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Study on the Efficacy Duration and Mechanism of Key Ingredients in Acne-Fighting Cosmetics

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Abstract. This study systematically analyzed five common acne-fighting ingredients, investigating their mechanisms of action, onset times, and side effects. The subjects included salicylic acid, benzoyl peroxide, tea tree oil, sulfur, and retinol. Results were derived through literature review and data synthesis. Findings indicate these ingredients exhibit differences in anti-inflammatory, antibacterial, keratolytic, and sebum-regulating properties, with varying efficacy and onset times. Salicylic acid acts rapidly with low irritation, benzoyl peroxide demonstrates the strongest antibacterial activity, tea tree oil is suitable for sensitive skin, while sulfur and retinol show significant efficacy in deep sebum regulation. Limitations include the absence of long-term clinical data and insufficient consideration of individual skin type variations. Future research may explore ingredient combinations, personalized skin type studies, clinical trials, novel drug development, or systemic optimization of current acne treatment strategies. These findings not only guide acne ingredient selection and personalized care but also establish a scientific foundation for new formulation development.

Keywords: Acne, Salicylic acid, Benzoyl peroxide, Sulfur, Tea tree oil.

1. Introduction

Acne is a common chronic inflammatory skin condition with a global prevalence of approximately 20.5%, primarily affecting adolescents and young adults [1]. Although acne is generally not life-threatening, it imposes a significant psychological and social burden, including anxiety, depression, and reduced self-confidence. Fifty percent of patients experience fatigue, and 41% suffer from sleep disturbances [2]. Current treatment aims primarily to eliminate skin lesions, prevent scarring, and mitigate psychological impacts. Common acne-fighting ingredients include salicylic acid, benzoyl peroxide, sulfur, tea tree oil, and vitamin A derivatives. These act through distinct mechanisms on various pathological aspects of acne, such as excessive sebum production, abnormal shedding of follicular epithelium, Propionibacterium acnes colonization, and inflammatory responses [3]. These ingredients vary in stability, penetration capacity, and duration of action. Therefore, this study aims to systematically evaluate the mechanisms of action and clinical efficacy of major acne-fighting ingredients through literature and data analysis.

Currently, multiple medications are available for treating acne. In cosmetic treatments, the mechanism of action and onset time of key active ingredients are particularly crucial. Common

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acne-fighting ingredients include salicylic acid, benzoyl peroxide, sulfur, and various plant extracts. Acne is a chronic disease affecting the sebaceous glands within hair follicles, involving four primary processes: excessive sebum production, abnormal follicular keratinization, colonization by Propionibacterium acnes, and inflammatory response [4, 5]. Excessive sebum production and keratin plug formation block hair follicles, creating a growth environment for Propionibacterium acnes. Its proliferation then triggers inflammation, leading to lesions such as erythema and pustules. Current treatments include topical medications, oral medications, and laser therapy, primarily targeting these pathological processes. However, treatment efficacy varies significantly among patients, and different ingredients exhibit differences in stability, penetration, and duration of action. Therefore, this study aims to systematically investigate the mechanisms of action and efficacy of key ingredients in acne-fighting cosmetics.

2. Acne

2.1. Excessive sebum production

Abnormal sebaceous gland activity is one of the fundamental causes of acne. Hormones and hormonal fluctuations may trigger or exacerbate acne.

Hormonal changes, particularly during adolescence and periods of hormonal fluctuation, result from increased secretion of adrenal and gonadal androgens or heightened androgen receptor sensitivity. stimulate sebaceous glands to produce excessive sebum. This excess sebum, combined with shedding keratinocytes, can clog hair follicles, forming comedones or acne lesions. Acne vulgaris is a chronic inflammatory process of the follicular sebaceous unit. The condition typically begins in early adolescence [6].

2.2. Abnormal follicular keratinization

Follicular keratinization represents another critical step in acne formation. Under normal conditions, keratinocytes within the hair follicle are shed periodically. However, in acne patients, follicular sebaceous duct obstruction may result from follicular hyperkeratinization, sebaceous gland hypertrophy (increased sebum production), and the formation of follicular plugs due to the shedding of keratinocyte masses. All these factors are influenced by androgens [7]. When hyperkeratinization obstructs normal sebum flow to the skin surface, microcomedones form. As sebum accumulates, microcomedones enlarge into macroscopic comedones [8].

2.3. Colonization of propionibacterium acnes

Propionibacterium acnes is the causative agent of acne. It proliferates within hair follicles, producing fatty acids that trigger localized inflammatory responses. These inflammatory reactions lead to symptoms such as redness, swelling, and pustules. Within the sebaceous glands of hair follicles, the lipase produced by Propionibacterium acnes (formerly known as Propionibacterium acnes) hydrolyzes triglycerides into free fatty acids and glycerol. Propionibacterium acnes proliferates dramatically during adolescence and is a key trigger for acne inflammation. Once released into the skin through ruptured follicles, free fatty acids exert cytotoxic effects and trigger inflammatory responses [9]. Subsequently, recruited inflammatory cells produce proinflammatory cytokines such as IL-1, IL-8, IL-12, and defensins, leading to the formation of inflammatory papules and pustules. In severe cases, cysts and nodules may also develop. Serum calprotectin levels (an inflammatory biomarker) are elevated in acne patients [10]. Recent evidence indicates that

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Propionibacterium acnes can activate components of both the innate and adaptive immune systems, and that P. acnes biofilms may promote follicular hyperkeratinization [11].

2.4. Inflammatory response

Inflammatory responses are the basis of acne symptoms. Studies show that Propionibacterium acnes are closely related to inflammatory acne. Clinical biopsies detected the bacterium in 68% and 79% of lesions on days 1 and 3, respectively [12]. It activates CD^{4+} T cells and macrophages, secretes IL-17A and other mediators, triggers Th1/Th17 immune responses, and exacerbates inflammation.1β, and MMPs, further damage the hair follicle and cause scar formation [13]. Norris and Cunliffe's histopathological study confirmed that inflammatory reactions appear in early acne lesions (6–72 hours) and are manifested as microcomedones and mild erythema, with 52% presenting as microcomedones [14]. Early on, there is lymphocytic infiltration around blood vessels, followed by neutrophil aggregation, follicular dilation, and the formation of pustules. Ultimately, due to persistent edema, the lesion ruptures. This indicates that inflammatory foci are present in seemingly non-inflammatory lesions and are a critical process in the development of acne [15].

3. Key ingredients and mechanisms in acne-fighting cosmetics

3.1. Salicylic acid

Salicylic acid is a commonly used beta-hydroxy acid (BHA). Due to its high lipophilicity, it can penetrate the sebaceous glands within hair follicles and promote keratin removal, effectively clearing sebum and dead skin cells that clog pores to prevent acne formation. Compared to alpha-hydroxy acids like glycolic acid, salicylic acid demonstrates superior penetration into oily skin [16]. Beyond exfoliation, salicylic acid reduces sebum production by inhibiting the AMPK/SREBP-1 pathway and decreases inflammatory mediator expression by suppressing the NF-κB pathway, thereby alleviating acne symptoms such as redness and pain.

Clinical studies demonstrate that topical salicylic acid formulations—such as gels, solutions, and cleansers—significantly reduce acne lesions, regulate sebum secretion, and simultaneously improve skin barrier function and hydration [17]. Compared to common acne medications, salicylic acid offers good tolerability and superior moisturizing effects, making it suitable for oily, acne-prone, and sensitive skin types. Visible results typically appear after 2–4 weeks of continuous use, manifesting as reduced comedones and inflammatory papules alongside improved skin texture and barrier function. Overall, salicylic acid is a safe, effective, and widely applicable topical acne-fighting ingredient.

3.2. Benzoyl peroxide

There should be a spacing before and after of 6-point. Benzoyl peroxide effectively treats acne without inducing antibiotic resistance [18]. Benzoyl peroxide (BPO) is a first-line treatment for mild to moderate acne. It penetrates the sebaceous glands within hair follicles to release free radicals that kill Propionibacterium acnes, while also providing mild comedolytic action. Additionally, benzoyl peroxide reduces sebum production and suppresses inflammatory responses. Different concentrations (e.g., 2.5%, 5%, 10%) show similar efficacy, but higher concentrations increase the risk of irritation reactions such as dryness, scaling, and erythema, while also potentially increasing skin moisture loss and causing clothing discoloration. Typically applied once daily, visible improvement occurs within 5 days, with more pronounced effects after 3 weeks and optimal results

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achieved at 8–12 weeks. Since BPO alone effectively improves acne while avoiding bacterial resistance, it is often combined with topical retinoids or antibiotics to enhance efficacy. For instance, the combination of erythromycin or clindamycin with BPO yields significantly higher improvement rates than antibiotics alone, with comparable tolerability, making combination regimens clinically advantageous [19].

3.3. Sulfur

Sulfur is widely used in acne treatment due to its keratolytic and antibacterial properties. It removes dead skin cells from the stratum corneum, reduces pore blockage, and kills bacteria, fungi, and parasites, thereby effectively inhibiting the growth of acne-causing bacteria. Sulfur is often combined with other acne-fighting ingredients to enhance efficacy, particularly for mild to moderate acne. Beyond acne, sulfur also possesses anti-inflammatory properties and is used to treat skin conditions such as psoriasis, seborrheic dermatitis, and dandruff. It has also demonstrated some effectiveness for eczema and rosacea [19]. Compared to benzoyl peroxide and salicylic acid, sulfur generally offers better tolerability and is suitable for sensitive skin types, though it may cause dryness and mild irritation in some patients. Clinical studies indicate that after 4 weeks of treatment with a 5% sulfur foam ointment, both inflammatory papules and closed comedones significantly decreased, with marked improvement in overall skin condition [20]. Overall, sulfur remains a safe, effective, and well-tolerated option for treating mild to moderate acne.

3.4. Tea Tree Oil

The sentence must end without a period. Tea Tree Oil (TTO) is derived from the Australian native plant Melaleuca alternifolia. Due to its natural origin and excellent efficacy, it is widely used in pharmaceuticals and cosmetics, but adulteration risks exist in the market [21]. Its primary active component, terpinen-4-ol, exhibits significant antibacterial and anti-inflammatory properties, inhibiting the growth of Propionibacterium acnes (P. acnes) and reducing local inflammation. Additionally, components such as α-pinene, γ-pinene, and 1,8-cineole in tea tree oil synergize with terpinen-4-ol to exert antibacterial, antifungal, and antiviral activities. This mechanism primarily disrupts cell membrane structure and function, thereby inhibiting pathogen survival. Clinical studies indicate that tea tree oil demonstrates comparable efficacy to benzoyl peroxide in treating mild to moderate acne, but with milder side effects, making it suitable for individuals with sensitive skin [22]. One trial demonstrated that 12 weeks of continuous use significantly reduced the number of lesions and improved skin condition with good tolerability, exhibiting only mild, reversible adverse reactions such as dryness and desquamation. Overall, as a natural plant-derived acne-fighting ingredient, tea tree oil combines antibacterial and anti-inflammatory properties with excellent tolerability, making it highly valuable for clinical applications.

3.5. Vitamin a derivatives

Data indicates that the efficacy of topical retinoids correlates positively with concentration. Animal studies and clinical trials demonstrate that higher concentrations of retinoids or adapalene significantly reduce microcomedones and acne lesions while maintaining good tolerability. Furthermore, fixed combination formulations of 0.3% adapalene and 2.5% benzoyl peroxide show superior efficacy in patients with severe acne.

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The latest evidence-based acne guidelines from both the American Academy of Dermatology (AAD) and the European Dermatology Forum (EDF) emphasize the central role of retinoids in acne treatment [23]. This is due to their ability to dissolve comedones, improve microcomedone lesions, exert anti-inflammatory effects, and help maintain acne clearance. However, prescription patterns reveal that dermatologists prescribe retinoids in only about 59% of cases, while non-dermatologists prescribe them in an even lower rate of approximately 32%, indicating that the clinical application of retinoids remains insufficient. Topical retinoids often cause mild to moderate skin irritation during initial treatment, such as scaling, erythema, dryness, and mild stinging. These effects typically occur within the first 1–2 weeks of use and gradually subside as keratinocytes rearrange. Concurrently, as the skin adapts, the anti-inflammatory effects and improvement in microcomedones become progressively apparent [24].

4. Results and discussion: composition analysis and timeliness analysis

According to Table 1, the mechanisms of action for the five acne-fighting ingredients show distinct differences. Salicylic acid primarily reduces sebum production through chemical exfoliation and inhibition of the AMPK/SREBP-1 pathway, with relatively weak antibacterial effects. Benzoyl peroxide and tea tree oil rapidly suppress Propionibacterium acnes through bactericidal action and exhibit potent anti-inflammatory effects. Sulfur offers mild anti-inflammatory and keratolytic effects with good tolerability, making it suitable for sensitive skin. Vitamin A derivatives focus on regulating keratinocyte turnover and anti-inflammation, with weak antibacterial activity but significant long-term improvement in microcomedones. These mechanism differences suggest that clinically appropriate ingredients can be selected based on acne type and skin tolerance.

Table 1. Mechanism comparison of key acne ingredients

Ingredient	Main Mechanism	Anti-inflammatory Effect	Antibacterial Effect	Exfoliation Effect
Salicylic Acid	β-hydroxy acid exfoliation	Inhibits NF-κB pathway	Weak	Exfoliates, regulates sebum
Benzoyl Peroxide	Releases oxygen free radicals to kill bacteria, comedolytic	Inhibits inflammation	Strong	Reduces sebum
Sulfur	Keratolytic, antibacterial, antiparasitic	Mild anti-inflammatory	Moderate	Removes dead skin, prevents clogged pores
Tea Tree Oil	Terpinen-4-ol and multi-component synergy disrupts cell membranes	Reduces local inflammation	Strong	Mild exfoliation
Vitamin A Derivatives	Promote skin cell turnover, prevent pore blockage	Strong anti-inflammatory	Weak	Dissolves comedones, improves microcomedones

According to Table 2, the onset times of the ingredients vary significantly. Benzoyl peroxide acts fastest, with improvements beginning at 5 days, becoming noticeable at 3 weeks, and reaching optimal efficacy at 8–12 weeks. Salicylic acid and sulfur show results within 2–4 weeks with good tolerability; tea tree oil takes longer to take effect, requiring 4–12 weeks, but has fewer side effects; vitamin A derivatives begin working in 4–6 weeks, with optimal results seen at 6–12 weeks.

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Table 2. Onset and optimal effect time of acne ingredients

Ingredient	Onset of Effect	Optimal Effect	Suitable Acne Type
Salicylic Acid	2–4 weeks	3–4 weeks	Mild to moderate, sensitive skin
Benzoyl Peroxide	Improvement in 5 days, noticeable in 3 weeks, best at 8–12 weeks	8–12 weeks	Mild to moderate acne
Sulfur	2–4 weeks	4 weeks	Mild comedonal acne
Tea Tree Oil	4–12 weeks	12 weeks	Mild to moderate acne, sensitive skin friendly
Vitamin A Derivatives	4–6 weeks	6–12 weeks	Mild to severe acne, inflammatory or microcomedones

5. Conclusions

This study comprehensively analyzed the efficacy, onset time, and side effects of five common acne-fighting ingredients: salicylic acid, benzoyl peroxide, tea tree oil, sulfur, and retinol. Results indicate significant differences in the mechanisms of action and timelines for efficacy among these ingredients, consistent with existing literature. Furthermore, this study clarifies variations in onset times for different ingredients, providing guidance for clinical practice and personal care. It suggests that selecting appropriate ingredient combinations based on skin type and acne severity can optimize treatment outcomes. However, this study has certain limitations. First, it primarily relies on literature data and ingredient analysis, lacking long-term clinical observation. Second, skin type and acne severity among different populations may influence ingredient efficacy, yet this study did not sufficiently account for individual variations. Therefore, future research should conduct large-scale clinical trials involving diverse populations and skin types. Future research should explore the efficacy, long-term safety, and suitability for sensitive skin when ingredients are used in combination. This study could focus on identifying optimal formulations and dosages for different ingredient combinations to balance efficacy and side effects, or conduct long-term clinical trials across various skin types and age groups to validate safety and sustainable outcomes, thereby further optimizing acne treatment strategies.

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