Carnegie Mellon
BIOMEDICAL ENGINEERING

42-101 Intro to BME

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Intro to BME: Where have we been?

"What a long, strange trip it's been…"

- *The Grateful Dead*

Intro to BME: Where have we been?

- Topic 0. Basic Stuff
  - Units
  - Dimensions
  - Conversions
  - Dimensionless Groups
  - Precision and Accuracy, Significant Figures
  - Statistical Analysis of Data

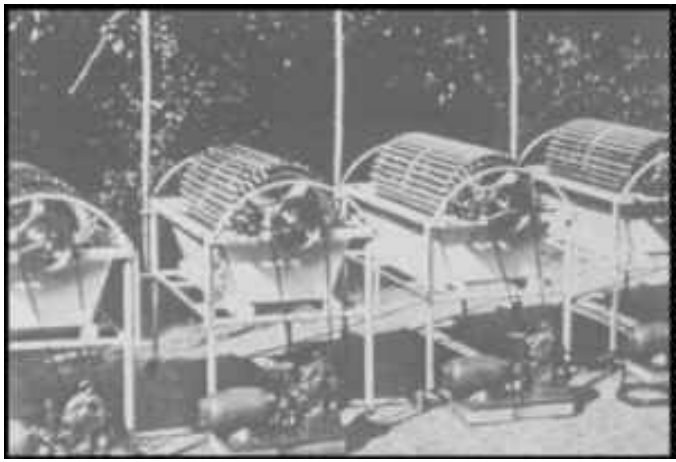
Intro to BME: Where have we been?

- Topic 1. Building Blocks of Living Systems
  - basic microbiology - cells
  - cellular composition
  - water
  - lipids
  - carbohydrates
  - nucleic acids
  - proteins
  - information flow
  - cellular stoichiometry

Intro to BME: Where have we been?

- Topic 2. Mass Balancing and Kinetics in Living Systems
  - general mass balance (conservation of mass) equation
  - special cases of the general mass balance
  - types of systems (batch=closed and continuous=open) and application of the general mass balance
  - general method of solution of mass balance problems
  - processes with recycle, bypass and purge
  - kinetics
  - microbial growth

Kidney Dialysis



- Use of semi-permeable membrane to extract wastes from blood
- 300,000 with chronic kidney failure in U.S.
- 1940's, Willem Kolff M.D. develops artificial dialysis
  - War-related shortage of membrane materials
  - Biochemist at Groningen University shows that cellophane sausage casing can be used as a membrane to exchange compounds between two liquids.
  - Prototype made of wood slats, orange juice cans and washing machine.
- Baxter Laboratories introduces first commercial dialysis machine in 1956.
- Novel techniques:
  - peritoneal dialysis uses peritoneal sac around abdominal organs as membrane, dialysis fluid injected into abdominal cavity; can be done at home
  - Ambulatory peritoneal dialysis – pump meters dialysis fluid into abdominal cavity while patient sleeps.

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- Topic 3. Living Systems as Engineering Systems
  - systems analysis
  - acceleration of reactions
  - energy coupling
  - control systems

Heart Pacemaker

- Originated in 1950's
  - First device was large, required wall outlet – caused shocks, blackouts a problem
  - 1957 Medtronic develops wearable, battery drive, book-sized pacemaker with electrode directly wired to heart
  - Problems with wires for long-term application, including infection and dislodging.
- VA Hospital in Buffalo develops miniature pacemaker following accidental use of wrong resistor in new heart-beat monitoring device – led to first totally implanted pacemaker with corrosion-resistant battery, technology licensed by Medtronic
  http://www.livingprimetime.com/AllCovers/dec1999/workdec1999/wilson_greatbatch_man_of_the_mil.htm
- Advances: more efficient electrodes with better adhesion, "intelligent" devices with heart monitoring and feedback, long-life (10 years) lithium batteries.
- Today pacemakers weigh 0.5 oz., measure 1 inch in diameter.

Intro to BME: Where have we been?

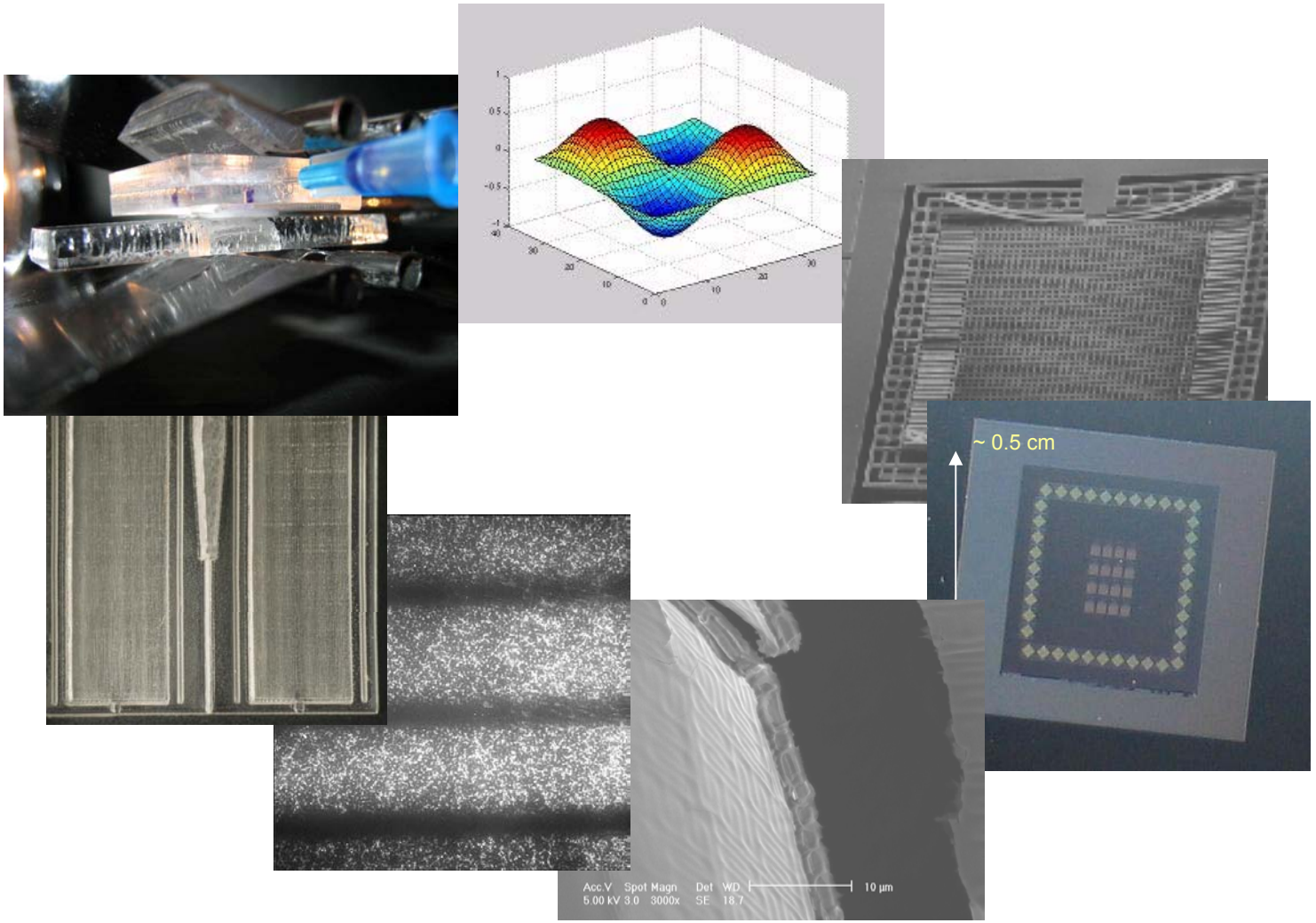
- Topic 4. Bioenergetics
  - reckoning energy and power
  - forms of energy
  - energy balances – conservation of energy
  - cellular energy production and storage
  - how cells make ATP: substrate level oxidation and oxidative phosphorylation (respiration)

Antaki, Ghattas: Pediatric Ventricular Assist Device

Intro to BME: Where have we been?

- Topic 5. Binding
  - Contexts for biomolecular binding
  - Specificity
  - Binding Kinetics and Thermodynamics
  - Enzyme Function and Kinetics

Przybycien, Hauan, Fedder/Gabriel: Acoustic Membrane Biosensor



Intro to BME: Where have we been?

- Topic 6. Organ Systems
  - Standard Man
  - Tissues and Organ Systems
  - Digestive System
  - Cardiovascular System
  - Lymph System
  - Renal System
  - Endocrine System

Heart-Lung Machine

- Device to pump and oxygenate blood during open heart surgery
  - Unoxygenated blood pumped from upper heart chambers to reservoir, then to “artificial lung” where blood absorbs O_2, then filtered to remove bubbles and pumped back into patient’s aorta
- Enables 750,000 open heart surgeries per year
  - Prior to 1950, open heart surgery was impossible
- Invented by John Gibbon in 1937 at Jefferson Medical College, Philadelphia
  - Two roller pumps
  - Problems with blood damage, infections, air bubbles
- 1945 Swedish group of scientists and chemical engineers developed rotating disc, film flow oxygenator with blood filter
- Modern devices allow for several hours of operation and control temperature (allows low T surgery)
- Risks still exist from blood clot formation and inflammation – motivates biocompatible materials research.

http://www.texasheartinstitute.org/hsurg.html

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- Topic 7. Gate Analysis

  - A simple model for power expenditure on walking

  - Stride optimization

  - Ergonomic analysis

Medical Robotics – Yoky Matsuoka

An anatomically-correct testbed (ACT) hand can serve in three capacities:

1. As a telemanipulator that mimics both the active and passive dynamics of a human hand for precision teleoperation and prosthetics,

2. As an experimental testbed to investigate the complex neural control of human hand movements, and

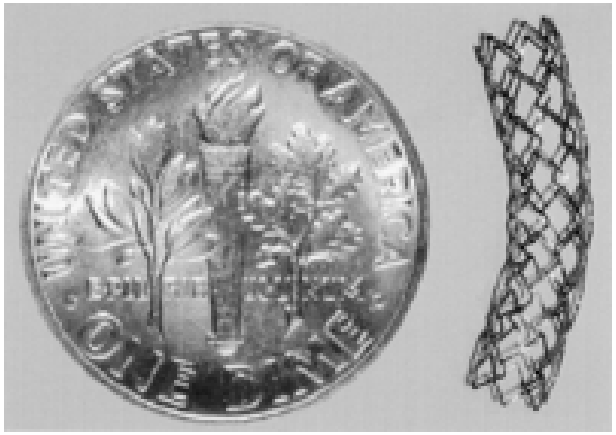
3. As a working physical model of the human hand for neuro- and plastic-surgeons to test new surgical reconstruction techniques for impaired hands.

Intro to BME: Where have we been?

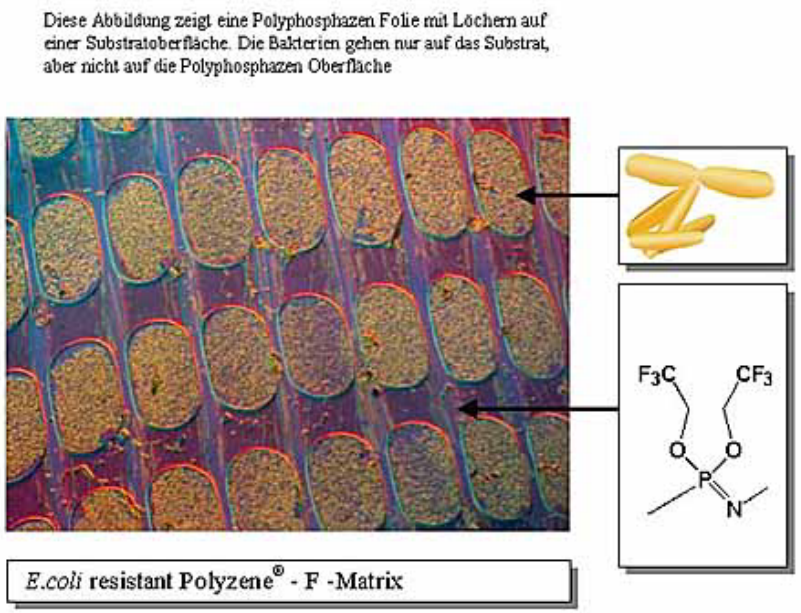
- Topic 8. Bio-Fluid Mechanics
  - fluid properties
  - hydrostatics
  - flow – mass balancing
  - flow – inviscid flow
  - flow – viscous flow
  - blood rheology

Angioplasty

- 1977, Swiss physician inserted catheter into coronary artery to inflate a balloon to clear blockage
  - Minimally invasive, mechanical solution to medical problem.
  - Problems; rapid re-closure of vessel
- Balloons now used to expand stents that are left behind.
- Problems: Restenosis (immune response to stent surface, producing scar tissue buildup).
- New research – stent coatings that release clot-deterring compounds, new biocompatible materials.
- Today > 1 million balloon angioplasties per year
  - World's most common medical intervention



from American Heart Association http://circ.ahajournals.org/cgi/content/full/105/22/2586)



from http://www.uni-heidelberg.de/presse/news/2310chem1.html)

Intro to BME: Where have we been?

- Topic 9. Biomaterials
  - biomaterials versus biological materials
  - materials properties
  - types of materials
  - body response to implanted materials and blood clotting

Hip Joint Replacement

- Total hip replacement “one of most successful surgical procedures” according to NIH (1994).
- 168,000 per year
- First performed in 1930’s
  - Unsuccessful due to infection, poor fit, bone wear
- Improvements
  - 1960’s: reduced friction by decreasing size of ball joint, improved stability using poly(methylmethacrylate) adhesive

- Use of Teflon cup – but Teflon wear harmed surrounding tissue

- High molecular weight polyethylene provides wear-resistant, durable implants.

- New research underway with porous hydroxyapatite coatings for cement-less implant fixation

Plastic model of human pelvic area, including both hip sockets.

Intro to BME: Where have we been?

- Topic 10. Biomedical Imaging

  - Biomedical imaging overview

  - Magnetic Resonance Imaging

  - Handling and Processing Image Data, the Fourier transform

Magnetic Resonance Imaging

F-6y, Coronal chest and neck, 24 cm FOV, 79.8 mm Thk, GE(30o), TR/TE = 6.4/1.4 ms, 1 Nex, 256x160 matrix

http://www.cis.rit.edu/htbooks/mri/inside.htm

Great Achievements in Medical and Biological Engineering

1950s and Earlier
Electrocardiogram (EKG/ECG)
Artificial kidney (Dialyzer)
Adhesive bandage
Insulin delivery (extraction, sensors, pumps)
Cardiopulmonary Bypass
Blood handling and fractionating
Plastic contact lens
X-ray
Cardiac pacemaker
EEG
Antibiotic production technology
Defibrillator
Geiger counter
Iron lung

1960s
Balloon catheter
Gamma camera
Vascular stents
Biomedical telemetry
Heart valve
Respirator
Intraocular lens
Electronic hearing aids
Dental implant
Ultrasound
Scanning electron microscope
CPR
Automated blood analyzer
Vascular grafts
Seat belts

AIMBE 2004

Great Achievements in Medical and Biological Engineering

1970s
Computer assisted tomography (CT)
Biological plant engineering (Green Revolution)
Immunnoassay Systems
Neurological electrical stimulation
Cochlear implant
Powered wheelchair
Sutures (staples, resorbable)
ICU monitoring (adults/infants)
Clinical use of computers
Auto safety testing
Endoscopy (Eliminate exploratory surgery)
Total joint replacement (hip/knee/ankle)

1980s
Artificial heart
Ventricular assist devices
Drug delivery systems
Imaging agents
Laser surgery (eye, esthetic, therapy)
Biosensors
Magnetic resonance imaging
Pulse oximeter
Microcatheter (steerable guidewire)
ECMO (pediatric)
Safe food processing
Microinvasive surgery

AIMBE 2004

Great Achievements in Medical and Biological Engineering

1990s and Forward
Image-guided surgery
Drug eluting stents
Tissue engineering (scaffolding/electrospinning)
Human genome (sequencing/microarrays)
PET Scan
Automated protein identification
Integrated pacemaker/defibrillator
Production of therapeutic proteins
Digital image archiving
Intelligent medical search (web access)
Swallowable diagnostics
Implantable neural stimulator
Bioremediation
NLM Visible Human Project

AIMBE 2004

Intro to BME: Where to next?

"… remember, no matter where you go, there you are."

- *The Adventures of Buckaroo Banzai Across the 8th Dimension*

The BME Dual Major
≤ Class of 2008

Core Courses

42-101 Intro to BME
03-121 Modern Bio OR 03-232 Biochem
42-201 BME Seminar
42-301 Physiology

BME Domain & Electives (total of 5)

≥ 3 BME Domain (42-xxx or most 03-xxx)
≤ 18 units 42-560 BME research and/or 39-500 CIT honors research with BME faculty

Capstone

42-401 BME Design

The BME Minor

CIT Majors

42-101 Intro to BME
42-301 Physiology
3 BME Domain Courses (42-xxx or most 03-xxx)

Non-CIT Majors

42-101 Intro to BME
2nd CIT Intro Course
06-101 Intro to ChE, OR
12-100 Intro to CEE, OR
18-101 Intro to ECE, OR
42-101 Fundamentals of Mech E, OR
27-100 Materials in Engineering
42-301 Physiology
2 BME Domain Courses (42-xxx or most 03-xxx)