Introduction to Applied Bioelectrical Engineering

January 29, 2019

580.435/635 Applied Bioelectrical Engineering
Prof. Leslie Tung
Department of Biomedical Engineering
Johns Hopkins University

Course Topics

- Week 1 (Jan. 29, Jan. 30)
  - Course introduction: measuring and administering bioelectric signals
  - The heart as a bioelectric source; bioelectric currents and voltages; bioelectric dipole sources
- Week 2 (Feb. 5, Feb. 7)
  - Electrocardiography and electrocorticography
  - Electrical stimulation I: strength-duration relation, excitation threshold; volume conductor
- Week 3 (Feb. 12, Feb. 14)
  - Electrical stimulation II: cells in electric fields, field stimulation
  - Electrical stimulation III: tissue fibers in electric fields, field stimulation, virtual electrodes
- Week 4 (Feb. 19, Feb. 21)
  - Cardiac pacemakers: dual chamber, rate-adaptive and antitachycardia pacing
  - Cardiac resynchronization therapy; implantable cardioverter-defibrillators
- Week 5 (Feb. 26, Feb. 28)
  - Functional neuromuscular electrical stimulation: devices to stimulate leg muscles, neuroprostheses, skin eletrodes
  - Ablation I: radiofrequency ablation; treatment of atrial fibrillation, liver tumors and other pathological conditions
- Week 6 (Mar. 5, Mar. 7)
  - Ablation II: electroporation, electrochemotherapy, gene transfer, transdermal drug delivery
  - Deep brain stimulation I: anatomy and Parkinson's Disease; mechanism of DBS
- Week 7 (Mar. 12, Mar. 14)
  - Deep brain stimulation II: electrodes and lead placement, computational models; DBS waveforms
  - Final exam

2

Grading

- 3 Homework assignments (15% each)
  - Homework 1 assigned Tue, Feb. 5, due Tue, Feb. 12
  - Homework 2 assigned Thu, Feb. 14, due Thu, Feb. 21
  - Homework 3 assigned Tue, Feb. 26, due Tue, Mar. 5
- In class final exam, Thu, Mar. 14 (45%)
- Class participation (10%)

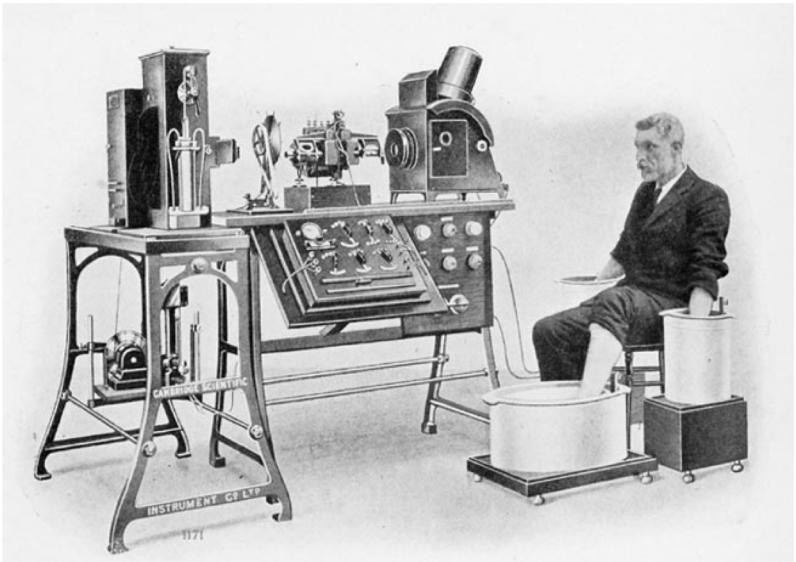
3

Part 1. Measuring Bioelectrical Signals

4

The Electrocardiogram (ECG)

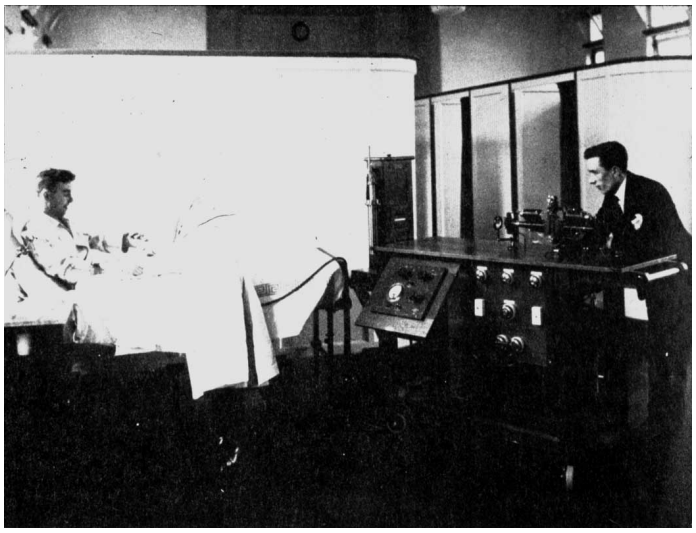
5



PHOTOGRAPH OF A COMPLETE ELECTROCARDIOGRAPH, SHOWING THE MANNER IN WHICH THE ELECTRODES ARE ATTACHED TO THE PATIENT, IN THIS CASE THE HANDS AND ONE FOOT BEING IMMERSED IN JARS OF SALT SOLUTION

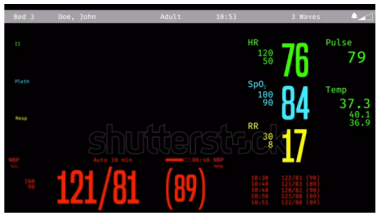
6

Early Electrocardiographic Equipment
(courtesy of Cambridge Instrument Company, New York)



7

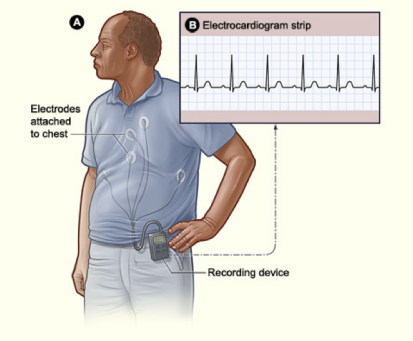
Bedside Monitor



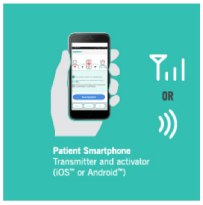
8

Ambulatory Cardiac Monitors

Holter monitor



Insertable monitor



Confirm Rx
from Abbott

9

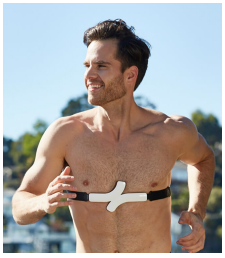
Cardiac Chest Electrodes

Snap electrodes

Tab electrodes

10

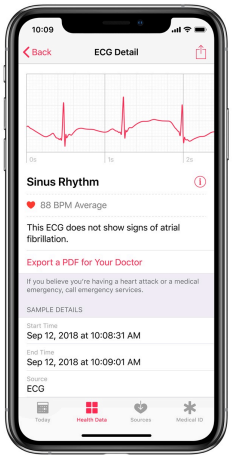
Miniature Hand-Held and Wearable Monitors



11

Wearable Monitors

Apple Watch Series 4



12

Questions that will be addressed in this course

- What sorts of bioelectrical signals exist in the body?
- What is the source for endogenous bioelectrical signals?
- How do bioelectrical signals distribute throughout the body?
- How does one measure bioelectrical signals?
- How can bioelectrical currents and voltages be used therapeutically?

13

Bioelectrical Signals in the Human Body

Electrocardiogram (ECG)	0.5 – 4 mV
Electroencephalogram (EEG)	0.5 – 4 mV
Electrogastrogram (EGG)	0.01 - 1 mV
Electromyogram (EMG)	0.1 – 5 mV
Eye potentials	
Electrooculogram (EOG)	0.05 – 3.5 mV
Electroretinogram (ERG)	0 – 0.9 mV
Galvanic skin response (GSR)	1 – 500 kΩ
Extracellular nerve potential	0.01 - 3 mV

Data from J. G. Webster. Medical Instrumentation (3rd ed). John Wiley & Sons, New York, 1998.

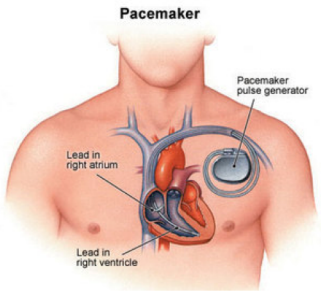
14

Part 2. Administering Bioelectricity

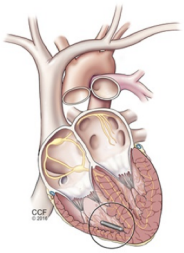
15

Cardiac Pacing

Conventional pacemaker



Leadless pacemaker



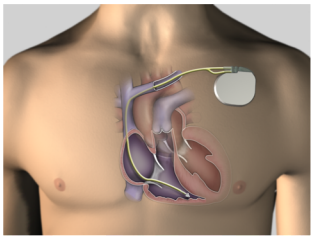
Micra™ from Medtronic

Nanostim from Abbott

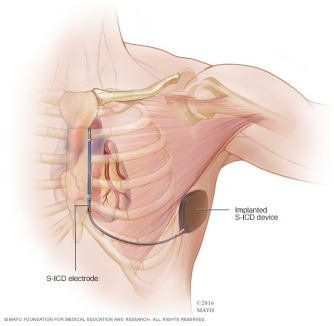
16

Cardiac Defibrillation

Conventional
implantable defibrillator



Subcutaneous
implantable defibrillator



S-ICD™
from Boston Scientific

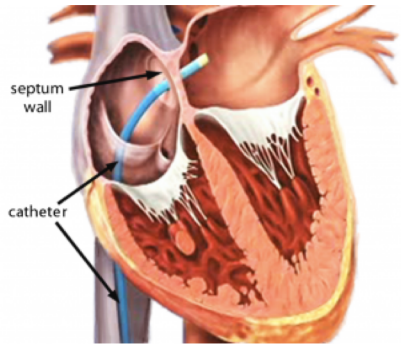
17

Functional Neuromuscular Electrical Stimulation

WalkAide®
from Innovative Neurotronics

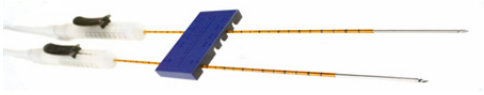
18

Radiofrequency Ablation



19

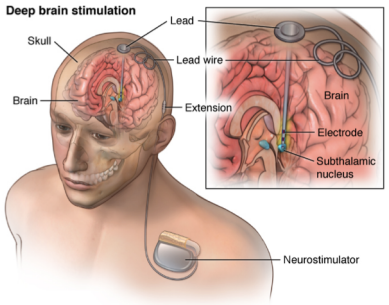
Surgical Ablation via Electroporation



NanoKnife®
from Angiodynamics

20

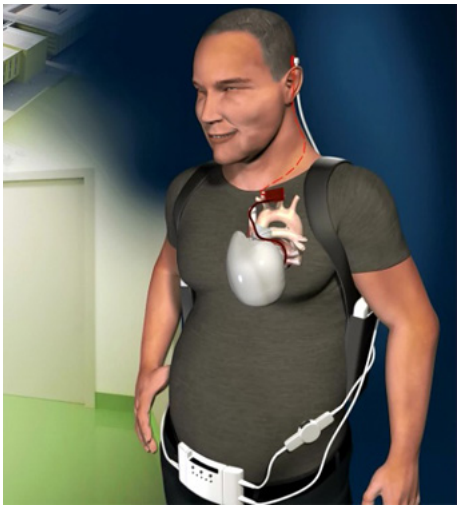
Deep Brain Stimulation

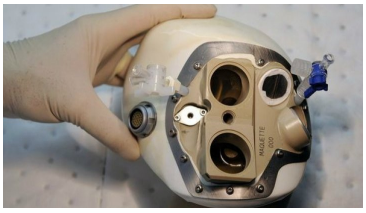


Activa PC™ Neurostimulator from Medtronic

21

Artificial Heart

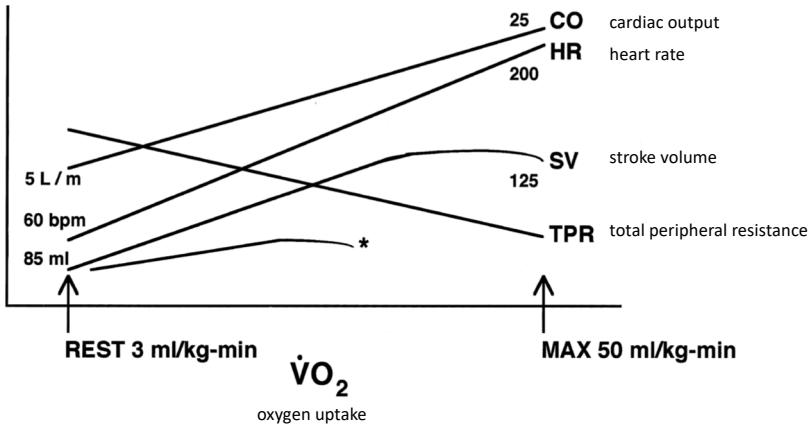




CARMAT Artificial Heart

22

Hemodynamic Response to Exercise



Alt, Am J Cardiol 83:17D, 1999

23

Sensors for Rate Adaptive Pacing

TABLE I Sensors Currently Available or Under Investigation

Sensor Signal	Sensor	Status
Mechanical		
Body activity	Piezo crystal	available
	Accelerometer	available
Peak endocardial acceleration	Endocardial accelerometer	available
Temperature	Thermistor	available
ECG		
QT interval	Unipolar lead	available
Depolarization gradient	Bipolar lead	investigational
Impedance		
Respiration rate	Auxiliary lead	available
Minute ventilation	Bipolar lead	available
Stroke volume	Multipolar lead	investigational
Pre-ejection interval	Multipolar lead	investigational
Impedance contractility (ANS)	Multipolar lead	available
Other		
dP/dt	Pressure sensor	investigational
O_2 saturation	Light-emitting diode and opto sensor	investigational

Alt, Am J Cardiol 83:17D, 1999

24

Rate-Responsive Biosensor

- Grow cardiomyocytes in a protected cell culture environment
- Design and build an electronic sensor to read out beating rate
- Verify rate-responsiveness of the cardiomyocytes to sympathetic stimulation (adrenaline)

25