Functional Neuroimaging Techniques

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PREFACE

These lecture notes are a collage from several books and my own experiences. I would like to thank my former student, Ms Zeynep Susam, for compiling these notes while I was lecturing. She was kind enough to include many pictures and graphics (along with some cartoons) to make these notes more attractive.
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**Introduction**

Definition of Biomedical Engineering

“Health care delivery team” that seeks new (innovative) solutions for the difficult problems confronting modern society

Innovation patent:

1. Novel $\rightarrow$ no one should have taught about these before
2. Non-(not) obvious
3. Applicable $\rightarrow$ must serve a new purpose

**Branches of BME**

```
Biomedical Engineering

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A QUICK REVIEW on PHYSIOLOGY & ANATOMY

Physiological Systems

A group of interconnected or independent organs that work together to perform a specific function or a group of functions in the body

\[ x(t) \rightarrow h(t) \rightarrow y(t) \]

System (Transfer) Function

System: processes inputs to produce outputs

INPUTS
- Biochemical
- Physical
- Electrical
- Environmental

OUTPUTS
- Biochemical
- Physical
- Electrical

HW 1

PART I: Find 2 different definitions of Biomedical Engineering

PART II: Find websites related to Biomedical Engineering and organize them under the following headings:

1. Academic Websites
2. Industry
3. Professional Organizations
**Circulatory (Cardiovascular) System**

*Organs:* heart, blood vessels

- **Left Ventricle:** Responsible for pumping oxygen rich blood to the body.

- The heart works with electricity.
SA node has a direct contact from central nervous system to control / modulate the rhythm of the heart.

Heart rate modulators:

1. Central nervous system
2. Hormonal stimulation
3. Blood flow (mechanical)
4. Biochemical / ionic modulations on a heart muscle

Coronary arteries supply oxygen, glucose, blood to the tissue of the heart.

➢ No blood supply due to obstruction $\rightarrow$ occlusion $\rightarrow$ ischemia $\rightarrow$ hypoxia $\rightarrow$ cell death

Ectopic focus $\rightarrow$ ventricular fibrillation
Nervous System

Integration and control of all body functions

Central Nervous System (CNS)  Peripheral Nervous System (PNS)
- All the nerve tissue enclosed by the bone
- Brain & spinal cord
- Nerve tissue that is not enclosed by the bone
- Nerve fibers from the spinal cord, muscle
  nerve fibers

Stroke: Bleeding of blood vessels \( \rightarrow \) resulting in partial paralysis

Blood Vessels
Coagulant  fills where there’s an explosion

➢ Fibers cross over in brain stem; left side of the brain controls the right side of the body.

Reflex Arch

Frontal  executive function
Parietal  motor-sensory systems
Temporal  auditory
Occipital  vision
There are multiple control systems in the brain.

- Split brain syndrome (still used to treat epilepsy)
- Underneath the frontal lobe \(\rightarrow\) emotional control and memory
- Cerebrospinal fluid underneath and around the brain
  - The top and under pressures are the same
  - The fluid is inside 4 ventricular chambers

Central Nervous System
\[\downarrow\]
Autonomic Nervous System
\[\downarrow\]
Sympathetic Nervous System \(\rightarrow\) Fight Mode!
- Excitatory
\[\rightarrow\]
Parasympathetic Nervous System \(\rightarrow\) Flight Mode!
Respiratory (Pulmonary) System

Enables cardiovascular system to exchange gases with air

➢ Nose, pharynx, larynx, trachea, lungs

\[
P_{\text{air}} V_{\text{air}} = P_{\text{lung}} V_{\text{lung}}
\]

\(P_{\text{air}} V_{\text{air}}\) is constant \(\Rightarrow P_{\text{lung}}\) decreases; \(V_{\text{lung}}\) increases \(\Rightarrow\) rush of fresh air through the lungs

Huge oxygen gradient between the deoxygenated blood and alveolar

As the red blood cell flows, oxygen is diffused through mucosa (secreted by the certain cells that have hair) and the red blood cell fills with oxygen. \(CO_2\) is formed as \(HCO_3^-\) because it is not desired in gas phase in the plasma. It is dissolved in acid form. The undissolved part is carried by the red blood cell.

\(CO_2\) is diffused freely in alveolar.
Smoking: Smoke has tar in it. Tar sits on top of mucosal layer. Alveolar needs to secrete more mucosa. The thickness has increased, diffusion takes longer. If you smoke more, the distance that the oxygen should travel increases and there’s no more oxygen transfer.

⇒ Emphysema

Respiratory system is controlled by signals if cerebellum.

**Gastrointestinal (Digestive) System**
Concerned with the ingestion and digestion of food, elimination of the residues of the gastrointestinal system

⇒ Liver, gallbladder, pancreas, stomach, intestines colon

---

Gastroesophageal reflux

1. Neoplasia
2. Dysplasia
3. Cancerous formation
   - Immortality
   - Uncontrolled growth

- Metastatic
- Barnett’s Esophagus

**Urogenital System**
- Production, storage, elimination of urine
- Reproduction
  - Kidneys, bladder, ovaries, prostate

Kidneys: Responsible for maintaining water equilibrium, balance of minerals, and removal of toxic components from the blood.

- Filtration system, continuous blood flow

Kidneys maintain mineral level (Ca, Mg, Zn, Fe)

→ Maintain homeostasis (static state of the body)
Kidneys are responsible for maintaining blood pressure.

Too much water \(\rightarrow\) pressure in blood vessels

Kidneys send hormones to blood vessels to relax the vessels \(\rightarrow\) renin activates angiotensin

\(\rightarrow\) Squeezing down the vessels

**Dialysis:** A filtration system to remove toxins and urea from the blood.

**Kidney Stone:**

**Pancreas:** Responsible for secreting hormones to maintain blood glucose level.

- Hypoglycemia
- Diabetes Mellitus

**Musculoskeletal System**

- Muscles & skeleton

Maintaining balance, movement, keeping warm
Amount of signals determine how many muscles should be recruited to carry the weight. Signals can be sent as a whole or one by one.
Force generated by muscles is a function of

- Neuronal stimulation from the brain (frequency & intensity)
- Amount of blood supply
- Available nutrients
- Ionic concentration around muscle (Ca$_{2+}$)
- Previous activity level

- Lactic acid vs. endurance
- Hypertrophy

**Endocrine System**
Regulation and control of visceral functions

- Secretes hormones via glands that control growth, metabolism and reproduction.
  - Pituitary gland, thyroid, parathyroid, adrenalin gland, thymus

Glands are bags that are covered by muscles.
Pituitary gland: growth, reproduction

Thyroid gland: around the trachea at the larynx

- Controls the rate of metabolism
  - Hyperthyroidism
  - Hypothyroidism

Parathyroid gland: on top (around) the thyroid gland

- Responsible for maintaining calcium balance in the blood stream and tissues

Adrenal glands $\rightarrow$ epinephrine

- Small amounts $\rightarrow$ vasodilation
- Large amounts $\rightarrow$ vasoconstriction
Hematopoietic System & Lymphatic System
Production of blood & blood components

Immune system components

➢ Bone marrow, spleen, lymphatic tissues

Bone marrow: production of red & white blood cells

Spleen: storage of blood cells

Lymphatic tissues: collection of plasma, dead red blood cells

➢ Production of immune system components

Red blood cells: storage of hemoglobin

White blood cells: soldiers of the body

Integumental System

Skin, hair, nails

Skin → protection

Nails → finger support

Hair → protects the brain from heating, provides sweating
BIOMEDICAL DEVICES

Sensors that are used to measure electrical, chemical, physical activities from human body

Biomedical Instruments

- Diagnostic
- Therapeutic

Invasiveness

- Non-invasive
- Minimally invasive
- Invasive

Invasive

- Ionization (radiation) X-ray, UV, γ-ray
- Contact with blood
- Intrusion into the body

Minimally invasive

- Contact with blood
- Intrusion into the body

Non-invasive

- Surface or remote diagnosis / therapy
A General Block Diagram for a Diagnostic Instrument
BIOMEDICAL SENSORS

Chemical Sensors
Blood components, glucose, ions, hormones, and pH, O₂, CO₂

---

![Clark Electrode Diagram]

- Invasive (accurate)
- Non-invasive (not so accurate)

---

Clark Electrode

Rate of electron transfer is measured by the resistance of electrodes.

\[ V = IR \quad \text{Ohm's Law} \]
\[ R = \frac{\rho L}{A} \]

\[ O_2 + H_2O + 4e^- \rightarrow 4OH^- \]
\[ Ag \leftrightarrow Ag^+ + e^- \]
\[ Ag^+ + Cl^- \rightarrow AgCl \downarrow \]
Pulse Oximetry

- Detector: non-laser red light sources

Light is used to measure the concentrations of [HbO$_2$] and [Hb]
(Near infrared)

\[
SO_2 = A - B \left[ \frac{OD(\lambda_1)}{OD(\lambda_2)} \right]
\]

S O$_2$: Saturation of O$_2$

OD: Optical Density

Biochemical Sensors
- Glucose, hormone, blood components
- O$_2$ measurement: spirometer to measure O$_2$ gas amount and CO$_2$ gas in the air exchanged by the lungs

Electrical Measurements
- Results of biopotentials \(\rightarrow\) biologically generated electrical signals

Cells are electrically excitable.
Resting membrane potential

Due to the existence of ions across the cell membrane

**Action Potential**

- Is due to the rapid exchange of ions across cell membrane through channels and gates
- Muscle cell → gates
- Heart muscle → gap junctions transfer electrical potentials between cells
- Dipole
- Einthoven’s triangle

**Electrical Sensors**

- Non-invasive
  - Surface type → Surface electrodes
- Invasive
  - Needle → deep tissue measurement

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Electrolyte: electrically conductive gel with NaCl

- It allows the passage of electrical signals to the metal

Adhesive secures the electrode onto the skin surface.

**Electrocardiogram (ECG)**

- P: atrial contraction
- QRS: left ventricle contraction
- T: refilling of the ventricle

- Heart Rate
- Pacemaker
Electromyogram (EMG)

- Measurement of electrical signals of the muscle

Needle electrodes

200-400 µm thick wires

Invasive

Electroencephalogram (EEG)

The electrodes make a goof approximation about the electrical activity.

- 20 electrodes across the head (cap electrodes)
Visual Evoked Potential

Evoked Response

Cortical electrodes

Physical Measurements

- Volume, force, temperature, pressure, sound

Volume Measurement

To measure the change in current:

\[ R = \frac{V}{I} \quad \rho \propto R \]
\[ R = \frac{\rho L}{A} \quad \Delta R \propto \Delta l \]
- Calibration curve

Linear sensitivity

- Transducer

Breathing by rubber strand:

\[ \text{Breath Rate} = \frac{\text{no of breaths}}{\text{min}} \]

12-15 min\(^{-1}\)

- Amplitude gives basic info about the amount of air exchange

**Force & Strain Measurement**
$F \propto \Delta R \propto \Delta l$

1. Intraesophageal balloon

2. Radioflouroscopy
   - Ingest a liquid $\rightarrow$ absorber of X-ray

3. Strain Gage
3 of these techniques are not accurate.

**Piezoelectric Transducer**

- Force, pressure, flow

A crystal that produces electricity when mechanically strained.

\[ Q = kF \]

- Q: electric charge produced
- F: force applied
- k: coefficient of the crystal
Blood Pressure Measurement

Temperature Measurement
1. Mercury Based Measurement
2. Electrical Thermometer
3. Optical Thermometer

Electrical Thermometer

\[
R(T) = R_0 \exp \left[ \beta \left( \frac{1}{T} - \frac{1}{T_0} \right) \right]
\]
ΔI \propto ΔR \propto \frac{1}{T}

**Biosensors**
Sensors that measure the concentration of chemical components of solution

Glucose + enzyme → glucanic acid → alters the pH of the sheet

pH \propto \text{Glucose}

**HW 4**

PART I: What is a biosensor? Find 1 clinical application for it.

PART II: What is a molecular beacon? What is a quantum dot? Find their usage in biology.
BIOMEDICAL INSTRUMENTATION

A generalized block diagram of a biomedical device

Data Processing Unit

Noise Removal

- Elimination of unwanted signals
- Electromagnetic interference
  
  = Power lines, TV-Radio broadcast, mobile phones, computers, lab equipment
1. **Noise filter**

\[ x(t) \xrightarrow{h(t)} y(t) \]

Transfer function \( \rightarrow \) filter out unwanted noise

2. **Data Filter**

- Designed to extract relevant physiological information out of others
  - Low pass filter, high pass filter, band pass filter

\[ x(t) \xrightarrow{h_D(t)} y(t) \]

Convolution: \( y(t) = x(t) \ast h_D(t) \)

3. **Gain**

- Performed to increase the amplitude of the signal

\[ x(t) \xrightarrow{G} y(t) = G \cdot x(t) \]
4. Differential Measurement

\[ V_1(t) = V_R(t) + n(t) \]
\[ V_2(t) = V_L(t) + n(t) \]
\[ V_o(t) = V_1 - V_2 = V_R(t) - V_L(t) \]

➢ To eliminate “common” noise

**Typical signal conditional steps**

\[ y(t) = G \left[ (x_1(t) - x_2(t)) * h_N(t) \right] * h_D(t) \]

\[ y(t) = G \left[ (x_1(t) - x_2(t)) * h_N(t) \right] * h_D(t) \]
Analog to Digital Convertors

Types of Signals

1. Analog  \rightarrow \text{real world, continuous signal}
2. Digital  \rightarrow \text{digitized signals}  \rightarrow \text{sampled and stored in the computer}
   - A digital representation of the signal

A / D Converter

\rightarrow \text{Resolutions}

1. Temporary Resolution
   - How fast a signal is sampled \text{[samples/sec]} = \text{sampling rate } F_s
   - Typically \( F_s = 1000 \text{ samples/sec} \)
2. Dynamic Resolution
   - How fine are you quantizing a signal? \text{[bits]}

\[ \lambda = \frac{\text{Dynamic Range}}{\text{no of levels}} = \frac{V_{\text{max}} - V_{\text{min}}}{2^n} \]

\( n: \text{number of bits} = 10-12 \text{ bits} \)

\text{Ex:} 12 \text{ bit A / D converter, } F_s = 200 \text{ samples/sec records data for 10 min from 16 electrodes.}

What is the size of the data file?

\[ \text{Data size} = \text{no of bits} \times F_s \times \text{Duration of record} \times \text{no of sensors} \]

\[ = 12 \times 200 \times (10 \times 60) \times 16 = 23M \text{ bits} \approx 2.8MBytes \]
Biomedical Signal Processing

**Characteristics of Signals**

- **Deterministic Signals**
  - Periodic
  - Aperiodic
- **Random (stochastic) Signals**

**Deterministic:** an explicit mathematical representation exists

- Periodic signals \( x(t) = x(t + T) \)

\[
x(t)
\]

- Aperiodic signals \( x(t) = Ae^{-t/T} \)

\[
x(t)
\]
Random: characterized by statistical values (mean, standard deviation)

- EEG signals

**Fourier Transform**

A means of representing the contribution (weight) of different frequencies within a signal

1. \[ x_1(t) = A_1 \sin(\omega_1 t) \]

![Diagram of \( x_1(t) \)]

\[ \omega_1 = 2\pi f_1 \quad f_1 = \frac{1}{T_1} = 12 \text{Hz} \]

2. \[ x_2(t) = A_2 \sin(\omega_2 t) \]

![Diagram of \( x_2(t) \)]

\[ \omega_2 = 2\pi f_2 \quad f_2 = \frac{1}{T_2} = 25 \text{Hz} \]

\( f_1 < f_2 \)

\( T_1 > T_2 \)

\( A_2 < A_1 \)

\[ x(f) = \int_{-\infty}^{\infty} x(t) e^{-j\omega t} dt \]

\[ x(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} x(f) e^{j\omega t} d\omega \]
Fourier Transform is random.

EEG

- Grand averaging – Ensemble averaging

---

Hi, Dr. Elizabeth?
Yeah, uh... I accidentally took the Fourier transform of my cat...

Meow!
Quality in Medical Imaging

1. Spatial Resolution
   - How small can we detect [pixels/area]

2. Contrast Resolution
   - How fine of colors do we see? [bits/pixel]

3. Temporal Resolution
   - How many images can you take in 1 second?
     - [frame rate] = [frames / second] ≥ 24 frames/sec (real time)
Radiation Imaging
- Depends on the use of X-rays to image the absorption (attenuation) distribution of the tissues

\[ I < I_0 \]

1896 – Discovery of X-ray

1901 – The very first Nobel Prize was given to Wilhelm Conrad Roentgen
Principles of X-Ray Imaging

Attenuation of X-rays by tissues between body parts having minimally different density, fat, muscle, result in a shadow image

- Collimator: aligns X-ray beam

![Diagram of X-ray imaging process]
Physics of X-Ray Imaging

\[ E = hf \]

h: Planck’s constant
f: frequency of electromagnetic wave

\[ \uparrow f = \frac{c}{\lambda} \downarrow \]

Ionization: decomposition of matter
- Vaporization of tissues

\( \gamma \) rays, X rays pass through tissues and give permanent damage to skin
\[ I(z) = I_0 e^{-\mu \rho z} \]

- \( z \): distance between source and detector
- \( \rho \): density of the object
- \( \mu \): attenuation coefficient

**Units of X-ray Exposure**

Roentgen \( \rightarrow R = 2.58 \times 10^{-14} \text{ C/kg} \)

- Produces ionization of either charge (+ or -)

When light enters \( (I_0) \), some of it is absorbed by the body not to eliminate X-ray immediately.

A typical X-ray session: 10 – 100 millirads

- Absorption of X-ray by body (chest X-ray)

Onset of radiative effect: 50 rads

Radiation death > 200 rads

**Geometric Unsharpness**
s: source to image plane distance

t: center of object to image plane distance

f: fixed size of the object

\[ d = \frac{f \cdot t}{s - t} \]

Goal: minimize d (f fixed)

1. Increase s \(\rightarrow\) increase source – detector distance

2. Decrease t \(\rightarrow\) bring the object close to image plane

X-rays \(\rightarrow\) planar image

**Computer Aide Tomography Scanner (CAT Scan)**

- Computerized Tomography (CT)

The detector rotates and cross-section images are obtained at every 1-2°
\[ \alpha_i = \rho_i \mu_i \]

We have 4 unknowns

We need 4 independent projections to solve \( \alpha_i \)'s

\[ \Rightarrow \text{Back Projection Algorithm} \]

- Reconstruct cross-sectional image of an object by projected data

**1st Generation CT**

1 source, 1 detector

60 seconds to 4-5 minutes for each rotation

Rotates at every 6\(^{\circ}\) angle for one cross-section

**2nd Generation CT**

1 source 30 detectors

All detectors are close to the source at equal distances to reduce geometrical sharpness

**3rd Generation CT**

300 detectors \( \Rightarrow \) 2 – 4 seconds
**4th Generation CT**

Only the source (fan beam) is rotating

700 detectors around (2 – 4 seconds)

**Fluoroscopy**

Patient is given a radio opaque (X-ray absorber) material and the movement of this material is observed under light by camera.

**Angiography**

Injection of radio opaque material into the veins for observation of occlusions
**Radionuclide Imaging**

Nuclear medicine → radioactive elements

Invasive → ionizing radiation

Functional physiological imaging → Curries

Nuclear particles

\[ n \rightarrow p^+ + e^- + \nu^+ + \text{energy} \]
\[ p^+ \rightarrow n + e^+ + \nu^+ + \text{energy} \]

The solution circulates in the body and targets several organs

I → radioisotope → mixed in the solution and accumulates in thyroid

\[ C_6H_{12}O_6 \rightarrow \text{Isotopes } C^{11}, C^{15} \rightarrow \text{accumulates in the parts where glucose is consumed} \]
Positron Emission Tomography (PET Scan)
An imaging technique that uses γ cameras (β cameras) to monitor the whereabouts and
intensity of a radioactive element injected into the body

It is possible to monitor the progress of the activity in
time.

It can be used to measure the effect of chemotherapy.
It can also be used to measure the effect of the drugs.

Radioactive Decay

\[ N(t) = N_0 e^{-\lambda t} \]

\( N_0 \): initial amount of material
\( \lambda \): decay constant
\( t \): time

\[ T_{1/2} = \frac{0.693}{\lambda} \]
Biological Half-life
Time needed for the body to excrete half of the amount of radionuclide. $T_{\text{b}_{1/2}}$

$$T_{1/2}^{\text{eff}} = \frac{T_{1/2} \times T_{\text{b}_{1/2}}}{T_{1/2} + T_{\text{b}_{1/2}}}$$

$^{15}O$, $T_{1/2} = 122$ sec

$^{11}C$, $T_{1/2} = 20.5$ min

- Molecular Beacon
- Quantum Dot
Magnetic Resonance Imaging (MRI)

- Uses non-ionizing radiation to probe the soft tissue contrast
- Provides excellent soft tissue contrast

Physics of MRI

Uses electromagnetic waves at radiofrequency (50-60 MHz)

Charged electron spinning around the axis

- Creation of 2 poles
- Magnetic dipole moment

1. All spinning nuclei have a characteristic resonance frequency which depends on the atomic composition
2. When atoms are combined to form larger molecules, their overall resonance frequency depends on their total weight
Nuclear Magnetic Resistance Spectroscopy (NMRS)

Different proportion of molecules
⇒ Different spinning frequency

Larmor Frequency
\[ \omega = \gamma \beta_0 \]
\[ \omega = 2\pi f \]
\( \gamma \): gyromagnetic ratio
\( \beta_0 \): applied magnetic field

Each molecule starts to rotate according to gyromagnetic ratio, resulting in \( \omega_A \), \( \omega_B \), \( \omega_C \), and \( \omega_D \).

\[ A\% \propto \frac{I_A}{I_T} \times 100 \]
\[ I_T = I_A + I_B + I_C + I_D \]
1. Place the sample inside a static magnetic field ($B_0$)

2. Close $S_1$ (off $S_2$)
   
   $\Rightarrow$ Generate a $B_1 \perp B_0$, $B_1 << B_0$ at a specific “$\omega_0$”

3. Off $S_1$, on $S_2$
   
   $\Rightarrow$ Listen to incoming signal

Free Induction Decay, which is a signal like this:

- $A$ the amount of compound present within the sample
- $\tau$ the density of compound present within the sample
Imaging In MR

Idea: Image 3-D object according to the distribution of $H^+$ ion

Each cube is called a voxel.

Min resolution: 1 mm x 1 mm x 1 mm

$$H^+ \rightarrow \gamma_{H^+}$$

$$B_T \uparrow = \omega_T \uparrow$$
PG require high current to operate
High current means heat generation \(\rightarrow\) cooling system is necessary

**MRI**
- An anatomical imaging technique
- Used in observing tissue contrast changes
  (Inflammations, lesions, tumor formation, muscle injury)
- Contrast agents \(\rightarrow\) enhances MR signal to investigate joints (Gd injection)

**Functional MRI (fMRI)**
- Used only for research
- Measurement of physiological changes in human body
  (Manic depressive – normal brain)

It uses hemoglobin molecule to trace the functional activity level of the brain.
ULTRASOUND IMAGING
Uses sound waves to probe the mechanical properties of the tissues (pressure waves)

\[ v = 1500 \text{ m/sec} \]

Some sound waves reflect from the boundary. Some continue their way.

“ultra” → not audible \( \approx 5 \text{ – } 30 \text{ MHz} \)

\[ P_{fat}(z) = P_0 e^{-\alpha_f z_f} \]

\( P_0 \): initial intensity of pressure wave

\( \alpha_f \): attenuation coefficient of the tissue

\[ \alpha_f = \alpha_0 f \quad f: \text{ frequency of operation} \]

\( \alpha_0 \): initial coefficient

\( z_f \): thickness of the tissue

\( f \uparrow P_f \downarrow \text{ (more attenuation) } \rightarrow \text{ less penetration depth } \rightarrow \text{ but spatial resolution increases} \)
Medical Ultrasound

Diagnostic

- Anatomical
- Functional
  - Blood flow

Therapeutic

- Kidney stones (lithotripsy)
- Wound healing
- Bone healing
- Muscle injury rehab
- Surgical

Amplitude (A – mode) Ultrasound

Pulse Generator

Receiver

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Brightness Mode (B Mode)

The echoes are turned into gray scale image

Array of US sensors

Non-invasive!
**Doppler Ultrasound**

Doppler Effect is the result of changing the wavelength of a source by its velocity.

\[ f_d = \frac{2\theta \cos \theta}{C} f_0 \]

\( \theta \): velocity of object  
\( C \): speed of sound

![Diagram of Doppler Ultrasound](image)

Front (coronal) view

9: measure the change in blood velocity
Kidney Imaging

Blood moving away from the probe

Blood towards the probe

Kidney stone

B – Mode + Doppler US

Echocardiogram

→ Live anatomical image of the heart

+ Movement of blood through the heart

B – mode: observe anatomical problems

Doppler: quantify the degree of disease

Doppler is less invasive than B – mode because the patient is exposed to less Ultrasound.

(Still the two applications are non-invasive)
Biomedical Optics

The use of light in diagnostic and therapeutic applications

Diagnostic
- Microscopic (<100µm)
- Macroscopic (>100µm)

Therapeutic
- Surgical
- Rehab
- Cosmetic
Light and Matter Interaction

\[ \xrightarrow{\text{Depends on the}} \]

1. Wavelength
2. Intensity

Visible Light Imaging

- Endoscopy
  - Coils to move the tubes to look around the organs
  - 4 holes, 5 mm in dimension

Fluorescence Imaging

- A certain color of light is used to excite certain chromophores
## Comparative Matrix of Imaging Systems

<table>
<thead>
<tr>
<th>Ionization</th>
<th>Operation</th>
<th>Clinical Use</th>
<th>Resolution (mm)</th>
<th>Real time</th>
<th>Cost*</th>
<th>Mobility</th>
<th>Invasiveness†</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-Ray</td>
<td>Very low</td>
<td>Anatomic</td>
<td>Soft/hard tissue contrast</td>
<td>3.5 mm</td>
<td>No</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>CT</td>
<td>Low</td>
<td>Anatomic</td>
<td>Soft tissue</td>
<td>1-2 mm</td>
<td>No</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>US</td>
<td>None</td>
<td>Anatomic/Functional</td>
<td>Soft tissue</td>
<td>2-3 mm</td>
<td>Yes</td>
<td>Moderate</td>
<td>Yes</td>
</tr>
<tr>
<td>MRI</td>
<td>None</td>
<td>Anatomic</td>
<td>Soft tissue</td>
<td>1-2 mm</td>
<td>No</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>PET</td>
<td>High</td>
<td>Functional</td>
<td>Metabolic</td>
<td>3-5 mm</td>
<td>No</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Endoscopy</td>
<td>None</td>
<td>Anatomic</td>
<td>Surface</td>
<td>1 mm</td>
<td>Yes</td>
<td>Low</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Low < $50K, Moderate $50K - $200-300K, High > $300K

† 1: Most non-invasive, 6: most invasive

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1 I would like to thank Mrs. Nilüfer Adoran from the MDSI (2012) program for helping me with this table

Ata Akin

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