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The effect of vitamin C on skin condition and health - mechanisms of action, clinical evidence, and therapeutic applications

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ABSTRACT
Vitamin C (L-ascorbic acid) is a crucial water-soluble antioxidant and a cofactor in multiple enzymatic processes essential for skin health. This review discusses the biochemical mechanisms of vitamin C function, clinical evidence of its efficacy, and its therapeutic applications in dermatology and cosmetology. Vitamin C is transported into the skin by sodium-dependent vitamin C transporters (SVCT1 and SVCT2), ensuring high intracellular concentration that protects against oxidative stress, supports collagen synthesis, and modulates melanogenesis. Topical and oral vitamin C have been shown to improve skin elasticity, reduce wrinkles and hyperpigmentation, and provide photoprotection against UV-induced damage. Clinical studies confirm its beneficial effects in photoaging, wound healing, and the management of inflammatory and neoplastic skin diseases, including atopic dermatitis, acne, and melanoma. However, limitations such as variable bioavailability, formulation instability, and heterogeneity in study designs remain challenging. Further research is needed to standardize dosing, optimize delivery systems, and clarify its role as an adjuvant therapeutic in dermatology. Vitamin C remains a key ingredient in evidence-based strategies for maintaining skin health and combating aging and disease.

KEYWORDS: vitamin C, L-ascorbic acid, skin health, antioxidant, collagen synthesis, melanogenesis, photoprotection, skin aging, hyperpigmentation, SVCT transporters

1. Introduction

The skin is the largest organ in the human body and performs many functions. It plays a key role in protecting the body from external factors, acting as a defensive barrier against chemical and mechanical substances, in addition to harmful pathogens. The proper condition of the skin has a significant impact on both health and aesthetic aspects. Maintaining a healthy and youthful appearance of the skin is one of the priorities of modern medicine and cosmetology. Vitamin C, also known as L-ascorbic acid, is one of the most commonly used ingredients in the production of dermatological and cosmetic products. Its popularity may be attributed to its various biological properties, including antioxidant activity, collagen synthesis support, and photochemical protection of the skin cells(1).

Vitamin C is a very powerful water-soluble antioxidant. Its absorption after oral consumption is limited, which is why in dermatology practice it is preferred to apply it topically(2).

This review aims to discuss the biochemical mechanisms of vitamin C on the skin, present clinical evidence of its efficacy and explore its various therapeutic applications. This paper provides a thorough overview of the latest research on the beneficial effects of vitamin C in protecting and regenerating the skin.

2. The biochemical role of vitamin C and its presence in the skin

2.1 Characteristics of vitamin C and its biological role

Vitamin C, also known as L-ascorbic acid (ASA), is a water-soluble organic substance that is essential for many biochemical processes in the body. Vitamin C must be supplied with food, as the human body does not have the enzyme L-gulono-1,4-lactone oxidase necessary for its synthesis(3). L-ascorbic acid is an essential cofactor for many enzymes, including those that play a key role in collagen biosynthesis. Other processes, such as iron ion reduction, gene transcription, protection against reactive oxygen species (ROS), synthesis of certain hormones, DNA demethylation, and hydroxylation of transcription factors, tRNA, and ribosomal proteins, occur thanks to the presence of vitamin C in the body(2).

2.2 Transport and distribution of vitamin C in the skin – the role of SVCT transporters

Ascorbate is transported in the skin by two sodium-dependent vitamin C transporters: SVCT1 and SVCT2. SVCT1 is a high-capacity transporter involved in the absorption of vitamin C from the gastrointestinal tract and in renal reabsorption. It is mainly found in epithelial tissues and its main role is to maintain homeostasis(4). SVCT2 is a transporter with a lower capacity than SVCT1 and is mainly found in metabolically active tissues such as fibroblasts, melanocytes, and nerve cells. This transporter ensures high concentrations of vitamin C in cells, which protects them from oxidative stress(5). Studies have shown that SVCT2 expression is regulated by intracellular ascorbate levels through a feedback mechanism. SVCT2 expression increases when intracellular ascorbate levels decrease in order to restore proper vitamin C levels in the cell(6). Both transporters are integral membrane proteins with 12 transmembrane segments. They use the sodium gradient (2 Na+ :ascorbate ion) to drive the uptake of vitamin C against its concentration gradient, enabling skin cells to efficiently accumulate ascorbate(5).

3. Mechanisms of vitamin C function on the skin

3.1 Antioxidant function and neutralization of free radicals

Environmental factors such as solar radiation, pollution, and smoking can accelerate skin damage by causing oxidative stress. This process creates reactive oxygen species (ROS), like superoxide anion (O_2^-), hydroxyl radical (OH·) and alkyl radicals (RO·). Vitamin C is one of the most powerful antioxidants present in the skin, neutralizing oxidative stress by forming a stabilized intermediate radical that allows it to react with highly reactive molecules such as hydroxyl radicals and superoxide anions, preventing damage to cellular biomolecules(7). Vitamin C regulates the level of oxygen free radicals at an early stage of their formation. It acts on their two main sources, namely the mitochondrial respiratory chain and enzymes such as NADPH oxidase (NOXs) and xanthine oxidase (XO). Studies have shown that at a concentration of 100 μM, vitamin C modifies both of these systems, preventing the formation of free radicals(8). The study showed that vitamin C protects the skin barrier structure by preventing the degradation of key intercellular adhesion proteins – desmocollin-1 and claudin-1, which are responsible for the integrity of connections between keratinocyte cells. Its antioxidant effect inhibits lipid peroxidation and protein oxidation induced by exposure to pollutants such as UV, ozone, and engine exhaust. As a result, vitamin C maintains the structural integrity of the epidermal layer and prevents excessive transepidermal water loss(9).

3.2 The effect of vitamin C on collagen synthesis

L-ascorbic acid serves as an essential cofactor for several enzymes, including prolyl-3-hydroxylases (P3H), prolyl-4-hydroxylases (P4H), and lysyl hydroxylases (LH), all of which are crucial for collagen biosynthesis. By transferring an electron to catalytic iron, it reduces the oxidized form Fe3+/Fe+4 to the active form Fe+2, stabilizing the triple helix of collagen. In the absence of ascorbic acid, procollagen accumulated intracellularly in a non-native form and could not be converted into mature collagen. However, in the presence of ascorbic acid, procollagen assumes its native triple helical structure, which is essential for the cleavage of propeptides and the formation of mature type I and IV collagen that can subsequently be secreted from cells(10).

3.3 The effect of vitamin C on melanogenesis

Vitamin C also plays a role as a depigmenting agent. It acts as a powerful skin lightening agent by inhibiting melanin production in melanocytes through the inhibition of tyrosinase activity. Vitamin C is a weak acid that acidifies the cytoplasm of melanocytes, reducing tyrosinase activity to a minimum. It achieves this anti-melanogenic effect by directly inhibiting the enzymatic activity of tyrosinase. In addition, vitamin C increases the expression of the SVCT-2 transporter in melanocytes, which enhances the uptake of ascorbate by cells and facilitates intracellular acidification and tyrosinase inhibition(11).

4. Vitamin C effect on the appearance and general health of the skin

4.1 The effect on wrinkles and ageing of the skin

Wrinkles are the most visible sign of skin ageing. Vitamin C is renowned for its anti-ageing properties, as it increases collagen synthesis, stabilizes collagen fibers and reduces collagen degradation(1). A study which gathered ultrasonographic data on cutaneous changes following the topical application of vitamin C to the face proved that such therapy increases collagen synthesis. This phenomenon was demonstrated by a decrease in low echogenic pixels and an increase in high echogenic pixels. Patients who took part in the research reported a visible reduction of fine wrinkles, softer skin, increased hydration and a slight depigmentation of brown spots after 3-4 weeks of vitamin C therapy(12). Another comprehensive study on patients with photoaged facial wrinkles showed that a formulation containing vitamin C, vitamin E, and green tea polyphenols visibly improved fine lines around the eye area and facial wrinkles and enhanced skin smoothness and radiance(13).

4.2 Skin elasticity

The elasticity and firmness of the skin are crucial for its youthful appearance. In a study on mice subjected to aging, oral vitamin C significantly inhibited the formation of wrinkles, skin atrophy, and loss of elasticity by increasing collagen production and inhibiting senescence-associated cellular pathways(14). Whereas in another study it was reported that a mixture of topical forms of polydeoxyribonucleotide (PDRN), vitamin C, and niacinamide attenuated skin pigmentation and increased skin elasticity by modulating nuclear factor erythroid 2-like factor 2 (Nrf2)(15).

4.3 Hyperpigmentation

Hyperpigmentation, including sun spots and melasma, is a common dermatological problem. In a meta-analysis of 31 randomized controlled clinical trials involving 741 volunteers, vitamin C was found to be effective in reducing UV-induced pigmentation in a dose-dependent manner. Vitamin C at a concentration of 10% showed a strong effect, while 7%, 5%, and 3% showed a moderate effect. The study also proved that vitamin C acts as an anti-pigmentation agent (preventing pigmentation) rather than a depigmentation agent (lightening), which is an important distinction that helps to understand its mechanism of action and its proper use(16). In another clinical study, the use of a topical preparation containing 25% vitamin C and a chemical penetration enhancer showed a significant reduction in melasma-induced hyperpigmentation after 16 weeks. Vitamin C acts as an antioxidant, inhibiting tyrosinase activity and reducing melanin production in melasma, which has led to a reduction in hyperpigmentation as assessed by the MASI (Melasma Area and Severity Index) and measurement with a mesometer. The quality of life of patients, as measured by the MelasQoL scale, also improved, without significant side effects such as dryness or skin irritation(17).

4.4 Photoaging

Photoaging is caused by chronic exposure to UV radiation and leads to damage to the collagen contained in the skin, loss of elasticity, and the formation of wrinkles. Vitamin C has the ability to protect the skin from photoaging through several mechanisms(1).

Factors contributing to carcinogenesis include UV-induced erythema and thymine dimer mutations. In addition, UV exposure causes the production of reactive oxygen species, which contribute to p53 gene mutations and, consequently, to DNA repair disorders and premature apoptosis. One scientific study demonstrated the effectiveness of topical application of 10% vitamin C, which led to an increase in the amount of vitamin in the skin, consequently reducing UVB damage in the form of a 52% reduction in UVB-induced erythema and a 40-60% reduction in sunburned cells(18). Clinical studies have also proven the effectiveness of vitamin C in reducing the formation of thymine dimer mutations, which are known to be associated with skin cancer(19).

Vitamin C also inhibits AP-1 activation, which leads to a reduction in the production of matrix metalloproteinases (MMPs) and, consequently, to a reduction in collagen damage. Ex vivo studies have shown that vitamin C at the required concentration can prevent UV-induced changes in MMP2 and MMP9(20).

5. The role of vitamin C in skin diseases

5.1 Atopic Dermatitis

Atopic dermatitis (AD) is a chronic inflammatory skin disease associated with an impairment of the lipid barrier of the epidermis, especially ceramide deficiency. In inflammatory skin diseases such as atopic dermatitis, the amount of vitamin C in the dermis is reduced(21). Researchers have shown that the more severe the atopic dermatitis, the lower the level of vitamin C in the blood plasma and the level of ceramides in the epidermis - over 82% of patients had vitamin C levels below the normal range (below 25 μmol/L). A positive correlation was found between vitamin C in plasma and ceramides in the epidermis, suggesting that vitamin C is essential for ceramide production and protection of the epidermal barrier in patients with AD(22).

5.2 Malignant Melanoma

Melanoma is a malignant skin cancer originating in melanocytes. Vitamin C has an anti-melanogenic effect by inhibiting melanin production in melanocytes through the inhibition of tyrosinase activity(11). Studies on genetically modified mice showed that vitamin C supplementation reduced B16FO melanoma metastasis by 71% compared to mice deprived of vitamin C. Microscopic histological analysis showed that tumors in mice receiving vitamin C had limited areas of necrosis and a strengthened type I collagen capsule, while tumors in mice deprived of vitamin C showed large dark cores and a weak collagen capsule(23). Vitamin C treatment increases 5-hydroxymethylcytosine (5hmC) content in melanoma cells toward levels of healthy melanocytes, leading to a decreased tumor-cell invasiveness and clonogenic growth through alterations in extracellular matrix remodeling pathways, making it a potential epigenetic treatment for melanoma(24).

5.3 Herpes Zoster and its consequences

Herpes zoster (HZ) is caused by the reactivation of the latent varicella-zoster virus (VZV) that remains in the body. Postherpetic neuralgia (PHN) refers to the persistence of neuralgia for 4 weeks after the disappearance of herpes lesions and constitutes chronic, debilitating neuropathic pain. Recent studies suggest that pain in HZ and PHN is associated with the involvement of oxygen free radicals and oxidative reactivity(25). The study showed that 92% of patients with postherpetic neuralgia had vitamin deficiencies, and 52% had vitamin C deficiency (below 45.0 mmol/l) compared to controls with mean concentration of 76.2 mmol/l. Lower concentrations of vitamin C (≤45.0 mmol/l) were found to independently increase the risk of PHN. Vitamin C has reversible, concentration-dependent antiviral activity, and the continuous presence of ascorbate is necessary to keep viruses suppressed(26).

5.4 Acne Vulgaris

Acne vulgaris is a common inflammatory skin disease affecting the pilosebaceous units of the skin and may result in inflammatory or non-inflammatory lesions. Some studies have shown that vitamin C has a positive effect on acne. In one study, acne patients receiving doxycycline in combination with vitamin C (500 mg daily) showed a significantly greater reduction in proinflammatory cytokines (IL-1β, IL-8, IFN-γ, TNF-α, and TLR-2) compared to patients receiving doxycycline alone, with a clinical response of 47% in the group receiving doxycycline in combination with vitamin C compared to 33% in the group receiving doxycycline alone(27). A split-face clinical trial in 10 patients tested a combination of two vitamin C derivatives - glyceryl-octyl-ascorbic acid (GOVC) and ascorbyl 2-phosphate 6-palmitate (APP) combined with alpha-tocopherol phosphate, applied twice daily for 3 months. The treated side showed significant improvement in postinflammatory hyperpigmentation and atrophic scars from acne, while the untreated control side showed minimal improvement(28).

6. Conclusions

Vitamin C plays a multidimensional role in maintaining skin health by acting as a potent antioxidant, an essential cofactor for collagen biosynthesis, and a modulator of melanogenesis and immune responses in the skin. Its presence in high concentrations in the epidermis and dermis, ensured by SVCT transporters, allows effective protection against oxidative stress, support of barrier function, and participation in wound healing and tissue regeneration. Clinical studies consistently demonstrate that vitamin C can improve wrinkles, skin elasticity, hyperpigmentation, and photoaging, and may support the management of inflammatory and neoplastic skin diseases such as atopic dermatitis, acne, and melanoma. At the same time, current evidence highlights several limitations, including variable bioavailability after oral intake, instability of many topical formulations, and heterogeneity of study designs, concentrations, and co-ingredients, which makes direct comparison of results difficult. Future research should focus on standardized clinical trials comparing oral versus topical routes, long-term safety and efficacy of high-concentration formulations, optimization of delivery systems (e.g. nanoformulations, microneedles), and clarification of the role of vitamin C as an adjuvant therapy in specific dermatoses and skin cancers. Such studies will help to better define evidence-based indications, dosing regimens, and combinations with other antioxidants or active substances in dermatology and cosmetology.

DISCLOSURE

Author's contribution

Conceptualization: B.Wróbel; methodology: B.Wróbel; check: S.Kosek; formal analysis: M.Filipski; investigation: L.Wójcik; resources: L.Wójcik; data curation: J.Klonowska; writing - rough preparation: B.Wróbel; writing - review and editing: S.Kosek;

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In preparing this work, the authors used Perplexity for the purpose of checking language accuracy. After using this tool, the authors have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

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