



Review Article

From Discovery to Modern Understanding: The Acid Mantle in Dermatology

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The acid mantle represents a critical aspect of skin physiology, intricately linked with both the skin barrier and microbiome. Originating from pioneering research by Heinrich Schade and Alfred Marchionini in the early 20th century, the acid mantle was found to play an important role in the inhibition of microbial growth early on. Subsequent studies throughout the mid-20th century further elucidated its influence on enzymatic activity essential for barrier function and its ability to shape the composition of the skin microbiome. Indeed, the tightly regulated pH within the acid mantle profoundly affects microbial diversity, favoring beneficial commensal bacteria while suppressing pathogens.

In the modern era, the recognition of the acid mantle's significance has driven advancements in skincare. These innovations reflect a paradigm shift towards holistic skincare approaches that prioritize maintaining barrier function and microbiome balance. Ongoing research continues to refine our understanding of the acid mantle's mechanisms and therapeutic potential, offering promising avenues for enhancing skin resilience and managing dermatologic conditions effectively.

INTRODUCTION

The acid mantle is integral to skin physiology, orchestrating a sophisticated interplay between the skin barrier and the microbiome. This delicate, protective layer maintains a mildly acidic pH range of approximately 4.5 to 5.5.¹ Its primary functions include acting as a barrier against environmental factors and preserving skin hydration and structural integrity. Despite its foundational role, the acid mantle has received less attention in dermatologic research in the past decade. Instead, focus had remained on investigating ceramides, filaggrin, and inflammatory pathways that directly impact barrier function and skin health, to some degree overshadowing the acid mantle's significance.

Nevertheless, the acid mantle remains crucial for skin health. Its mildly acidic pH supports the structural integrity of the stratum corneum, the outermost skin layer that provides a physical barrier against external threats.¹ Additionally, this environment plays a pivotal role in shaping the skin microbiome, fostering the growth of beneficial bacteria such as *Staphylococcus epidermidis*, while discouraging harmful pathogens such as *Staphylococcus aureus*.²

Disruptions in the acid mantle's pH balance have been linked to various dermatologic conditions. For instance, an alkaline pH can compromise the skin barrier, leading to increased transepidermal water loss (TEWL) and vulnerability to infections or inflammatory skin disorders including atopic dermatitis (AD) and acne.³ Therefore, maintaining the optimal pH of the acid mantle is essential for overall skin health.

From a clinical perspective, the acid mantle presents a promising avenue for intervention in dermatology. Unlike complex molecular pathways that are often difficult to directly target with precision, the pH of the acid mantle can be effectively adjusted through topical formulations or lifestyle modifications. This characteristic underscores its potential as a focal point for innovative dermatologic therapies aimed at optimizing skin health and managing dermatoses more effectively.

Adjusting the pH of the acid mantle—for better or for worse—can be achieved through various approaches. Topical formulations, such as pH-appropriate cleansers and moisturizers, are designed to help restore or maintain the skin's natural acidic environment. These products aim to support the acid mantle's role in maintaining barrier function and microbial balance, crucial for overall skin health. By ensuring the pH remains within the optimal range (typically between 4.5 and 5.5), these formulations enhance the skin's natural defense mechanisms against environmental stressors and microbial pathogens. One study investigated the effects of buffered skin care products with a pH \leq 4.5 on skin health.⁴ Over a four-week period, participants' skin surface pH, hydration, and barrier function were measured before and after treatment. Results indicated that buffered skin care products effectively acidified and maintained physiological skin pH, with a significant reduction in pH from 5.09 to 4.67 ($p < 0.05$) and improved skin hydration ($p < 0.05$).⁴

Furthermore, lifestyle modifications can also impact the pH of the acid mantle. Factors such as diet, stress levels, and environmental exposures can influence the skin's acid-

Table 1. Factors Supporting the Acid Mantle and their Relevance to Dermatology.

Factor	Description
Mildly Acidic pH (4.5-5.5)	Maintains skin hydration and structural integrity; inhibits growth of harmful bacteria and fungi.
Structural Integrity of Stratum Corneum	pH environment supports barrier function, preventing transepidermal water loss (TEWL).
Influence on Skin Microbiome	Creates favorable conditions for commensal bacteria (eg, <i>Staphylococcus epidermidis</i>), inhibits pathogens (eg, <i>Staphylococcus aureus</i>).
Role in Enzymatic Activities	pH-dependent enzymatic processes crucial for barrier repair and maintenance.
Impact on Skincare Product Development	Led to development of pH-appropriate cleansers, AHAs/BHAs, and moisturizers to preserve acid mantle and enhance skin health.
Clinical Relevance	Can be manipulated through topical formulations, influencing therapeutic strategies for dermatoses including atopic dermatitis and acne.
Historical and Modern Importance	Foundational in skin physiology; ongoing research revitalizes its significance in contemporary dermatology.
Implications for HS and Rosacea	Chlorhexidine gluconate and benzoyl peroxide, used for HS, can disrupt the skin barrier by altering acidity, causing irritation and increased TEWL. Research indicates that maintaining balanced pH may alleviate rosacea symptoms, underscoring the importance of pH-supportive topical agents.

ity. Adopting habits that promote skin health, such as reducing exposure to harsh chemicals, maintaining a balanced diet rich in antioxidants and essential nutrients, and managing stress effectively, can contribute to maintaining an optimal acid mantle pH. These lifestyle adjustments complement topical treatments, providing a holistic approach to supporting skin barrier function.

In clinical practice, manipulating the acid mantle's pH is a tangible target for dermatologic intervention. Optimizing the skin's acidic environment may alleviate symptoms of dermatoses like atopic dermatitis and acne, where disruptions in pH are implicated (Table 1). Ongoing research on ingredients targeting acid mantle pH shows promise in advancing dermatologic care, offering new strategies to enhance skin resilience and treatment outcomes. This review elucidates the acid mantle's biochemistry, its relationship with the skin barrier and microbiome, and its importance in modern dermatologic research and practice.

MATERIALS AND METHODS

This narrative review synthesizes historical and contemporary literature to explore the biochemical underpinnings, developmental milestones, and clinical implications of the

acid mantle in dermatology. A comprehensive search of electronic databases, including PubMed, Google Scholar, and Embase, was conducted using keywords such as "acid mantle," "skin barrier," "microbiome," and "pH balance." Emphasis was placed on seminal works by Heinrich Schade and Alfred Marchionini, pioneers in researching the skin's acidic nature and its protective role. Key publications were selected to provide a thorough historical context and contemporary understanding of the acid mantle's influence on barrier function, enzymatic activities, and microbial ecology. Additionally, historical texts, review articles, and clinical guidelines were reviewed to synthesize findings across different epochs, illustrating the evolution of scientific understanding and clinical applications related to the acid mantle in maintaining skin health and managing dermatologic conditions.

HISTORY

The concept of the acid mantle emerged in the early 20th century through groundbreaking research conducted by German physician and biochemist Heinrich Schade in collaboration with Alfred Marchionini.⁵ In their seminal work published in 1928, Schade and Marchionini meticulously investigated the chemical composition of the skin's surface and uncovered its acidic nature, which they termed the "Säureschutzmantel," or acid mantle.⁵ Their findings revealed that the skin maintains a delicate balance with a slightly acidic pH, typically ranging between 4.5 and 6.2, with an optimal pH around 5.0.⁵

Schade and Marchionini's findings represented a profound leap forward in dermatology and skin physiology. They demonstrated that the acidity of the acid mantle plays a pivotal role in the skin's defense mechanisms against harmful microorganisms. Specifically, their research showed that this mildly acidic environment creates an inhospitable habitat for pathogenic bacteria and fungi, effectively inhibiting their growth and proliferation.⁵ This acidic pH acts as a natural barrier that contributes significantly to the innate immune response of the skin, bolstering its ability to resist infections and maintain overall health.

Moreover, their studies highlighted the dynamic nature of the acid mantle, revealing how its pH can fluctuate in response to various factors such as environmental conditions, skincare products, and individual skin health. They emphasized the critical importance of maintaining this acidic barrier to support optimal skin function and resilience against external stressors, underscoring its role in preserving the skin's barrier integrity and moisture balance.⁵

Schade and Marchionini's research also illuminated how the mildly acidic environment may influence critical enzymatic activities essential for barrier repair and maintenance. Specifically, several enzymes whose functions are pH-dependent, including those involved in lipid synthesis, protein processing, and desquamation within the stratum corneum.

For instance, lipases and glucosidases, which play crucial roles in lipid metabolism and glycosylation processes, respectively, have been shown to exhibit optimal activity

within the acidic pH range typical of the acid mantle (approximately pH 4.5-5.5).⁶ These enzymes are essential for synthesizing and processing lipids, ceramides, and proteins that constitute the skin barrier.⁶ Maintaining the acidic pH of the acid mantle is thus critical for ensuring optimal enzymatic function and supporting the structural integrity of the stratum corneum.

Moreover, Schade and Marchionini's findings hinted at deeper biochemical interactions within the skin that contribute to overall homeostasis. Their findings prompted future investigations showing that the acid mantle's pH also influences the activity of antimicrobial peptides (AMPs).⁷ AMPs are natural components of the skin's innate immune system that help defend against microbial colonization and infection.⁸ An acidic pH environment enhances the expression and efficacy of AMPs, further bolstering the skin's defense mechanisms.⁸

Furthermore, their research suggested that disruptions in pH balance—whether due to environmental factors, such as exposure to alkaline soaps or harsh cleansers, or internal factors like skin disorders—can compromise the skin's ability to maintain barrier integrity, leading to increased susceptibility to infections, dehydration, and inflammatory conditions.⁹ Many skin disorders, including AD and acne, are linked to changes in the acid mantle's pH. In AD, the skin often has a higher pH due to impaired barrier function and reduced natural moisturizing factors.¹⁰ This elevated pH may also compromise AMPs that protect against bacterial and fungal infections.¹⁰

DEVELOPMENTS

Subsequent research throughout the mid-20th century expanded upon Schade and Marchionini's foundational discoveries, revealing insights into how the skin's acidic environment supports pH-dependent enzymatic activities crucial for barrier function and repair. For instance, studies have demonstrated that enzymes involved in lipid metabolism, such as ceramidases and lipases, exhibit optimal activity within the pH range typical of the acid mantle.¹¹ Specifically, ceramidase activity was found to peak at pH 5.5, aligning with the natural acidity of healthy skin and emphasizing the pH sensitivity of lipid processing enzymes essential for maintaining the skin barrier integrity.¹¹ Furthermore, investigations into enzymatic processes regulating desquamation have shown that proteases responsible for facilitating the shedding of dead skin cells are also pH-dependent, with optimal activity observed at acidic pH levels around 5.0 to 5.5.¹² This pH dependency ensures efficient turnover of the stratum corneum, contributing to skin resilience. Additionally, the production and activity of AMPs are enhanced under acidic conditions.¹³ Such findings underscore the multifaceted role of the acid mantle in supporting enzymatic functions fundamental to skin barrier maintenance, repair mechanisms, and overall skin health.

The implications of skin cleansers on conditions such as hidradenitis suppurativa (HS) and rosacea are particularly noteworthy. Chlorhexidine gluconate wash and ben-

zoyl peroxide washes are commonly prescribed for HS due to their antibacterial properties. However, both chlorhexidine and benzoyl peroxide can disrupt the skin barrier by altering the skin's natural acidity. Chlorhexidine, while effective at killing a broad spectrum of bacteria, can create a more alkaline environment on the skin surface, which may compromise its protective barrier.¹⁴ Similarly, benzoyl peroxide, although effective in treating acne and reducing inflammation, can lead to increased skin irritation and dryness.¹⁵ Disruption of the acid mantle can result in significant changes to the skin microbiome, potentially allowing pathogenic bacteria to thrive. This imbalance may not only exacerbate inflammation associated with HS but also increase susceptibility to secondary infections. Moreover, a disrupted acid mantle can result in increased TEWL, which may cause dryness and irritation.¹⁶

Investigations into the acid mantle also reveal its influence on the composition and balance of the skin microbiome. In a study by Li et al, it was demonstrated that a lower skin pH (4.33 to 6.22) was significantly associated with increased stratum corneum antibacterial activity ($p < 0.05$), with each unit decrease in pH leading to a 68.1% increase in *S. aureus* cell death.¹⁷

A notable logarithmic relationship between pH levels and the growth dynamics of *Staphylococcus* species on the skin's surface has also been demonstrated. *Staphylococcus* bacteria, including both beneficial commensals like *Staphylococcus epidermidis* and potentially pathogenic species such as *Staphylococcus aureus*, demonstrate distinct responses to variations in pH. One study examined how skin pH affects the growth of *Staphylococcus epidermidis* and *Staphylococcus aureus*, identifying that *S. epidermidis* growth is relatively stable across a pH range of 5-7, while *S. aureus* exhibits a significant pH-dependent logarithmic growth pattern.¹⁸ Gompertz's model showed that *S. aureus* equilibrium count is particularly sensitive to pH changes, with a shift in growth rate observed at pH 6.5-7.¹⁸

The logarithmic nature of this pH-growth relationship underscores the sensitivity of skin microbiota to pH changes.¹⁹ Even small alterations in pH, whether due to intrinsic factors or external influences such as skincare products or environmental exposure, can disrupt the delicate balance of the skin microbiome. Further, *S. aureus* colonization is prevalent in over 90% of AD patients,²⁰ and is known to release a host of toxins that can drive inflammation, itch, and skin barrier damage.²¹ This further supports the hypothesis that maintaining an acidic skin pH facilitates an environment conducive to balancing the skin microbiome and supporting healthy skin.

In the context of rosacea, emerging research has identified a relationship between skin pH and clinical presentation. In a retrospective study by Zhong et al, 30 patients with rosacea were treated with a 5% tranexamic acid solution applied twice daily for two weeks.²² Post-treatment, there was a notable reduction in inflammatory lesions, with an average decrease of 5.5 lesions on the treated side compared to four on the control side.²² Additionally, skin biophysical functions improved significantly, including a marked decrease in TEWL and skin surface pH ($p < 0.05$).²²

Studies suggest that maintaining a balanced pH may alleviate some symptoms of rosacea by supporting the skin barrier and reducing irritation.²³ The use of newer topical agents formulated with this understanding is becoming increasingly relevant.

FUTURE DIRECTIONS

The recognition of the critical role of the acid mantle has spurred advancements in the skincare industry. This understanding has led to the development of a diverse array of products specifically formulated to preserve or restore the skin's natural pH, thereby supporting its inherent protective functions.

A key advancement in dermatological formulations is the introduction of cleansers with significantly lower alkalinity compared to traditional soaps. This development addresses issues related to the high alkalinity of conventional soaps, which can lead to epidermal dehydration and disruption of the skin barrier.²⁴

True soap is produced through saponification, where triglycerides such as fats or oils react with strong bases such as sodium hydroxide (NaOH) or potassium hydroxide (KOH).²⁵ This process results in soap and glycerin, with the final product typically having a pH between 9 and 10.²⁵ In one study, all cleansing agents, including tap water, were found to increase skin pH, with the highest rise (+0.45) and the greatest fat reduction ($-4.81 \mu\text{g}/\text{cm}^2$) from alkaline soap.²⁶ These changes can damage the skin's acid mantle, alter bacterial flora, and affect enzyme activity, potentially leading to increased TEWL and greater susceptibility to irritation and inflammatory conditions.²⁶

Some modern cleansers are formulated to match the skin's physiological pH. These pH-appropriate products help prevent barrier disruption and support skin homeostasis, reflecting an advanced understanding of skin physiology and improving both the efficacy and safety of cleansing products.

Additionally, the introduction of acidic toners containing Alpha Hydroxy Acids (AHAs) and Beta Hydroxy Acids (BHAs) exemplifies another significant development. These toners not only assist in maintaining the acid mantle by promoting gentle exfoliation and improving skin texture but also contribute to pH regulation.²⁷ AHAs and BHAs work synergistically with the skin's natural acidity to enhance barrier function and facilitate optimal cellular turnover.

While moisturizers play a crucial role in supporting the acid mantle, determining their pH can be challenging. Recent comparative studies, such as one conducted by Shi et al, quantified the pH of various emollients sold in the United States.²⁸ Their findings revealed a wide range of pH values (from 3.7 to 8.2), with the majority of products aligning closely with the physiologic skin pH of 4 to 6.²⁸ This research underscores the importance of pH balance in skincare formulations and its impact on maintaining the stratum corneum acid milieu, which is crucial for skin hydration and resilience.

The evolution of skincare products aimed at maintaining the acid mantle highlights a paradigm shift towards holistic skincare approaches that prioritize skin barrier function and microbiome balance. Ongoing research efforts continue to refine our understanding and therapeutic strategies surrounding the acid mantle, paving the way for innovative solutions in dermatologic care.

DISCUSSION

Despite evolving trends and shifting research priorities, the concept of the acid mantle persists as a fundamental pillar in our comprehension of skin physiology and health. Originally discovered by Heinrich Schade and Alfred Marchionini in the early 20th century, the acid mantle remains integral to understanding how the skin maintains its protective barrier and interacts with its microbiome.

Recent scientific inquiry has rekindled interest in the acid mantle, exploring its intricate relationships with modern dermatological concepts and therapeutic interventions. Studies have examined its pivotal role in supporting barrier function, regulating the skin microbiome, and influencing the efficacy of skincare products. This renewed understanding has prompted innovative approaches in dermatology, where pH-appropriate formulations are increasingly recognized for their potential to optimize treatment outcomes and enhance overall skin health. By leveraging insights into the acid mantle's functions, researchers and clinicians are advancing strategies that not only restore but also maintain the skin's natural pH balance, thereby improving therapeutic efficacy and promoting long-term skin resilience against environmental stressors and microbial challenges. Future research should focus on how pH variations impact the skin microbiome and barrier function across diverse skin types and demographics. Prioritizing longitudinal studies which track changes in the acid mantle among predisposed individuals and novel therapeutic interventions aimed at restoring its optimal pH balance will enhance personalized dermatologic care and improve skin health outcomes.

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CONFLICTS OF INTEREST

PL reports being on the speaker's bureau for AbbVie, Arcutis, Eli Lilly, Galderma, Hyphens Pharma, Incyte, La Roche-Posay/L'Oréal, Pfizer, Pierre-Fabre Dermatologie, Regeneron/Sanofi Genzyme, Verrica; reports consulting/advisory boards for Alphyn Biologics (stock options), AbbVie, Almirall, Amyris, Arcutis, ASLAN, Bristol-Myers Squibb, Burt's Bees, Castle Biosciences, Codex Labs (stock options), Concerto Biosci (stock options), Dermavant, Eli Lilly, Galderma, Janssen, LEO Pharma, Lipidor, L'Oréal, Merck, Microcos, MyOR Diagnostics, Regeneron/Sanofi Genzyme, Sibel Health, Skinfix, Suneco Technologies (stock options), Soteri Skin (stock options), Theraplex, UCB, Unilever, Ver-

dant Scientific (stock options), Verrica, Yobee Care (stock options). In addition, Dr. Lio has a patent pending for a Theraplex product with royalties paid and is a Board member and Scientific Advisory Committee Member emeritus of the National Eczema Association.

IT declares no conflicts of interest.

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