Carnegie Mellon
BIOMEDICAL ENGINEERING

42-101 Intro to BME

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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

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

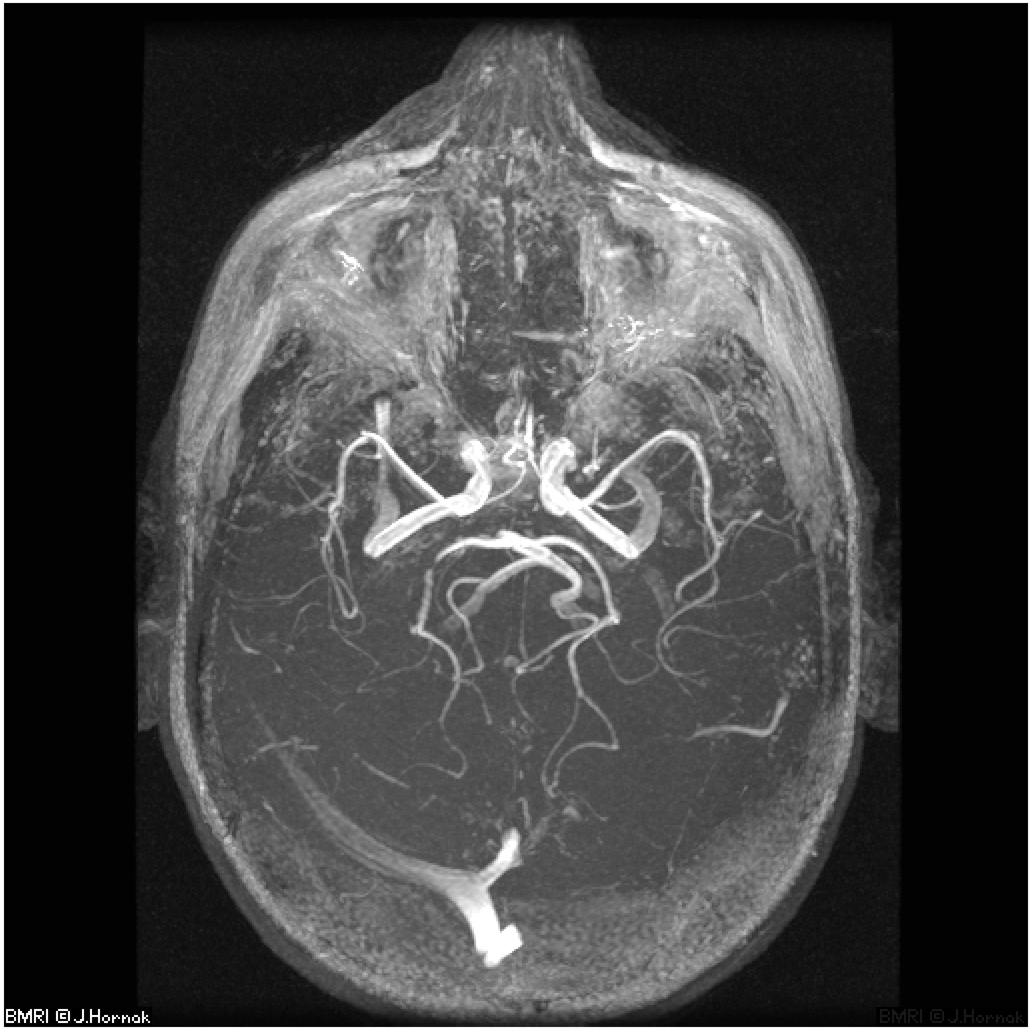
Plastic model of human pelvic area, including both hip sockets.

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

Magnetic Resonance Imaging



Axial head, 22 cm FOV, 256x224 matrix

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

Magnetic Resonance Imaging

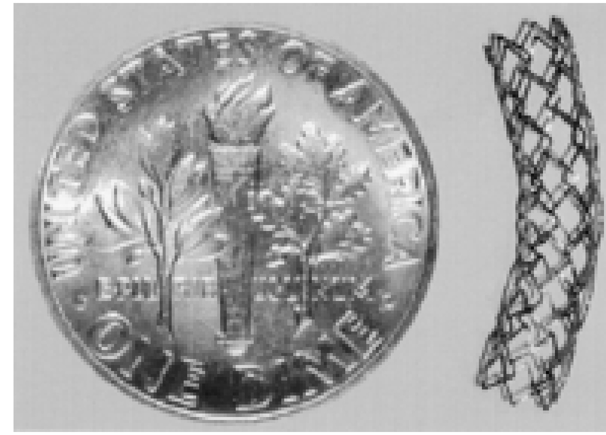
- 1952 Nobel prize in physics to Bloch and Purcell for nuclear magnetic resonance
- MRI: non-invasive imaging without dyes or harmful x-rays
- Applies magnetic fields and detects radio waves emitted by atoms
  - Radio emission depends on local chemical environment
  - 1970's discovery: Local environment varies from one tissue type to another, including cancerous vs. non-cancerous tissue
  - 1980's: used to visualize abnormalities in brain and upper spine
- Problems: long times required to image, breathing and heart beat interfered with chest imaging
- Solution: High field magnets
- Today: MRI can discriminate tissues based on water content, iron, fat, blood; can image blood flow, cerebrospinal fluid flow
- Research:
  - Functional imaging (local metabolism in tissues) to diagnose source of Parkinson's, epilepsy…
  - MRI-guided surgery

Heart Pacemaker

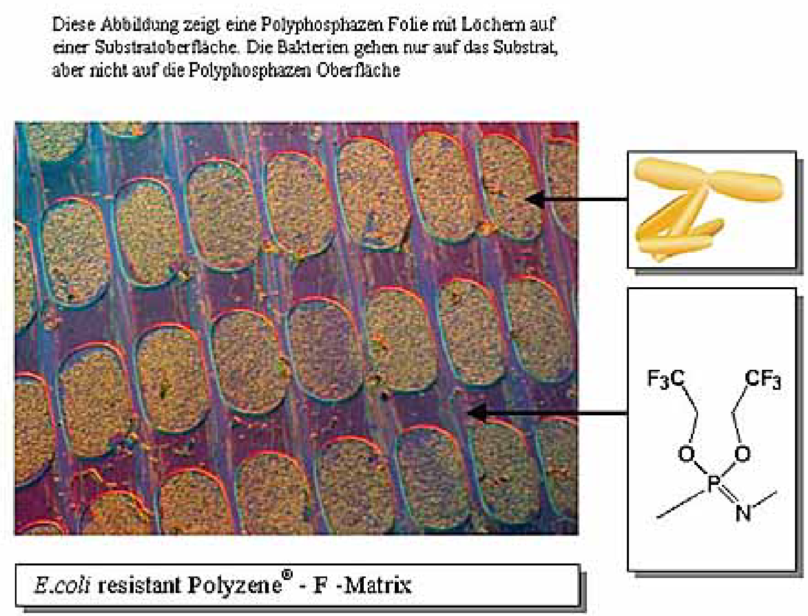
- Originated in 1950's
  - First device was large, required wall outlet – caused shocks, blackouts a problem
  - 1957 Medtronic develops wearable, battery drive, book-sized pacemaker with electrode directly wired to heart
  - Problems with wires for long-term application, including infection and dislodging.
- 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.

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

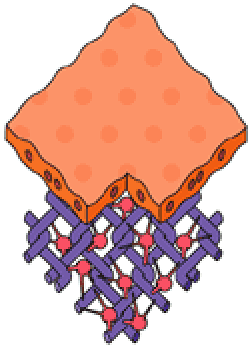


from American Heart Association http://circ.ahajournals.org/cgi/content/full/105/22/2586)



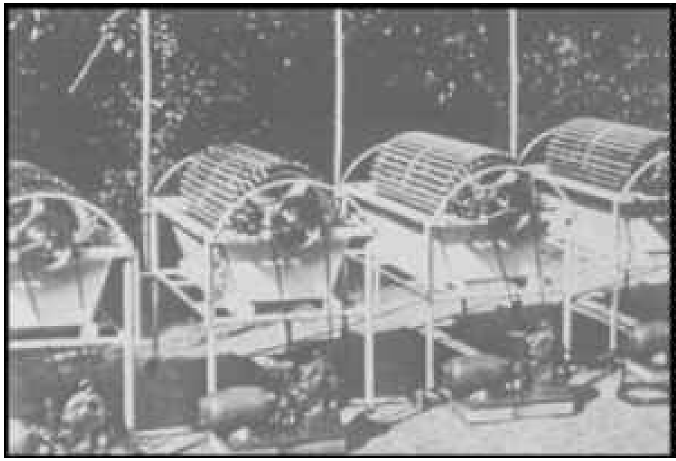
from http://www.uni-heidelberg.de/presse/news/2310chem1.html)

Bioengineered Skin



- Early success of tissue engineering to treat burn victims
- 1977 FDA approves Advanced Tissue Sciences' TransCyte® as temporary wound cover
  - Human dermis with synthetic epidermis – blocks fluid loss, reduces infection until skin regrows (2^{nd} degree) or surgical skin graft (3^{rd} degree)
- 1998 FDA approves Organogenesis' Apligraf® synthetic skin for diabetic ulcers
  - Bovine collagen + human skin cells in base layer; epidermis formed by prompting keratinocytes (skin cells) to differentiate to mimic human skin.
- In U.S. 1500 burns requiring grafts, 40,000 2^{nd} degree burns per year; 800,000 with diabetic foot ulcers requiring 80,000 amputations per year.

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.

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

The Five BME Foci

Biomedical Image and Signal Informatics

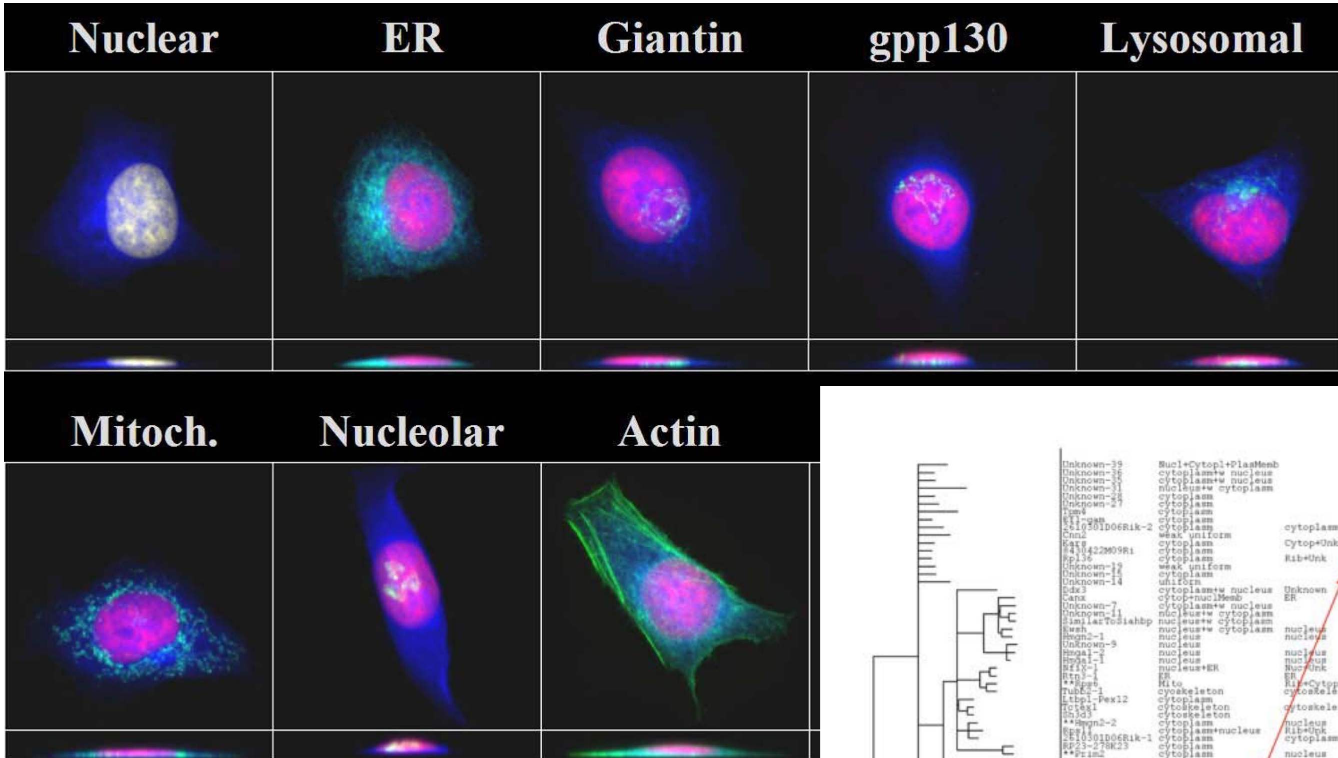
Regenerative Medicine

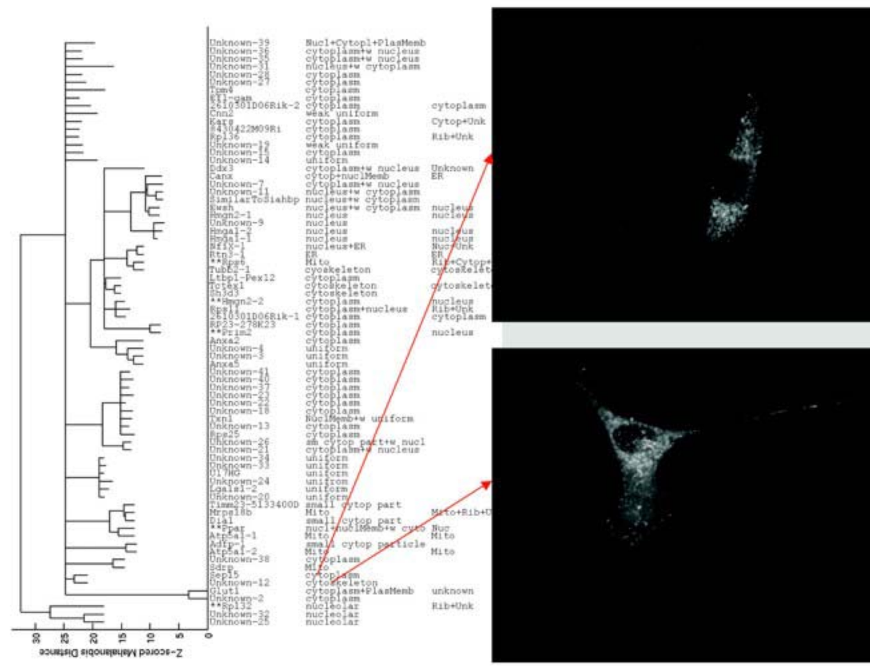
Computational Biomechanics & Devices

Medical Robotics

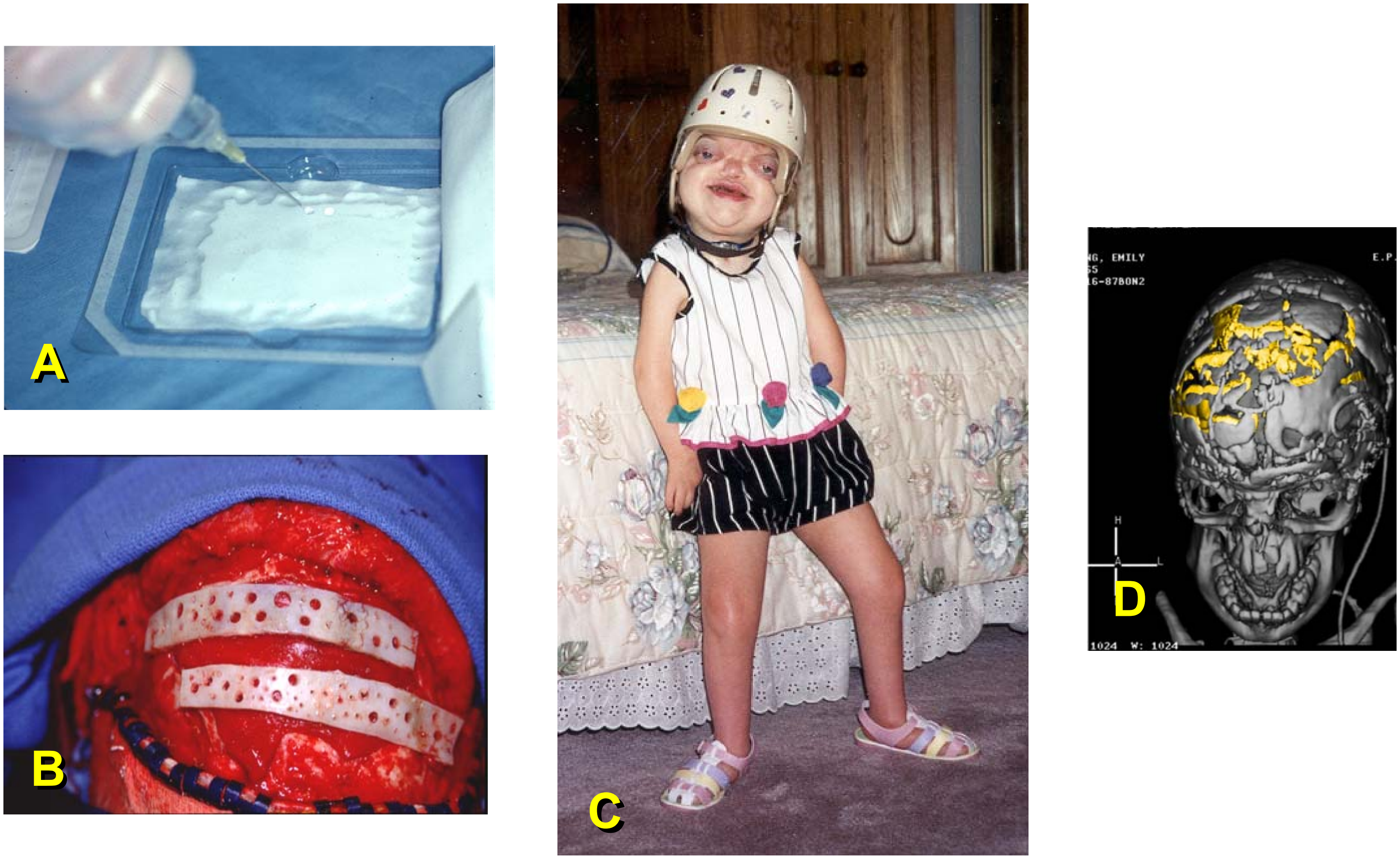
Molecular & Cellular Biotechnology

Murphy: Location Proteomics



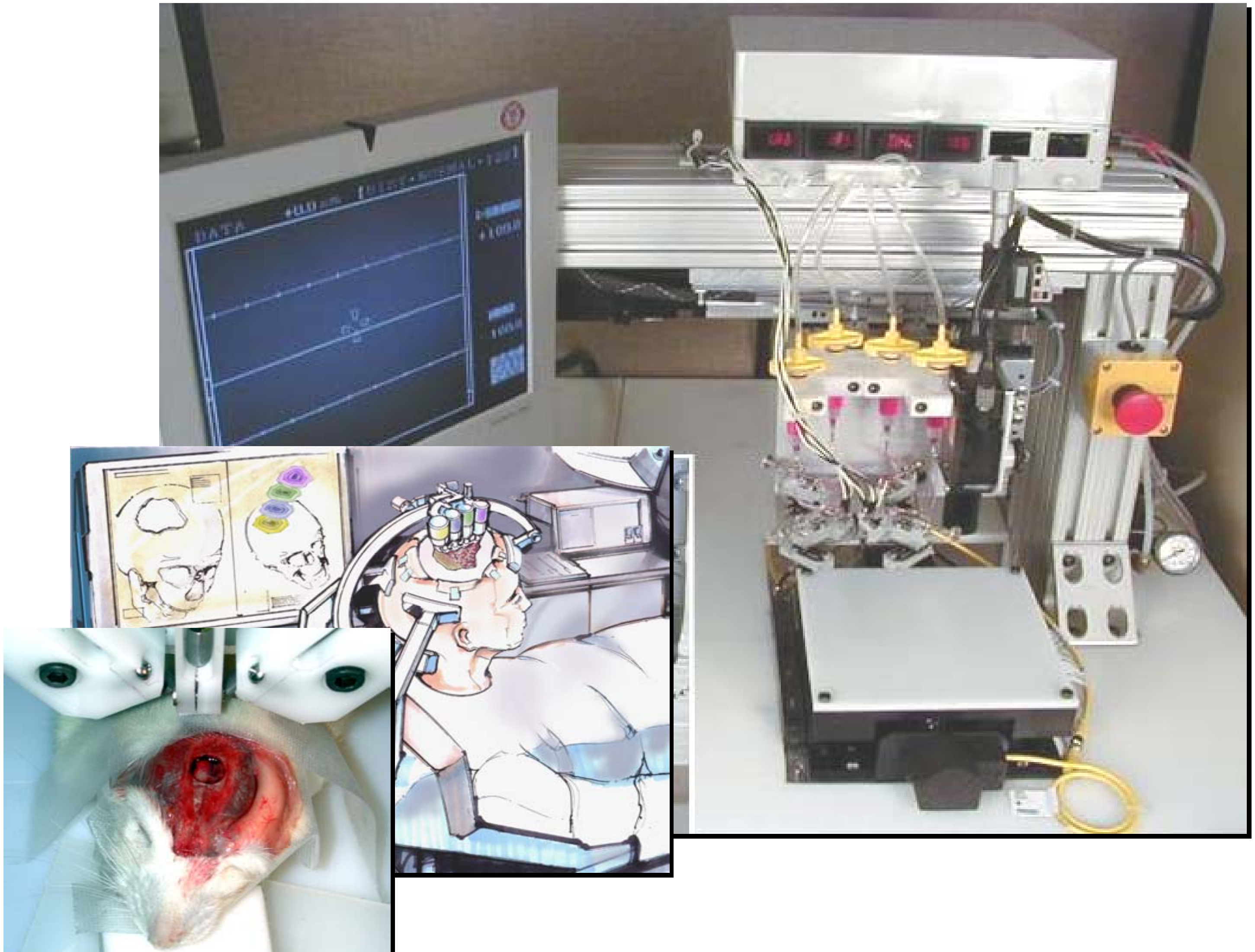


Hollinger: Repair of Craniofacial Bone Deficits



Antaki, Ghattas: Pediatric Ventricular Assist Device

Weiss: *In situ* Printing of Tissue Scaffolds



Przybycien, Hauan, Fedder/Gabriel: Acoustic Membrane Biosensor