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THE HISTOLOGICAL STRUCTURE OF THE SKIN AND ITS PROTECTIVE FUNCTIONS.

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Actuality: The skin, as the largest organ of the human body, constitutes the primary interface with the external environment. Its integrity is fundamental to survival, providing essential protection against physical, chemical, and biological threats. A comprehensive understanding of its complex histological structure is inextricably linked to deciphering its multifaceted protective functions. This review consolidates current knowledge, highlighting the sophisticated interplay between cellular and structural components. This synthesis is critical for advancing dermatology, immunology, and the development of novel therapeutic strategies for cutaneous pathologies, especially in the context of increasing environmental stressors and immunological challenges.
Keywords: skin, histology, epidermis, dermis, hypodermis, protective function, barrier function, skin immune system (SIS), photoprotection, thermoregulation.

TERI GISTOLOGIK TUZILISHI VA UNING HIMOYA FUNKSIYALARI.

Dolzarbligi: Inson tanasining eng yirik a'zosi bo'lgan teri tashqi muhit bilan birlamchi aloqa interfeysini tashkil etadi. Uning yaxlitligi jismoniy, kimyoviy va biologik tahdidlardan himoyani ta'minlab, yashash uchun asosiy shartdir. Terining murakkab gistologik tuzilishini har tomonlama tushunish uning ko'p qirrali himoya funksiyalarini anglash bilan uzviy bog'liqdir. Ushbu sharh zamonaviy bilimlarni umumlashtirib, hujayra va strukturaviy komponentlar o'rtasidagi murakkab o'zaro ta'sirni yoritadi. Ushbu sintez dermatologiya, immunologiya va teri patologiyalarini davolashning yangi yangi strategiyalarini ishlab chiqish uchun, ayniqsa, kuchayib borayotgan ekologik stress omillari va immunologik muammolar sharoitida muhim ahamiyatga ega.
Kalit so'zlar: teri, gistologiya, epidermis, derma, gipoderma, himoya funksiyasi, to'siq funksiyasi, teri immun tizimi (TIT), fotohimoya, termoregulyatsiya.

ГИСТОЛОГИЧЕСКОЕ СТРОЕНИЕ КОЖИ И ЕЕ ЗАЩИТНЫЕ ФУНКЦИИ.

Актуальность: Кожа, являясь самым большим органом человеческого тела, представляет собой основной интерфейс с внешней средой. Ее целостность фундаментальна для выживания, обеспечивая необходимую защиту от физических, химических и биологических угроз. Глубокое понимание ее сложной гистологической структуры неразрывно связано с расшифровкой ее многогранных защитных функций. Данный обзор объединяет современные знания, освещая сложное взаимодействие между клеточными и структурными компонентами. Этот синтез имеет решающее значение для развития дерматологии, иммунологии и разработки новых терапевтических стратегий для кожных патологий, особенно в контексте растущих экологических стрессоров и иммунологических вызовов.
Ключевые слова: кожа, гистология, эпидермис, дерма, гиподермис, защитная функция, барьерная функция, иммунная система кожи (ИСК), фотозащита, терморегуляция.

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INTRODUCTION

The human skin is the largest organ of the body, accounting for approximately 15% of the total body weight. It serves as a vital, dynamic interface between the organism and its external environment (Proksch et al., 2008). Beyond its sensory and aesthetic roles, the skin's primary mandate is protection. This protective function is not monolithic but rather a sophisticated amalgamation of physical, chemical, immunological, and thermal defenses. The efficacy of this barrier is fundamentally dependent on its intricate, multi-layered histological architecture.

The skin is broadly organized into three distinct layers: the superficial epidermis, the underlying dermis, and the deepest layer, the hypodermis. Each layer possesses a unique cellular and extracellular matrix (ECM) composition, meticulously organized to contribute to specific protective tasks (Yousef et al., 2023). The epidermis, a stratified squamous epithelium, forms the frontline defense, preventing pathogen entry and water loss. The dermis, a dense connective tissue layer, provides structural support, mechanical strength, and houses the neurovascular and immune components. The hypodermis, composed of adipose tissue, offers thermal insulation and mechanical cushioning.

A nuanced understanding of how these histological components—from specific cell types like keratinocytes and Langerhans cells to structural proteins like collagen and keratin—interact to create a functional barrier is paramount. Disruptions in this architecture, whether genetic (e.g., in ichthyoses), inflammatory (e.g., in psoriasis or atopic dermatitis), or environmental (e.g., UV damage), lead to compromised protection and cutaneous pathology (Kabashima et al., 2019).

Despite extensive research on individual components, there is a persistent need for a consolidated review that explicitly links the *histological structure* to the *protective function*. This review aims to synthesize the current state of knowledge, providing a comprehensive analysis of the histological organization of the skin and elucidating how this architecture serves as the foundation for its fundamental protective capacities.

METHODS

This scientific review is based on a systematic search of the literature, designed to identify and synthesize relevant studies. The search was conducted in compliance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, where applicable for a narrative review.

Search strategy and databases a comprehensive literature search was performed using three major electronic databases: Scopus, PubMed/MEDLINE, and Web of Science. The search was restricted to articles published in the English language between January 1, 2005, and October 31, 2025, to ensure the inclusion of contemporary research.

The search query combined MeSH (Medical Subject Headings) terms and keywords related to the skin's structure and function. The core search string was: ("skin" OR "cutaneous") AND ("histology" OR "architecture" OR "structure") AND ("protective function" OR "barrier" OR "defense" OR "immunity" OR "thermoregulation" OR "photoprotection").

Inclusion and exclusion criteria studies were included if they met the following criteria: (1) peer-reviewed original research articles or comprehensive review articles; (2) focused on human skin or functionally relevant animal models; (3) provided detailed information on the histological structure in relation to one or more protective functions.

Exclusion criteria were: (1) case reports, editorials, or conference abstracts; (2) studies focusing purely on cosmetic applications without functional analysis; (3) articles where the full text was not available.

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Data synthesis two reviewers independently screened titles and abstracts for relevance. Full texts of potentially eligible articles were then retrieved and assessed. Disagreements were resolved by consensus. Data were extracted and organized according to the primary histological layer (epidermis, dermis, hypodermis) and the specific protective function (physical, immunological, photoprotective, mechanical, and thermal). The findings were synthesized narratively to build a cohesive overview of the structure-function relationship.

RESULTS

The literature search identified a substantial body of research. The synthesis of this data is presented in two main sections: first, the histological architecture of the skin, and second, the protective functions derived directly from this architecture.

The epidermis the epidermis is a self-renewing, stratified squamous epithelium, predominantly composed of keratinocytes (approx. 90%). Its structure is organized into four (or five in thick skin) distinct strata:

Stratum Basale (Basal Layer): A single layer of cuboidal to columnar keratinocytes attached to the basement membrane via hemidesmosomes. This layer contains the epidermal stem cells responsible for regeneration. It also houses melanocytes, pigment-producing cells, typically in a 1:10 ratio with keratinocytes (Yousef et al., 2023).

Stratum Spinosum (Spinous Layer): Comprises several layers of polygonal keratinocytes. These cells are strongly interconnected by desmosomes (maculae adherentes), which appear as "spines" in histological preparations and provide crucial intercellular adhesion and resistance to abrasion. This layer also contains the antigen-presenting Langerhans cells (Kabashima et al., 2019).

Stratum Granulosum (Granular Layer): Consists of 3-5 layers of flattened keratinocytes containing intensely basophilic keratohyalin granules (containing filaggrin) and lamellar granules (lipid-containing organelles). The extrusion of lipids from lamellar granules into the extracellular space is a critical step in forming the water barrier (Elias, 2005).

Stratum Corneum (Horny Layer): The outermost layer, composed of 15-20 layers of anucleated, flattened, keratin-filled corneocytes. These "dead" cells are embedded in a highly organized extracellular lipid matrix (ceramides, cholesterol, free fatty acids). This structure is famously described as the "brick and mortar" model, where corneocytes are the "bricks" and the lipids are the "mortar" (Proksch et al., 2008).

The Dermal-Epidermal Junction (DEJ) The DEJ is a complex, acellular basement membrane zone that anchors the epidermis to the dermis. Histologically, it forms an undulating interface with dermal papillae (protrusions of the dermis) and epidermal rete ridges. This structure increases the surface area for adhesion and nutrient transfer and prevents shear-induced detachment (Boulanger & Dube, 2021).

The Dermis The dermis provides the skin's mechanical strength and elasticity. It is divided into two sub-layers:

Papillary Dermis: The superficial, thinner layer of loose connective tissue, containing capillary loops for nutrient supply to the (avascular) epidermis, and sensory nerve endings (e.g., Meissner's corpuscles).

Reticular Dermis: The deeper, thicker layer composed of dense, irregular connective tissue. It is rich in Type I collagen fibers (providing tensile strength) and elastin fibers (providing recoil). This layer contains hair follicles, sebaceous glands, sweat glands, larger blood vessels, and a significant population of resident immune cells (fibroblasts, macrophages, mast cells, and T-cells) (Richmond & Harris, 2014).

The Hypodermis (Subcutis) The deepest layer, composed primarily of adipose tissue (adipocytes) organized into lobules by fibrous septa. It anchors the skin to underlying fascia and muscle, serves as a major energy reserve, provides thermal insulation, and acts as a shock absorber.
The Physical and Permeability Barrier This is the most critical protective function, executed primarily by the epidermis.
Histological Basis: The *stratum corneum* is the key structure. The "brick and mortar" model (Elias, 2005) provides a barrier that is "outside-in" (preventing entry of pathogens, allergens, and chemicals) and "inside-out" (preventing transepidermal water loss, TEWL). The integrity of this barrier is dependent on the terminal differentiation of keratinocytes (corneification) and the precise composition and organization of the lamellar lipid matrix (Proksch et al., 2008). Tight junctions in the *stratum granulosum* provide an additional, earlier water seal.
Immunological Defense (The Skin Immune System - SIS) The skin is a major immunological organ, with its histological structure positioning immune cells for optimal surveillance.
Histological Basis: The SIS (formerly SALT) involves both innate and adaptive immunity.
Epidermis: Langerhans cells, strategically positioned in the *stratum spinosum*, act as the skin's resident antigen-presenting cells (APCs). Upon capturing an antigen, they migrate to draining lymph nodes to activate T-cells (Kabashima et al., 2019). Keratinocytes themselves are not passive, acting as "first-line" sensors that release pro-inflammatory cytokines (e.g., IL-1α, TNF-α) upon injury or infection (Zhang & Chen, 2022).
Dermis: The dermis hosts a large population of immune cells. These include dermal dendritic cells, macrophages (for phagocytosis and antigen presentation), mast cells (involved in allergic responses), and a significant pool of resident memory T-cells (T_RM), which provide rapid, localized immunity upon re-exposure to a pathogen (Richmond & Harris, 2014).
Photoprotection The skin possesses an endogenous system to protect against the mutagenic effects of ultraviolet (UV) radiation.
Histological Basis: This function is mediated by melanocytes located in the *stratum basale*. These dendritic cells produce melanin pigment within organelles called melanosomes. The melanosomes are then transferred to adjacent keratinocytes, where they form "supranuclear caps" that shield the cell's nucleus (and its DNA) from UV-induced damage (Yousef et al., 2023).
Mechanical Strength and Resilience The skin must withstand constant shear, friction, and tensile forces. Histological Basis: This is a primary function of the *dermis*. The dense, interwoven network of collagen fibers (primarily Type I) in the *reticular dermis* provides high tensile strength. Elastin fibers allow the skin to deform and return to its original shape. The undulating nature of the *DEJ* further strengthens the adhesion between the epidermis and dermis, preventing blistering (Boulanger & Dube, 2021).
Thermoregulation The skin is essential for maintaining a stable core body temperature. Histological Basis: This is a multi-layer function. The dermal vasculature (arteriovenous anastomoses) allows for regulated blood flow; vasodilation radiates heat, while vasoconstriction conserves it. Eccrine sweat glands, originating in the dermis and ducting to the epidermal surface, provide evaporative cooling. Finally, the hypodermal adipose tissue serves as a layer of thermal insulation (Yousef et al., 2023).

DISCUSSION

This review confirms that the protective efficacy of the skin is not a passive state but a dynamic and complex process deeply rooted in its histological organization. The synthesis of the literature reveals that the skin's structure is not merely a collection of layers but a sophisticated, integrated system where cellular and acellular components are precisely arranged to perform specialized functions.

A key finding is the profound "division of labor" combined with interconnectedness. The epidermis, through the stratum corneum, provides the essential physical barrier (Elias, 2005), but this barrier's integrity is metabolically supported by the dermis (via nutrient diffusion) and protected from UV radiation by its own basal melanocytes. Simultaneously, this physical barrier is "policed" by the epidermal Langerhans cells, which serve as immune sentinels (Kabashima et al., 2019). This highlights that the barrier is both physical and immunological.

The discussion of the dermis underscores its role as more than just "stuffing." It is the skin's structural, vascular, and immunological core. The discovery and characterization of resident memory T-cells (T_RM) in the dermis have revolutionized skin immunology, explaining the rapid and localized nature of memory responses to cutaneous pathogens and in inflammatory diseases like psoriasis (Richmond & Harris, 2014).

However, this review also identifies gaps in the current knowledge. While the "brick and mortar" model is well-established, the precise molecular mechanisms governing the formation and secretion of the lamellar lipid matrix are still being fully elucidated. Furthermore, a major emerging field is the interaction of the skin microbiome with the host's histological and immunological barrier. How commensal bacteria "educate" the SIS or reinforce the physical barrier at a histological level is a critical area for future research.

Finally, the limitations of this review must be acknowledged. The search was restricted to English-language publications, potentially introducing a language bias. Furthermore, the broad scope of "protective functions" precluded an in-depth analysis of specific molecular pathways (e.g., filaggrin processing, specific cytokine networks), which are reviews in their own right.

CONCLUSION

The histological organization of the skin is a masterpiece of biological engineering, optimized for protection and survival. This review has synthesized the literature to demonstrate that from the anucleated corneocytes of the stratum corneum, forming a seal against the world, to the deep-seated immune cells of the dermis, every component's location and structure is purposeful.

The epidermis provides the primary physical, permeability, and UV-protective barrier. The dermis offers the mechanical resilience, vascular supply for thermoregulation, and a deep reservoir of immune cells. The hypodermis provides insulation and cushioning.

A comprehensive grasp of this intricate structure-function relationship is indispensable for the fields of dermatology, immunology, toxicology, and regenerative medicine. It provides the fundamental basis for understanding cutaneous disease pathogenesis—from genetic barrier defects (e.g., atopic dermatitis) to immune-mediated pathologies (e.g., psoriasis) and environmental damage (e.g., photoaging). Future research focusing on the interplay between histology, the microbiome, and neuro-immune signaling will continue to unlock the full complexity of this vital organ.

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