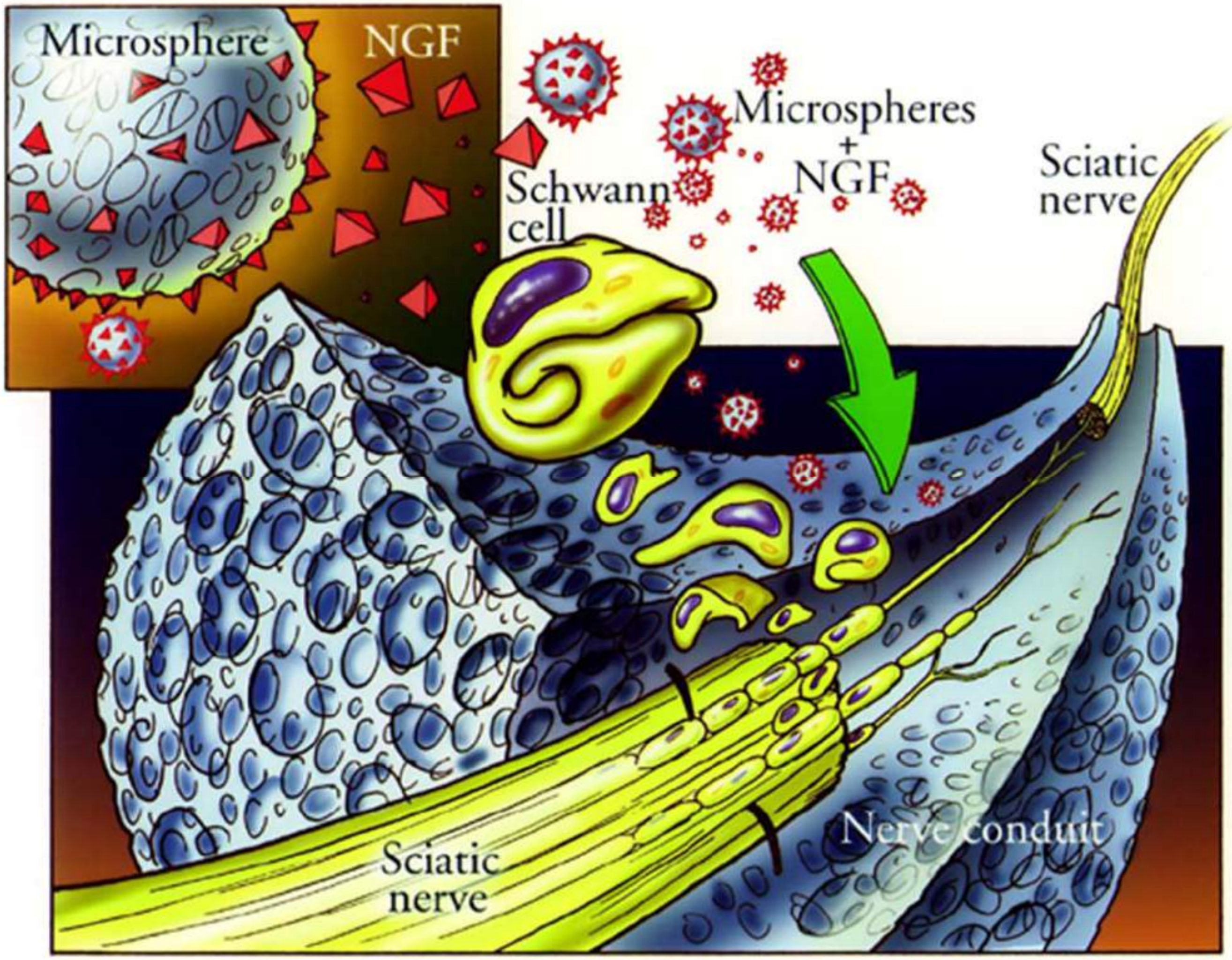
Challenges in Tissue Engineering

- Most cells know how to form organs in vitro
- They need:
  - -support to grow
  - -supply of nutrients
  - -removal of waste
  - -protection against immune rejection
- Tissue engineers attempt to overcome these limitations

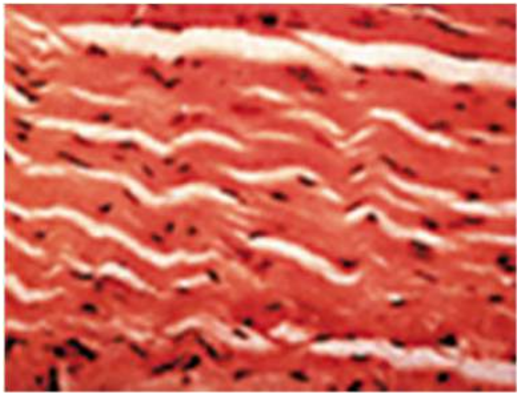
Engineering of Cartilage Tissue



Engineering of Nerves

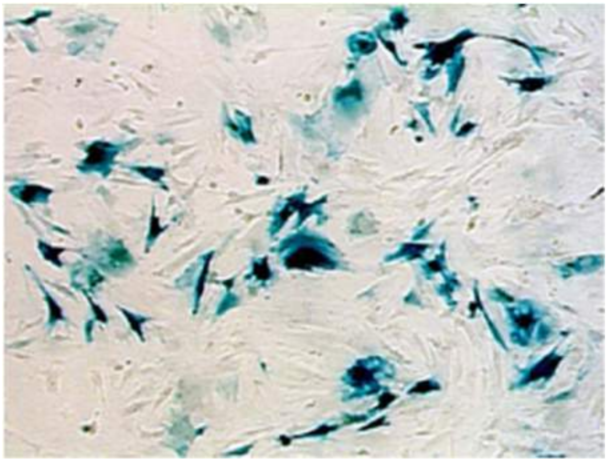


Examples of Engineering Tissues



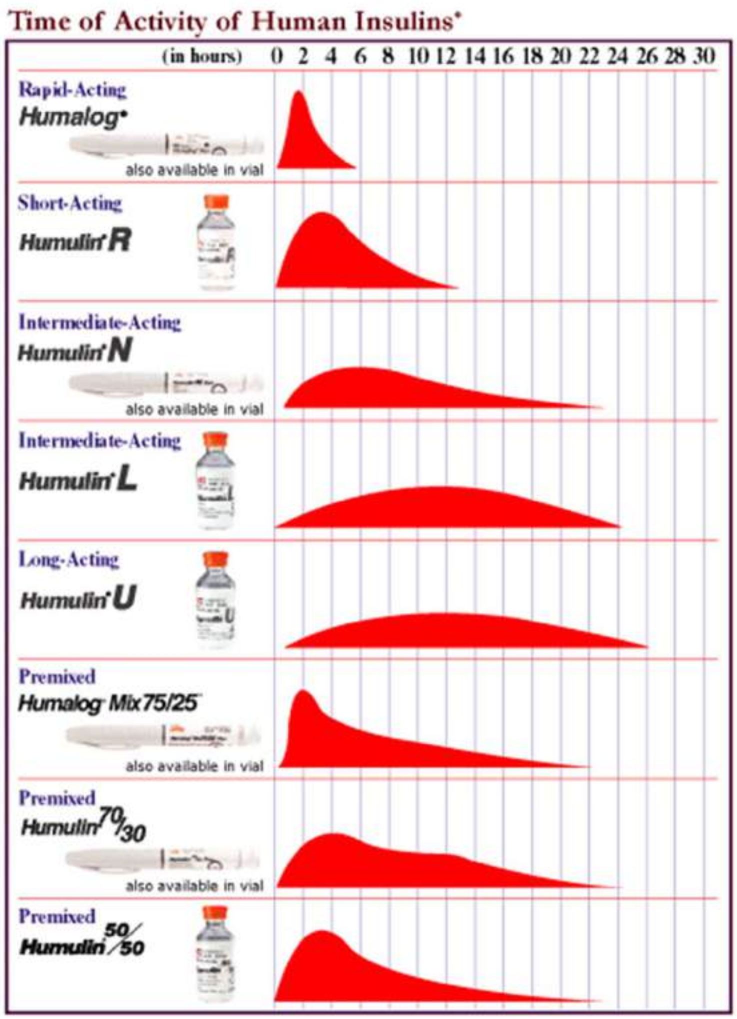
Ligament

Cartilage



Nerves

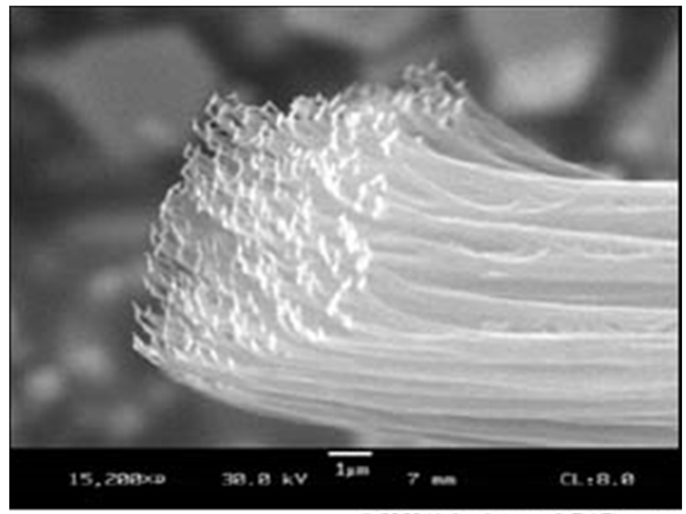
Protein Engineering



Biomimetic Approaches to Engineering

Learn from the Nature and Biology

By Connie Speight / courtesy Santa Barbara Zoo



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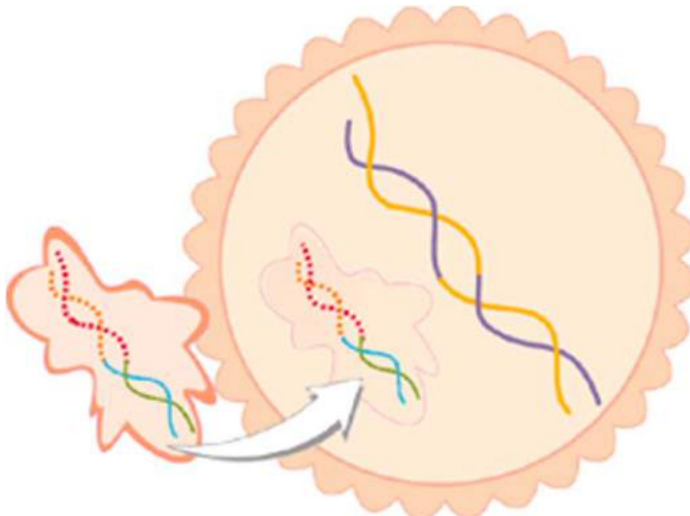
Biomimetic Approaches: Gene Therapy



Viruses know how to enter the cells

Biomedical Engineering: Summary

- Better understanding of biological and physiological functions
- Improvements of existing devices/methods
- Discovery of novel biomaterials
- Better methods of drug delivery and diagnostics
- Deeper integration of Engineering, Biology, and Medicine

Books

- No required textbook for this class
- Handouts will be given whenever appropriate
- References for engineering fundamentals

  Transport Processes: Transport Phenomena (Bird, Stewart, and Lightfoot)
  Thermodynamics: Introduction of Chemical Engineering Thermodynamics (Smith, van Hess, and Abbott)
  Kinetics: Elements of Chemical Reaction Engineering (Fogler)

- References for medical and biological terminology

  Physiology: Textbook of Medical Physiology (Guyton)
  Molecular Biology of the Cell (Alberts et al)
  Medical Dictionary (Webster)