Madenat Alelem University

College of Pharmacy

Medical physics

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Reference Books

1- Medical Physics by John R. Cameron

2- Physics of the Human Body by Irving Herman

Learning Objectives

By the end of this lecture, students should be able to:

- Define medical physics and describe its major sub-disciplines.
- Explain the role of physical principles in understanding human physiology and medical practice.
- Describe the purpose and limitations of scientific modeling in medicine.
- Distinguish between accuracy and precision in medical measurements.
- Identify sources of measurement uncertainty and diagnostic error in clinical practice.

Lecture 1

Terminology, Modelling, and Measurement

1. Introduction to Medical Physics

Medical physics is the application of the concept of physics concepts in medicine, healthcare, and medical sciences. We study physics concept in medical faculties to understanding physical aspect of the body such as; forces on and in the body, work, energy, power of the body, heat, blood flow, respiration, electricity, circulation and hearing. Medical physics has many branches, namely, Ultrasound, Magnetic Resonance, Computed Tomography, Nuclear Medicine, X-rays, Radiation Therapy. These branches where continued research is being conducted by a very large group of dedicated researchers consisting of highly qualified physicists, engineers and radiologists.

The field of medical physics overlaps the two very large fields of medicine and physics. The term medical physics refers to two major areas:

1. The applications of physics to the function of the human body in health and disease.

2. The applications of physics in the practice of medicine. The first of these could be called the physics of physiology; the second includes such things as the physics of the stethoscope, the tapping of the chest (percussion), and the medical applications of lasers, ultrasound, radiation, and so forth.

The words physicist and physician have a common root in the Greek word physiké (science of nature). The branch of medicine referred to as physical medicine deals with the diagnosis and treatment of disease and injury by means of physical agents such as manipulation, massage, exercise, heat, and water.

Physical medicine

Physical medicine, or Physiatry (Physical Medicine & Rehabilitation - PM&R), is a medical specialty focused on restoring function and improving quality of life for people with physical impairments or disabilities affecting the brain, spinal cord, nerves, bones, muscles, and joints.

3. Physical therapy

Physical therapy is the treatment of disease or bodily weakness by physical means such as massage and gymnastics rather than by drugs.

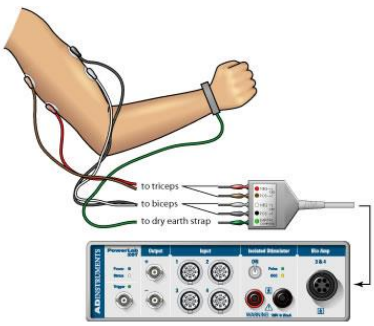
4.**Applications of Physics in Medicine**

Stethoscope

Manometer (blood pressure)

Electrocardiograph(ECG)

Electroencephalograph(EEG)



Electromyography (EMG)

Gamma camera to study the function of kidney, liver, and lungs.

- X- Ray
- Computer tomography (CT scan)
- Ultrasound
- Magnetic Resonance Imaging (MRI)
- Optics

5. Scientific Modeling in Medical Physics

5.1 Concept of Modeling

Modeling is the process of simplifying complex biological systems by using physical analogies, mathematical equations, diagrams, or conceptual descriptions. Because many physiological processes are difficult or impossible to observe directly, models provide a practical way to analyze, explain, and predict system behavior.

5.2Examples of Models

- **Eye–Camera Analogy:** The eye is often compared to a camera, with the retina acting as a light detector. While useful conceptually, the analogy has limitations because biological tissues differ fundamentally from photographic film.
- **Blood Flow–Electrical Circuit Analogy:** Blood flow in the cardiovascular system can be modeled using electrical circuits, where pressure corresponds to voltage, blood flow to current, and vascular resistance to electrical resistance. This model successfully describes many cardiovascular phenomena, although it cannot fully capture biological complexities such as changes in hematocrit.

5.3 Purpose and Limitations

Scientific models may be used for visualization (e.g., three-dimensional models of proteins), hypothesis testing, or quantitative prediction. All models have limitations, and understanding these limitations is essential to avoid misinterpretation.

6. Measurement in Medical Physics

Measurement is a cornerstone of science and clinical medicine. Progress in medical science has closely followed advances in the ability to measure physiological quantities accurately and reproducibly.

Examples of measured quantities include:

- Body temperature
- Pulse and respiratory rate
- Electrical signals from organs
- Imaging-based structural and functional information.

Physiological measurements can be classified into:

1. **Repetitive processes:** Such as heart rate and breathing rate
2. **Non-repetitive processes:** Such as renal clearance time or nerve action potentials

Time scales in the human body range from milliseconds (nerve impulses) to decades (human lifespan).

7. Accuracy and Precision

In scientific measurements, accuracy and precision have distinct meanings:

- **Accuracy:** The closeness of a measurement to the true or accepted value.
- **Precision:** The reproducibility or consistency of repeated measurements.

A measurement may be precise without being accurate, and vice versa. In medical physics, both are essential for reliable diagnosis, treatment planning, and patient safety. Calibration and quality assurance procedures are designed to ensure high accuracy and precision in clinical instruments.

For Example: An ill person measured her temperature ten times in a row and got the following values in degrees Celsius (formerly called degrees centigrade): 36.1, 36.0, 36.1, 36.2, 36.4, 36.0, 36.3, 36.3, 36.4, and 36.2. The precision was fairly good, with a variation of 0.2C° from the average value of 36.2C°. In general, it is desirable to have both good accuracy and good precision. However, sometimes an accurate measurement cannot be obtained even with a measuring technique that has good precision. See Fig 1.

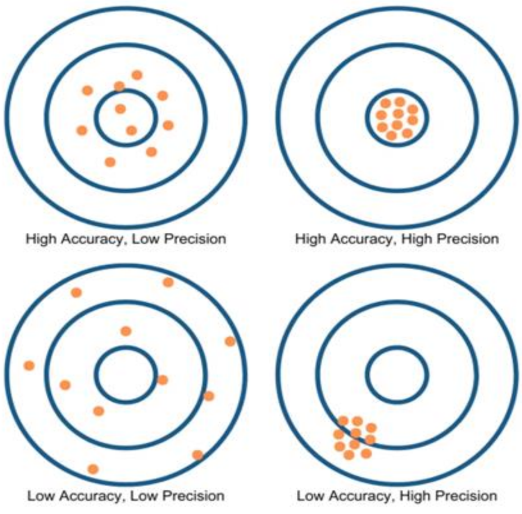


Fig 1. Accuracy & precision

It is an accepted fact in science that the process of measurement may significantly alter the quantity being measured. This is especially true in medicine.

Accuracy	Precision
Accuracy refers to the level of agreement between the actual measurement and the absolute measurement	Precision implies the level of variation that lies in the values of several measurements of the same factor
Represents how closely the results agree with the standard value	Represents how closely results agree with one another
Single-factor or measurement are needed	Multiple measurements or factors are needed to comment about precision
It is possible for a measurement to be accurate on occasion as a fluke. For measurement to be consistently accurate, it should also be precise.	Results can be precise without being accurate. Alternatively, the results can be precise and accurate

8. Measurement Uncertainty and Observer Effects

The act of measurement can influence the quantity being measured, particularly in biological systems. Examples include:

- Patient anxiety affecting blood pressure measurements
- Motion artifacts in imaging
- Instrument interaction with the measured system

Understanding and minimizing these effects is a key responsibility of medical physicists.

9. Diagnostic Errors: False Positives and False Negatives

Clinical decision-making relies on medical history, physical examination, and laboratory or imaging measurements. Diagnostic errors may occur and are classified as:

- **False positive:** A disease is diagnosed when it is not present
- **False negative:** A disease is missed when it is present

Both types of errors can have serious consequences for patients. Reducing diagnostic error requires improved instrumentation, better measurement techniques, and ongoing research into test performance.

Note: In some situations, a diagnostic error can have a great impact on a patient's life.

For Example: A young woman was thought to have a rheumatic heart condition and spent several years in complete bed rest before it was discovered that a false positive diagnosis had been made-she really had arthritis, a disease in which activity should be maintained to avoid joint stiffening. In the early stages of many types of cancer it is easy to make a false negative diagnostic error because the tumor is small. Since the probability of cure depends on early detection of the cancer, a false negative diagnosis can greatly reduce the patient's chance of survival.

10. The Standard Human and Scaling

Medical physics often relies on reference models of the “standard human” to estimate physiological parameters, radiation dose, and imaging response. Scaling laws relating body size, organ mass, and surface area are essential when adapting diagnostic and therapeutic techniques to different patient populations, including pediatric patients.

For example, what does “**hypertrophic cardiomyopathy” mean**? “Hyper” means something that is more than normal or expected. “Trophic” denotes size. “Cardio” refers to the heart. “Myo” means muscle. “Pathy” refers to disease. So hypertrophic cardiomyopathy is a disease or disorder due to the enhanced size of the heart muscle (due to thickened heart muscle). Use of acronyms as part of the medical jargon can also be a barrier.

What is HCM? It is “**h**” ypertrophic “**c**” ardio “**m**” yopathy. Much of medical jargon of interest to us is the terminology used in anatomy, and much of that in anatomy relates to directions and positions.