



ECE 331 – INTRODUCTION TO BIOMEDICAL ENGINEERING

STUDY GUIDE: INTEGUMENTARY SYSTEM FOR BIOMEDICAL ENGINEERING

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1.0 OBJECTIVE

To understand the structure, function, and biomechanical properties of the integumentary system necessary for the design of medical devices, biomaterials, diagnostic tools, and in tissue engineering.

2.0 CORE ANATOMY & PHYSIOLOGY

2.1 Core Functions of the Skin

1. **Barrier:** Prevents water loss and blocks pathogens, chemicals, and UV radiation.
2. **Sensation:** Contains receptors for touch, pressure, vibration, temperature, and pain.
3. **Thermoregulation:** Regulates body temperature via sweat glands and blood vessel dilation/constriction.
4. **Immunity:** Langerhans cells (a type of dendritic cell) are key antigen-presenting cells.
5. **Synthesis:** Produces Vitamin D upon exposure to sunlight.

2.2 Layered Structure of the Skin

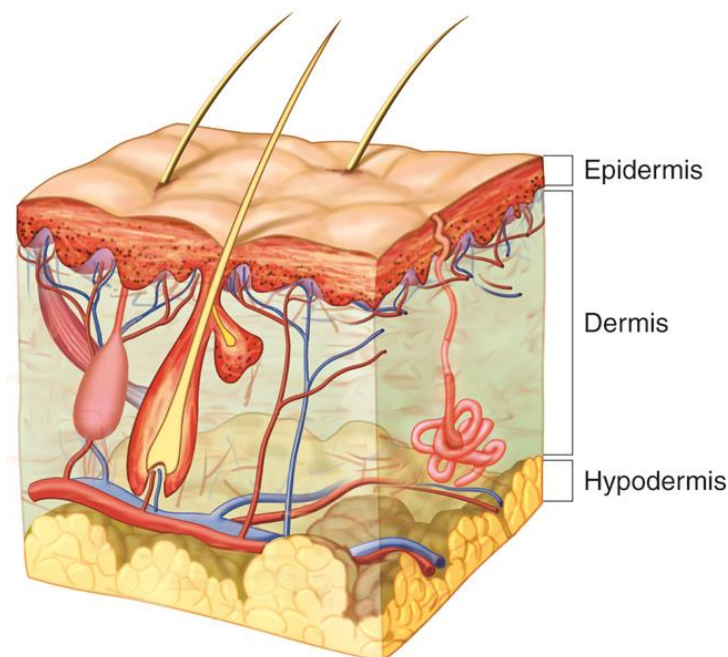


Figure 1. Pictorial representation of layers of the skin

The skin as a complex, multi-layered composite material consisting of:

1. Epidermis (The Outer Shield)

- **Primary Cell Type:** Keratinocytes (produce keratin, a tough structural protein).
- **Key Process: Keratinization.** Cells are produced at the base and migrate outward, undergoing apoptosis (programmed cell death) to form a protective, keratin-filled outer layer.

- **Layers (Stratum):**
 - **Basale:** Deepest layer; continuous cell division (stem cells).
 - **Spinosum:** "Spiny" layer; keratinocytes connect via desmosomes.
 - **Granulosum:** Cells fill with keratin granules and begin to die.
 - **Lucidum:** (Only in thick skin) Clear, flat dead cells.
 - **Corneum:** Outermost layer; 20-30 layers of dead, flattened, keratinized cells. This is the primary **barrier layer**. *Engineers: Think of this as a natural, semi-permeable polymer film.*

2. Dermis (The Structural Support):

- **Composition:** A dense, irregular connective tissue. This is the layer that gives skin its strength and elasticity.
- **Key Components:**
 - **Collagen Fibers:** Provide tensile strength.
 - **Elastic Fibers:** Provide elasticity and recoil.
 - **Ground Substance:** Hydrated gel (proteoglycans) that resists compression.
- **Structures Found in Dermis:** Blood vessels, nerves, hair follicles, sweat glands, sebaceous (oil) glands.
- *Engineers: Think of this as a hydrated, fibre-reinforced composite hydrogel.*

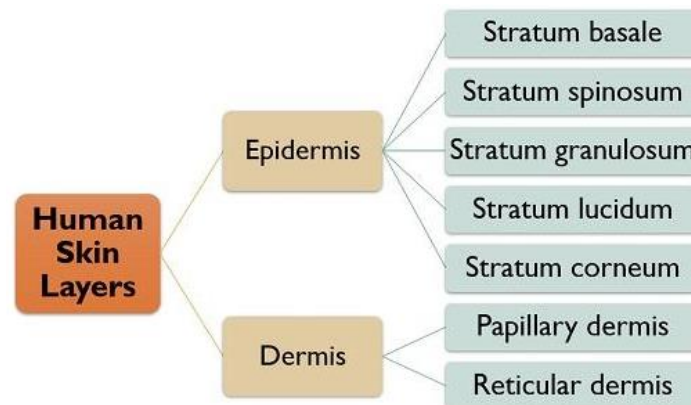


Figure 2. Summary of various parts of the skin layers

3. Hypodermis (Subcutaneous Layer; The Insulation & Shock Absorber):

- **Composition:** Mostly adipose (fat) tissue and loose connective tissue.
- **Functions:** Anchors skin to underlying structures, insulates, and stores energy.

2.3. Appendages

- **Sweat Glands (Eccrine & Apocrine):** For thermoregulation.
- **Sebaceous Glands:** Produce sebum (oil) to lubricate skin and hair.

- **Hair Follicles:** Sensory and protective functions.
- **Nails:** Protect distal digits.

3. KEY ENGINEERING-RELEVANT PROPERTIES & CONCEPTS

Biomedical engineers must understand the structure and function of the integumentary system for the following reasons:

3.1 Biomechanical Properties

- Tensile Strength:** Primarily provided by the collagen network in the dermis. Skin is **anisotropic** (its strength varies with direction due to the alignment of collagen fibres, known as Langer's lines).
- Elasticity/Viscoelasticity:** Skin is not purely elastic; it exhibits **viscoelastic** behaviour (time-dependent, stress-relaxation, creep). This is crucial for understanding:
 - **Surgical Incision and Healing:** Cutting along Langer's lines reduces tension and improves healing.
 - **Device Design:** Wearables must account for skin's movement and deformation.
- Friction:** The outermost layer (stratum corneum) has a specific coefficient of friction, important for designing grips, prosthetic interfaces, and preventing blisters.

3.2 Transport Properties

- **Permeability:** The stratum corneum is a highly selective barrier. Understanding **transdermal drug delivery** is a major biomedical engineering application.
 - Factors affecting permeability: lipophilicity/hydrophilicity of the drug, molecular size, and use of enhancers (chemical, electrical [iontophoresis], ultrasound [sonophoresis]).
- **Wound Exudate Management:** Designing dressings that manage moisture vapor transmission rate (MVTR) is key to optimal healing.

3.3. Thermal Properties

The skin serves as the body's primary dynamic thermal interface, regulating temperature through vasodilation/vasoconstriction of blood vessels and sweat evaporation.

Applications: Knowledge of thermal properties of the skin is important during the design of thermal blankets, burn treatment devices, non-contact thermometers (measuring infrared radiation), and interpreting thermal imaging data.

3.4. Electrical Properties

The electrical properties of skin are characterized by the highly resistive outer layer (stratum corneum) acting as a barrier, while the deeper, hydrated layers are more conductive, a critical consideration for designing biomedical electrodes and transdermal drug delivery systems. For instance, ECG electrode need good skin contact to reduce impedance.

4. BIOMEDICAL ENGINEERING APPLICATIONS & CHALLENGES

4.1. Wound Care & Tissue Engineering

- **Goal:** Develop scaffolds that promote healing for chronic wounds (diabetic ulcers, burns).
- **Scaffold Design Requirements:**
 - **Biocompatibility**
 - **Mechanical Match:** Should mimic the native skin's elasticity and strength to avoid stress shielding.
 - **Porosity:** For cell migration, nutrient diffusion, and exudate management.
 - **Degradation Rate:** Should match the rate of new tissue formation.
- **Advanced Concepts:** Bioprinting of skin grafts with multiple cell types (keratinocytes, fibroblasts).

4.2. Transdermal Drug Delivery (TDD)

- **Engineering Challenge:** Overcoming the formidable barrier of the stratum corneum.
- **Devices/Methods:** Patches (nicotine, hormones), microneedle arrays (create microscopic pathways without hitting nerves), wearable infusion pumps.

4.3. Sensors & Wearables

- **Challenge:** Creating a stable, comfortable, and accurate interface between wearables and biological surface.
- **Examples:**
 - **Electrophysiological:** ECG, EEG, EMG electrodes.
 - **Biochemical:** Sweat sensors for lactate, glucose, electrolytes (non-invasive monitoring).
 - **Physical:** Flexible strain gauges to measure movement, pulse, and respiration.

4.4. Prosthetics & Orthotics

- **Interface Design:** The socket-skin interface is critical for comfort and function. Must manage pressure distribution, shear forces, moisture, and heat to prevent skin breakdown.



Figure 3. Elements of a limb prosthesis

4.5. Dermatology Diagnostics:

Using spectroscopy, optical coherence tomography (OCT), or laser Doppler flowmetry to non-invasively diagnose skin conditions (e.g., melanoma, psoriasis) and assess blood flow.

5. STUDY STRATEGIES & ACTIVE LEARNING

- **Draw and Label:** Draw the layers of the skin from memory, including all major cell types and structures. Annotate your drawing with key functions and material properties.
- **Compare and Contrast:** Create a table comparing the epidermis and dermis in terms of structure, primary cell types, key proteins, and primary functions.
- **Think Like an Engineer by answering the following questions:**
 - How would you design a material to replace the dermis? What properties would you prioritize?
 - What are the key design constraints for a wearable sweat sensor?
 - Why might a deep burn that destroys the dermis not heal well on its own? (Hint: think about stem cells).
- **Connect to Clinical Problems:** Link each concept to a medical need (e.g., "poor elasticity in aged skin" -> "higher risk of injury from shear forces" -> "need for better protective dressings in elderly care").
- **Use Online Resources:** [Watch animations of keratinization, wound healing, and videos of surgical procedures](#) to see the mechanical behaviour of skin in real-time.

6. SAMPLE EXAM QUESTIONS (BME FOCUSED)

1. **(a) Explain** why the skin is considered a viscoelastic material.
(b) Describe one medical device whose design must account for this property and why.
2. A patient has a third-degree burn, destroying both the epidermis and dermis. **Propose** key design criteria for an artificial skin graft scaffold to aid their recovery. Justify your choices based on the biological functions of the lost layers.
3. **Compare and contrast** the challenges and mechanisms of delivering a small, lipid-soluble drug versus a large, protein-based drug (e.g., insulin) across the skin.
4. **Describe** the primary structural proteins in the dermis and the mechanical property each one provides. How does the alignment of collagen fibres affect the anisotropic behaviour of skin?