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Vitamin C and Human Heath : An Intergative Review of its Biological and Clinical Significance

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Abstract: *Vitamin C (L-ascorbic acid) is a vital dietary antioxidant that participates in many cellular processes essential for human health. Because humans lack the enzyme required for its synthesis, the body depends entirely on external intake to maintain sufficient levels. Vitamin C contributes to tissue integrity through its role in collagen formation and supports immune, neurological, and metabolic functions by acting as a cofactor for several enzymes. Recent scientific work from 2020 to 2025 has broadened its clinical relevance, showing benefits in reducing oxidative stress, supporting immune defense during infections, improving endothelial function, and assisting in gastrointestinal and metabolic health. Evidence also indicates a potential role for vitamin C in neuroprotection and skin repair, while high-dose intravenous formulations are being explored for severe conditions such as sepsis, acute respiratory distress, and cancer as an adjunctive therapy. Although mechanistic studies strongly support its biological importance, clinical outcomes vary due to differences in dosage, delivery route, and patient status. This review brings together current findings on the chemistry, biological actions, therapeutic applications, and emerging research directions of vitamin C, offering an updated overview of its multifaceted significance in promoting and maintaining human health.*

Keywords*:* Vitamin C, Ascorbic acid, Antioxidant, Immune function, Nutrition, Clinical significance, Chronic disease

I. INTRODUCTION

Vitamin C (L-ascorbic acid) is a fundamental water-soluble micronutrient essential for maintaining numerous biological, biochemical, and clinical processes in the human body. Because humans have lost the ability to synthesize vitamin C due to mutations in the GULO gene, adequate intake from dietary or supplemental sources is critical for sustaining physiological homeostasis [1]. Across modern research, vitamin C continues to be recognized for its antioxidant capacity, involvement in enzymatic reactions, and broad therapeutic significance [2].

In recent years, scientific interest in vitamin C has intensified, particularly between 2020 and 2025, due to its roles in oxidative stress reduction [3], immune enhancement [4], metabolic regulation [5], neuroprotection [6] , gastrointestinal health [7], endothelial function [8], and the management of viral infections such as COVID-19 [9]. These findings collectively highlight that vitamin C is not only a classical nutrient required for the prevention of scurvy but also a molecule with wide-ranging biochemical and therapeutic potential.

Biochemically, vitamin C functions as a potent electron donor capable of reducing reactive oxygen and nitrogen species while regenerating other antioxidants such as vitamin E, thereby maintaining cellular redox balance [10]. Its essential cofactor roles support collagen synthesis, neurotransmitter production, and peptide hormone activation, linking vitamin C to tissue repair, neurochemical balance, and stress response modulation [11]. Vitamin C further influences iron metabolism by reducing ferric to ferrous iron, enhancing gastrointestinal absorption [4]. This wide scope of activity explains its high concentration in metabolically active tissues such as leukocytes, adrenal glands, and the brain.

Clinically, modern research recognizes vitamin C as a promising adjunctive therapy in several chronic and acute conditions. Recent insights highlight its potential in reducing oxidative vascular injury [3], supporting glycemic regulation in type 2 diabetes [8], improving cognitive resilience [6], mitigating gastric inflammation associated with

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Helicobacter pylori [7], and enhancing immune defense during viral infections [9]. Vitamin C has also gained interest in critical care for its potential benefits in sepsis, ARDS, and systemic inflammation [1].

Altogether, vitamin C represents a multifunctional nutrient whose importance extends far beyond classical deficiency disorders. With rapidly growing evidence from biochemical, clinical, and translational research, a modern integrative review is essential to understand its evolving role in human health. This paper synthesizes findings from the literature between 2020 and 2025 to provide an updated understanding of vitamin C's biological functions, therapeutic applications, and future potential.

CHEMICAL STRUCTURE AND PROPERTIES OF VITAMIN C

Vitamin C (L-ascorbic acid) is a six-carbon lactone structurally derived from glucose. Its molecular formula is $C_6H_8O_6$, and its distinctive chemical reactivity arises from the C2–C3 enediol group, which readily donates electrons and undergoes reversible oxidation–reduction cycling [3]. This enediol structure is responsible for vitamin C's high reducing potential and underlies its central role in antioxidant defense mechanisms and enzymatic hydroxylation reactions.

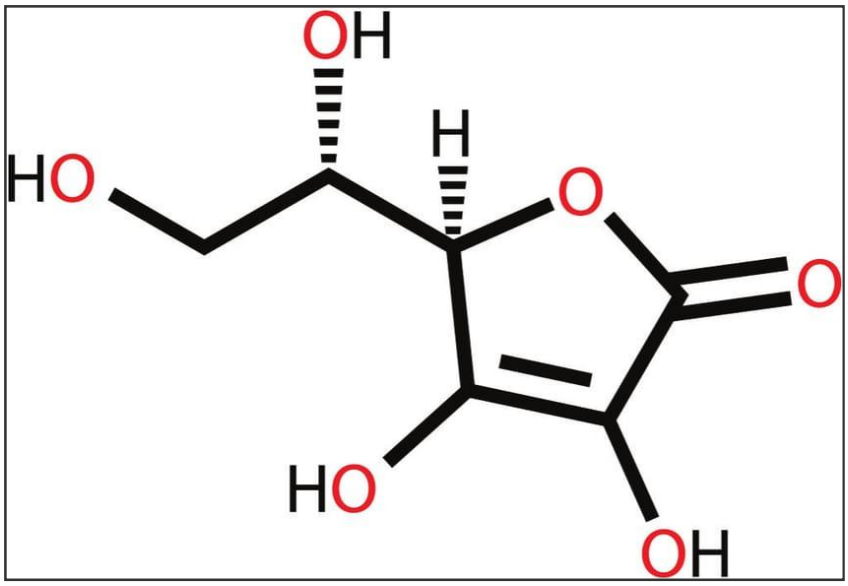

Fig.No.1.Chemical structure of L-ascorbic acid

Ascorbic acid exists in two primary redox states:

1. Ascorbic acid (AA) — the reduced, biologically active form
2. Dehydroascorbic acid (DHA) — the oxidized form, which can be regenerated back to AA intracellularly

This reversible interconversion allows vitamin C to function as a dynamic antioxidant system, stabilizing reactive oxygen species and regenerating other antioxidants, such as tocopherols [10]. The ability of DHA to enter cells through glucose transporters enhances its biological distribution, particularly under oxidative stress conditions [11].

Vitamin C is highly water-soluble, enabling rapid diffusion across extracellular fluids. However, it is also chemically unstable when exposed to heat, light, or oxygen. Degradation involves oxidation to DHA and further breakdown into diketogulonic acid, followed by cleavage to smaller metabolites, including oxalate [2]. This chemical fragility explains the substantial losses of vitamin C during food storage, processing, and prolonged cooking—an important consideration in nutritional planning [4].

The ionizable hydroxyl groups contribute to vitamin C's weak acidity, with pKa values allowing it to exist primarily in anionic form at physiological pH. This property facilitates its role as a cofactor in several Fe^{2+}/α-ketoglutarate-dependent dioxygenases, including prolyl hydroxylase, lysyl hydroxylase, dopamine β-hydroxylase, and peptide

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amidating monooxygenase, all of which require a reducing environment maintained by vitamin C [11]. These enzymatic actions support collagen stability, catecholamine synthesis, and peptide maturation.

Overall, the chemical structure of vitamin C underpins its diverse physiological roles, allowing it to act as an antioxidant, enzymatic cofactor, and metabolic regulator. These structural characteristics make vitamin C unique among micronutrients and essential for maintaining cellular integrity and metabolic health.

NATURAL SOURCES AND BIOAVAILABILITY OF VITAMIN C

Vitamin C is widely distributed in plant-based foods, particularly fresh fruits, leafy vegetables, and certain herbs. Natural dietary sources remain the primary contributor to daily vitamin C intake because humans lack endogenous synthesis due to the evolutionary loss of the GULO gene [1]. Fruits such as citrus, guava, kiwi, papaya, and berries consistently provide high concentrations of ascorbic acid, while vegetables such as broccoli, bell peppers, tomatoes, spinach, and cabbage also contribute significantly to dietary intake [4].

Table 1. Major Dietary Sources of Vitamin C

The vitamin C content in these foods, however, depends heavily on cultivation conditions, ripeness, storage duration, and cooking methods, since ascorbic acid is highly sensitive to heat and oxidative degradation [2].

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Beyond conventional dietary sources, certain medicinal plants, herbs, and functional foods also contain measurable levels of vitamin C. Recent analytical studies report that various plant-based formulations and botanical extracts retain significant ascorbic acid content that may contribute to antioxidant capacity and clinical benefits [3]. These findings have strengthened growing interest in functional nutrition and the therapeutic potential of natural vitamin C–rich preparations.

Bioavailability

Vitamin C bioavailability depends on intestinal absorption, tissue transport, metabolism, and renal reabsorption. Ascorbic acid is absorbed in the small intestine through sodium-dependent vitamin C transporters (SVCT1), while dehydroascorbic acid (DHA) is absorbed through glucose transporters (GLUT1 and GLUT3) and subsequently reduced intracellularly to ascorbate [12]. Under normal dietary intake (≤200 mg/day), absorption efficiency remains high, often exceeding 80–90%. However, at higher oral doses, the sodium-dependent transporters become saturated, resulting in diminished fractional absorption—a major limiting factor in the systemic rise of plasma vitamin C after oral supplementation [11].

Once absorbed, vitamin C is actively transported to metabolically demanding tissues such as leukocytes, adrenal glands, the brain, and ocular tissues, all of which maintain intracellular concentrations far higher than plasma levels [6]. Renal reabsorption via SVCT1 ensures conservation of ascorbate at physiological levels, but excessive intake leads to urinary excretion.

Factors Affecting Bioavailability

Bioavailability is significantly influenced by physiological and lifestyle factors:

Oxidative stress and inflammation increase tissue demand and may accelerate vitamin C turnover [9].

Smoking and alcohol use reduce plasma ascorbate due to increased metabolic utilization [8].

Chronic infections, such as Helicobacter pylori, reduce gastric vitamin C secretion and alter its stability in the gastric environment [7].

Disease states, including diabetes and metabolic syndrome, alter utilization and may increase requirements [5].

PHARMACOKINETICS AND TISSUE DISTRIBUTION OF VITAMIN C

Vitamin C pharmacokinetics involve a tightly regulated system of absorption, transport, distribution, metabolism, and excretion that maintains optimal tissue concentrations despite its water-soluble nature and limited body storage capacity. Understanding these pharmacokinetic processes is essential to interpreting the clinical significance of vitamin C, especially in conditions of oxidative stress, infection, or increased metabolic demand.

1. Absorption Mechanisms

Dietary vitamin C is absorbed primarily in the small intestine through sodium-dependent vitamin C transporters. SVCT1, located on the apical membrane of intestinal epithelial cells, mediates the uptake of the reduced form, ascorbic acid, with high efficiency at physiological dietary doses [12]. Dehydroascorbic acid (DHA), the oxidized form, is absorbed via glucose transporters (GLUT1 and GLUT3) due to its structural resemblance to glucose and is subsequently reduced intracellularly to ascorbate, enhancing retention during oxidative stress conditions [11].

At low-to-moderate dietary intakes (≤200 mg/day), the absorption rate exceeds 70–90%. However, at higher oral doses, SVCT1 becomes saturated, reducing fractional absorption and preventing proportional increases in plasma concentrations [2]. This represents a major limitation of oral supplementation, contributing to interest in intravenous routes for clinical applications.

2. Plasma Levels and Transport

Plasma vitamin C levels are tightly regulated through intestinal absorption, renal reabsorption, and tissue-specific uptake. Under normal physiological conditions, plasma concentrations range from 50–70 µmol/L, with saturation occurring at approximately 70–80 µmol/L [3]. Excess vitamin C is filtered by the kidneys, but significant reabsorption occurs through SVCT1 in the renal tubules to prevent deficiency, especially at lower intake levels [5].

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Circulating vitamin C is transported to tissues via passive diffusion and active uptake through SVCT2, a high-affinity transporter expressed in metabolically active tissues such as the brain, adrenal glands, pancreas, and immune cells [6]. This targeted distribution highlights differential tissue requirements and functional roles across physiological systems.

3. Tissue Distribution Patterns

Vitamin C distribution is not uniform throughout the body. Certain tissues maintain concentrations several-fold higher than plasma due to specific functional needs:

Adrenal glands and pituitary possess extremely high levels due to involvement in steroidogenesis and stress-response pathways [11].

Brain and neural tissues hold elevated concentrations essential for neurotransmitter synthesis, neuroprotection, and oxidative defense [6].

Leukocytes accumulate vitamin C up to 10–20 times more than plasma levels to support immune activity [9].

Ocular tissues rely on vitamin C to protect against photo-oxidative stress and maintain collagen-rich structures [3].

This preferential tissue distribution underscores vitamin C's diverse biological functions and emphasizes the importance of adequate dietary intake during stress or illness.

4. Metabolism and Excretion

Ascorbic acid undergoes reversible oxidation to dehydroascorbic acid (DHA), followed by irreversible degradation into diketogulonic acid and subsequently oxalate and other organic acids [2]. Renal excretion of these metabolites increases at higher intake levels. Although vitamin C is considered safe, excessive supplementation in predisposed individuals—particularly those with renal impairment—may elevate urinary oxalate excretion and marginally increase the risk of calcium-oxalate stone formation (5)

MOLECULAR MECHANISM

Vitamin C exerts its molecular activity primarily through redox regulation, where it donates electrons to neutralize reactive oxygen and nitrogen species, thereby protecting cellular biomolecules from oxidative injury [10]. It also modulates major cell-signaling pathways, including suppression of NF-κB–driven inflammation and activation of the Nrf2 antioxidant response system [6].

As a key enzyme cofactor, vitamin C supports prolyl and lysyl hydroxylases for collagen maturation and regulates hypoxia-inducible factors (HIFs) through prolyl hydroxylation [13]. Additionally, it facilitates TET-enzyme–mediated DNA demethylation, helping maintain epigenetic balance and proper gene expression patterns [4]. These combined mechanisms underpin vitamin C's anti-inflammatory, cytoprotective, immunomodulatory, and tissue-repair effects observed across clinical and pre-clinical research [11].

BIOLOGICAL AND PHYSIOLOGICAL ROLES OF VITAMIN C

Vitamin C is a multifunctional micronutrient involved in numerous biochemical and physiological processes essential for human health. Its unique redox chemistry enables it to function both as an antioxidant and as a cofactor in several enzymatic reactions. Modern research (2020–2025) has expanded the understanding of these biological roles, highlighting its relevance across connective tissue maintenance, immune regulation, metabolic support, neuroprotection, and cellular signaling.

1. Antioxidant Defense

Vitamin C serves as the primary water-soluble antioxidant in human plasma and tissues. Its ability to donate electrons from the enediol group neutralizes reactive oxygen species (ROS) such as superoxide, hydroxyl radicals, and peroxynitrite, preventing oxidative damage to lipids, proteins, and DNA [10]. Through redox cycling, dehydroascorbic acid (DHA) is rapidly reduced back to ascorbate within cells, sustaining antioxidant capacity even under conditions of increased oxidative stress. Vitamin C also regenerates other antioxidants, such as vitamin E, further enhancing cellular defense mechanisms [3].

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2. Collagen Formation and Connective Tissue Stability

One of the most critical biological functions of vitamin C is its role as a cofactor for prolyl and lysyl hydroxylases, enzymes required for the post-translational modification of collagen [11]. Hydroxylation of collagen polypeptides enables triple helix stabilization and cross-linking, providing tensile strength to skin, bone, cartilage, tendons, ligaments, gingiva, and vasculature. Deficiency in vitamin C results in defective collagen synthesis, manifesting clinically as impaired wound healing, gum bleeding, easy bruising, and in severe cases, scurvy [1].

3. Immune System Regulation

Immune modulation is another major physiological role of vitamin C. Leukocytes—particularly neutrophils and lymphocytes—accumulate vitamin C at concentrations many times higher than plasma, reflecting the nutrient's importance in immune defense [4]. Vitamin C enhances chemotaxis, phagocytosis, microbial killing, and neutrophil apoptosis, promoting efficient clearance of pathogens while limiting inflammation-related tissue injury [9]. In adaptive immunity, vitamin C supports T-cell differentiation and enhances antibody production, providing an essential link between micronutrient status and host defense.

4. Neurotransmitter Synthesis and Neuroprotection

Vitamin C plays a significant role in brain function through its involvement in neurotransmitter synthesis and neuroprotection. It acts as a cofactor for dopamine β-hydroxylase, converting dopamine to norepinephrine, and supports peptide amidation required for hormonal signaling [6]. Additionally, its antioxidant and anti-inflammatory effects protect neurons from excitotoxicity and oxidative injury, contributing to cognitive resilience during aging and neurological stress. High concentrations of vitamin C in neuronal and glial tissues highlight its essentiality in central nervous system physiology [2].

5. Energy Metabolism and Carnitine Production

Vitamin C is required for the biosynthesis of carnitine, a molecule essential for the transport of long-chain fatty acids into mitochondria for β-oxidation. Reduced vitamin C availability compromises energy metabolism and may contribute to fatigue, exercise intolerance, and metabolic imbalances [5]. These findings offer mechanistic insight into the relationship between vitamin C status and metabolic health.

6. Iron Metabolism and Nutrient Interactions

Vitamin C enhances non-heme iron absorption by reducing ferric (Fe^{3+}) to ferrous (Fe^{2+}) iron in the gastrointestinal tract and forming soluble complexes that facilitate uptake [4]. This property makes it essential for preventing iron deficiency in populations with plant-based diets or increased iron requirements.

7. Anti-Inflammatory and Redox Signaling Functions

Beyond classical antioxidant activity, vitamin C modulates several redox-sensitive pathways. It downregulates NF-κB activation and upregulates Nrf2-mediated antioxidant gene expression, thereby reducing inflammation and oxidative injury [3]. Ascorbate also supports TET enzyme–mediated DNA demethylation, linking vitamin C to epigenetic regulation and cellular differentiation [11].

CLINICAL SIGNIFICANCE

Vitamin C demonstrates broad therapeutic relevance across multiple clinical domains due to its antioxidant, immunomodulatory, anti-inflammatory, and enzymatic cofactor functions.

1. Respiratory Infections and COVID-19

Vitamin C reduces oxidative stress in respiratory tissues and supports immune cell function. Clinical observations show shorter illness duration and reduced symptom severity in viral respiratory
infections, while trials in COVID-19 suggest potential improvement in oxygenation and inflammatory markers, particularly with intravenous vitamin C [9,14].

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2. Gastrointestinal Disorders & H. pylori

Vitamin C concentrations in gastric mucosa decline significantly during Helicobacter pylori infection. Supplementation helps restore antioxidant status and may modestly enhance eradication therapy outcomes [7]. Its protective effects also support mucosal healing and reduce gastric oxidative injury [4].

3. Cardiometabolic Health

Vitamin C contributes to vascular protection by reducing endothelial oxidative stress and improving nitric-oxide–mediated vasodilation. Supplementation has shown benefits in improving insulin sensitivity, lowering oxidative biomarkers, and reducing inflammatory load in metabolic syndrome and type 2 diabetes [8,5].

4. Neuroprotective Applications

High neuronal ascorbate levels support neurotransmitter synthesis and protect against excitotoxic and oxidative neuronal damage. Studies highlight reduced neuroinflammation and improved neurocognitive outcomes associated with adequate vitamin C status [6].

5. Dermatological Use

Vitamin C enhances collagen synthesis, reduces photoaging, improves hyperpigmentation, and protects against UV-induced oxidative stress. Topical and systemic formulations demonstrate significant improvements in skin texture and .dermal collagen deposition [13].

6. Critical Illness and Sepsis

Critical illness rapidly depletes vitamin C levels. Intravenous high-dose therapy restores plasma concentrations and may reduce vasopressor requirements in sepsis and acute respiratory distress cases, though outcomes are variable and ongoing trials aim to clarify therapeutic value [1,11].

7. Adjunct Cancer Therapy

High-dose intravenous vitamin C may create selective oxidative pressure in tumor microenvironments, potentially sensitizing cancer cells to chemotherapy or radiation. While preclinical data are promising, robust clinical validation is still required [3].

8. Musculoskeletal Health & Collagen Disorders

Vitamin C plays an important role in maintaining cartilage and bone health by enhancing collagen production and lowering oxidative stress. Findings show that sufficient vitamin C intake can improve joint performance and decrease inflammatory markers linked to osteoarthritis. Its involvement in collagen cross-linking is vital for bone remodeling and the repair of connective tissues[12] .

9. oral health

Vitamin C plays an important role in maintaining oral health. It supports collagen formation, which strengthens the gums and tooth structure. Adequate vitamin C levels help lower the risk of dental caries by inhibiting the growth of bacteria such as Streptococcus mutans. Deficiency of vitamin C can lead to gum weakness, bleeding, and delayed wound healing. Overall, vitamin C is essential for protecting and maintaining healthy oral tissues.(16)

EVIDENCE AND LIMITATIONS

The current evidence on vitamin C demonstrates substantial biological and clinical relevance, supported by diverse research designs ranging from molecular studies to randomized clinical trials. Strong mechanistic support is seen in pharmacology and biochemical studies, which consistently show antioxidant, anti-inflammatory, collagen-modulating, and immunomodulatory roles of vitamin C [2,3]. These biochemical findings are reinforced by dermatological and cellular studies demonstrating enhanced collagen synthesis, photoprotection, and anti-aging benefits [13]. Clinical reviews provide additional strength, showing improvements in metabolic health, glycemic control, cardiovascular markers, and neuroinflammation [5,8,6]. Evidence regarding infectious diseases, including H. pylori control and COVID-19, is promising, with several studies demonstrating reduced inflammation and improved clinical outcomes [7,9]. Neuroprotective insights are strongly supported through both pre-clinical and clinical evaluations showing reduced neuronal injury and improved recovery in neurotrauma [11,6].

Despite these strengths, the evidence base has limitations. Many clinical trials involve small sample sizes, short durations, or heterogeneous dosing strategies, creating difficulty in establishing standardized guidelines. Some

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therapeutic areas—such as oncology and critical illness—show biological plausibility but inconsistent clinical outcomes, often due to variations in intravenous dosing protocols and patient conditions [1,3]. Several reviews highlight the challenge of accurately measuring vitamin C status because plasma levels fluctuate rapidly with dietary intake and illness severity [14]. Furthermore, population variability, coexisting nutrient deficiencies, and differences in supplement formulations may influence treatment outcomes [4,12]. While mechanistic and observational data are strong, more large-scale, controlled clinical trials are required to confirm the therapeutic efficacy of vitamin C across diverse conditions. Overall, existing evidence strongly supports vitamin C's biological importance but underlines the need for standardized, high-quality research to strengthen clinical recommendations.

SAFETY,TOXICITY AND CONTRAINDICATION

Vitamin C is recognized as one of the safest micronutrients due to its water-soluble nature and efficient renal clearance. Across clinical and biochemical studies, adverse effects remain minimal at standard dietary and supplemental intakes. However, certain considerations are essential for safe therapeutic use, particularly with high-dose oral or intravenous administration. High oral intake may lead to gastrointestinal discomfort, including bloating, nausea, or diarrhea, primarily due to unabsorbed ascorbate in the intestinal lumen[8,5]. Individuals prone to kidney stone formation may experience increased urinary oxalate excretion with chronic high-dose supplementation, highlighting the need for caution in patients with a history of calcium-oxalate nephrolithiasis [15,2].

Because vitamin C enhances non-heme iron absorption, excessive intake may pose risks for individuals with iron-overload conditions such as hereditary hemochromatosis, necessitating monitored supplementation [16]. Intravenous vitamin C, while generally well tolerated, requires screening for glucose-6-phosphate dehydrogenase (G6PD) deficiency due to the potential risk of hemolysis at high pharmacological doses [1,9]. Additionally, patients with severe renal impairment may require close supervision to prevent oxalate accumulation following high-dose intravenous therapy. Emerging dermatological formulations indicate excellent cutaneous safety, though stability issues and potential irritation with strong acidic formulations remain areas of ongoing improvement [13].

Overall, evidence from clinical and mechanistic research demonstrates that vitamin C maintains a strong safety profile across diverse applications. However, individualized assessment, dosing precision, and awareness of specific contraindications remain crucial as research continues to expand its therapeutic use [11,4].

FUTURE PERSPECTIVE

1. Personalized and Precision Supplementation

Future research will focus on personalizing vitamin C intake based on genetics, metabolic status, inflammation levels, and individual absorption differences to optimize therapeutic outcomes [2,11].

2. Role in Immune Modulation and Infection Control

Vitamin C's influence on neutrophil resolution, cytokine regulation, and antiviral immunity continues to gain interest. Upcoming studies will clarify its role in severe infections and immune dysfunction [9,1].

3. High-Dose Intravenous Vitamin C in Critical Illness

Large trials are underway to determine whether IV vitamin C can reduce organ damage, inflammation, and mortality in sepsis, ARDS, and critical illness, aiming to establish standard clinical protocols [17,1].

4. Neuroprotective Applications

Because of its antioxidant and neurotransmitter-supporting functions, future work will explore vitamin C in neurological disorders such as Alzheimer's, Parkinson's, stroke recovery, and cognitive decline [6,18] .

5. Advanced Delivery Systems

Novel delivery forms including liposomal, nano-encapsulated, and controlled-release formulations may improve absorption, stability, and targeted delivery, enhancing its therapeutic potential [12,10].

II. CONCLUSION

Vitamin C is an essential micronutrient with widespread biological and clinical significance. Its roles extend from antioxidant defense and immune regulation to collagen synthesis, metabolic support, and neuroprotection. Research

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from 2020–2025 has strengthened the understanding that maintaining optimal vitamin C status is crucial for preventing deficiency, reducing oxidative stress, and supporting overall physiological stability. The nutrient demonstrates beneficial effects across multiple systems, including cardiovascular health, respiratory immunity, gastrointestinal protection, cognitive performance, and dermatological repair.

Emerging evidence also highlights the therapeutic potential of high-dose vitamin C, particularly in critical illness, metabolic dysfunction, and certain infections, although further large-scale trials are required to establish standard dosing and clear clinical guidelines. With ongoing advancements in precision nutrition, pharmacology, and delivery systems, vitamin C continues to remain at the center of interest for future medical and therapeutic innovations. Overall, ensuring adequate vitamin C intake through diet or supplementation remains a simple yet effective strategy for promoting long-term human health and resilience.

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