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Therapeutic Potential of Silicon Supplementation in Age-Related Diseases: A Comprehensive Review

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Abstract

Silicon, the second most abundant element in nature, plays a crucial role in human health. Despite its understated presence, silicon's multifaceted contributions to various physiological processes make it a promising option for therapeutic intervention. Through a comprehensive analysis of recent scientific literature, this review explores the impact of silicon supplementation on bone health, cardiovascular function, metabolic regulation, and neuroprotection. Review methods involved the analysis of scientific publications found in

databases such as PubMed and scientific journals, including meta-analyses, randomized trials, and systematic reviews, concerning the scope of medical and nutritional problems, excluding case reports.

Key findings suggest that silicon supplementation may positively influence bone mineral density, bone regeneration, and collagen synthesis, offering potential benefits for individuals at risk of osteoporosis and musculoskeletal disorders. Furthermore, evidence highlights silicon's role in regulating cardiovascular health, indicating its potential to mitigate atherosclerosis risk and improve lipid profiles, thereby offering promise in managing conditions such as diabetes and dyslipidemia. Additionally, emerging research underscores silicon's neuroprotective properties, hinting at its potential in combating neurodegenerative diseases like Alzheimer's. This review emphasizes the promising prospect of silicon supplementation as a complementary strategy for enhancing overall health and addressing age-related diseases.

Key words: silicon, orthosilicic acid, age-related diseases

Introduction

Throughout recent decades, an array of studies has underscored the myriad health benefits associated with silicon (Si) [1]. Following oxygen, silicon stands as the second most prevalent element in nature and ranks third among trace elements found in human tissue [2]. Predominantly existing in water as free orthosilicic acid (OSA; H_4SiO_4), silicon also occurs naturally in foods as silicon dioxide (SiO_2) and silicates [1]. Its unique properties have rendered it indispensable across various manufacturing sectors, spanning from food and beverage to cosmetics industries. In addition to its known contributions to reducing the risk of atherosclerosis and mitigating metal accumulation in Alzheimer's disease, silicon fosters a robust immune system, aids in bone mineralization, facilitates general collagen synthesis, and bolsters the structural integrity of skin, hair, and nails. Consequently, the market for several silicon-based dietary supplements has experienced exponential growth in recent years [2].

Age-related disorders stem from a complex interplay of biochemical and genetic pathways intricately linked to the physiological processes of aging. Despite significant advancements in prolonging human life expectancy over recent decades, a corresponding improvement in

healthspan has yet to materialize. Consequently, there has been a surge of interest within the scientific community in exploring strategies to extend life by addressing the underlying pathophysiology of aging [3].

In this research paper, we examine the latest studies to determine whether supplementation with silicon, as described above, can confer health-promoting effects and influence the progression of certain age-related diseases.

Benefits of Silicon Supplementation

Skeletal system

Orthosilicic acid is the accessible form of silicon present in both humans and animals. Recent research suggests its potential benefits in bone regeneration, as it has been found to suppress osteoclastogenesis and promote bone mineralization [4].

Human intervention studies, such as a retrospective study involving 53 osteoporotic women over a period of 14–22 months, demonstrated that Si treatment resulted in a significant increase in femoral bone mineral density (BMD) compared to treatments with fluoride, etidronate, and magnesium [5]. Additionally, OSA therapy has been shown to positively impact calcium mineralization by inducing silicic acid-mediated autophagy, making cells more susceptible to calcium deposition [4]. This process involves the regulation of key markers such as alkaline phosphatase (ALP), collagen 1 (COL1), and osteocalcin (OCN) through bone morphogenetic protein 2 (BMP2)/Smad/Runt-related transcription factor 2 (RUNX2) [6]. Studies indicate that intake of Si through vegetables was positively correlated with total serum alkaline phosphatase, an important marker of bone formation, suggesting a potential positive role of Si deriving from vegetables on bone health [5]. Moreover, OSA, when systemically delivered, has been observed to passively aggregate and remain in inflammatory joints [4].

Overall, these findings suggest that combining OSA (6 mg) with calcium and vitamin D may have a positive impact on bone turnover, particularly on bone collagen, and potentially on femoral bone mineral density, compared to using calcium and vitamin D alone [5].

Cardiovascular System

Proteoglycans form integral components of the extracellular amorphous ground substance enveloping collagen, elastic fibers, and cells, thereby conferring structural integrity upon tissues. Through its role in cross-linking proteoglycans and proteins, silicon assumes a pivotal structural function within the extracellular matrix, fortifying artery walls by enhancing

matrix strength and reducing permeability. Given silicon's involvement in glycosaminoglycan synthesis and its presence as an essential constituent of glycosaminoglycans and their protein complexes, connective tissue exhibits a notable concentration of this element [7]. This phenomenon may underpin some benefits of silicon supplementation, such as inhibiting intimal hyperplasia in rabbits fed cholesterol and potentially elucidating the observed decrease in cardiovascular disease risk associated with higher silicon intake in epidemiological studies [7]. When administered to rabbits on a high-fat diet, silicon induced regression of atherosclerosis at a dosage of 20 mg/ml, in contrast to 10 mg/ml [7]. Authors suggest another mechanism possibly explaining the positive effects of silicates on the cardiovascular system: poorly soluble forms of polymeric silicic acid or silica binding bile acids in the gastrointestinal tract, thereby facilitating the removal of cholesterol metabolism by-products. Additionally, this process may directly bind cholesterol, potentially mitigating atherosclerosis [7].

Research indicates that silicic acid supplementation in drinking water increases the excretion of tritium-labeled cholesterol and its metabolites in feces while reducing their absorption in the liver, spleen, and kidneys, supporting the proposed concept. Moreover, silicon, alongside other metal ions like calcium, magnesium, lithium, and strontium, may mitigate cardiovascular mortality by competitively interacting with sodium and potassium during gastrointestinal transit [7].

Furthermore, studies demonstrate that rats fed a cholesterol-rich diet supplemented with silicon exhibited significantly lower concentrations of protein and total mass very-low-density lipoprotein (VLDL), suggesting a tangible reduction in VLDL particles. Silicon appears to counteract the adverse effects of cholesterol feeding on lipemia, lipoproteinemia, VLDL oxidizability, and liver arylesterase enzyme activity, thereby enhancing the ratio of its activity to cholesterol. One theory posits that silicon achieves this by increasing the availability of fatty acids for hepatic cholesterol esterification [8 - 10]. Collectively, these findings underscore the multifaceted, health-promoting effects of silicon on the cardiovascular system.

Endocrine System

Recent studies by Hernández-Martín indicate that the functional ingredient silicon found in meat, when consumed within the context of a high-saturated-fat high-cholesterol diet, possesses a significant effect in reducing non-HDL cholesterol and slowing down the progression of type 2 diabetes in a rat model [11]. This is attributed to silicon's role in reducing cholesterol intestinal absorption by decreasing the absorptive area and Acetyl-Coenzyme A acetyltransferase-2 (ACAT2) levels; and increasing cholesterol excretion to the lumen by

induction of the liver X receptor (LXR) and consequent increase of adenosine triphosphate-binding cassette transporter (ABCG5/8). These mechanisms collectively offer promise for a nutritional approach to managing diabetic dyslipidemia. Additionally, the consumption of silicon-supplemented meat improves the glycemic profile [11], consistent with other sources suggesting that silicon exhibits novel anti-diabetic properties in animal models by reducing blood glucose levels and enhancing insulin, leptin, and adiponectin tolerance [7]. The results suggest that silicon may represent a new group of functional ingredients capable of synergistically lowering cholesterol and fat levels. Furthermore, alongside this effect, there is a notable decrease in glycemia, supporting the use of silicon supplements in diabetic dyslipidemia. This could potentially mitigate the adverse effects of a diet high in meat, saturated fat, and cholesterol, particularly for individuals with diabetes [11].

Nervous System

In a 2012 study conducted by Foglio, it was indicated that supplementing with silicon seems to prevent aging of the neurological system [12]. An increase of 10 mg/day in silicon intake has been associated with a lower incidence of dementia, particularly Alzheimer's disease (AD) [7, 13]. According to a multivariate study that accounted for potential confounding variables, women with AD appeared to have had lower baseline exposure to silicon [14]. Another study found that higher Si levels in drinking water were associated with a reduced risk of dementia. This suggests that silicon may play a protective role against AD beyond any interactions with other elements [15]. Moreover, silicic acid appears to have the potential to help prevent destruction of the nitrergic system. At healthy levels, silicon sustains the quantity of nitrergic neurons and their production of nitrergic enzymes. High silicon concentrations in drinking water minimized the impairment of nitrergic neuron function [12].

Fig. 1 Effects of orthosilicic acid on selected systems

Metabolism

Silicon can be obtained from both environmental exposures and dietary sources [2]. Orthosilicic acid, a monomeric form of silicon, is highly soluble and therefore one of the most bioavailable sources of Si [1, 2, 13]. The absorption of Si from food and dietary supplements depends not only on their organic or inorganic nature but also on their molecular structure, whether monomeric or polymeric, and the degree of polymerization [1]. The therapeutic

benefits of silicon depend on its bioavailability, or the body's ability to utilize it effectively, similar to other nutrients. Factors such as nutritional status and the composition of the matrix can significantly influence Si bioavailability in individuals [5]. Research suggests that solid foods, high in fiber and whole grains, particularly cereals, oats, beans, spinach, dried fruit, and red lentils, are rich sources of available silicon [13]. Beer contains the highest Si levels among beverages, while drinking water varies in Si content. Approximately 80% of beer brands tested had Si levels of 20 mg/L or higher [16]. In terms of Si excretion, the kidney plays a key role in this process. High renal clearance of Si occurs due to its easy filtration by the renal glomerulus, as Si does not bind to plasma proteins. Studies have shown that nearly the entire dose of OSA consumed is excreted in the urine and feces within a day, indicating efficient elimination from the body [1]. However, the amount and form of silicon in one's diet determine the extent of mineral excretion in urine [13].

Age-Related Health Considerations and Therapeutic Potential of Orthosilicic Acid

Aging, from a pathophysiological standpoint, is a gradual and irreversible process marked by declining tissue and cell activity and an increased susceptibility to various age-related disorders, encompassing immune system dysfunctions, musculoskeletal issues, metabolic disorders, cardiovascular ailments, and neurodegenerative conditions [17]. At the molecular level, aging involves altered protein turnover, post-translational modifications, and protein aggregation, disrupting protein homeostasis and contributing to the onset of age-related illnesses [3].

Elderly individuals are particularly prone to degenerative musculoskeletal ailments, notably osteoarthritis (OA) and sarcopenia, characterized by the age-related decline in muscle mass and function. By age 80, skeletal muscle mass and function can diminish by 30 to 50%, exacerbated in sedentary individuals. Inflammatory processes trigger increased reactive oxygen species (ROS) production in skeletal muscles, leading to cell death and altered muscle catabolism. Sarcopenia development is also associated with compromised antioxidant defenses and impaired mitochondrial function [3].

Aging significantly impacts the cardiovascular system, elevating the risk of cardiovascular diseases (CVD) such as hypertension, atherosclerosis, myocardial infarction, and stroke [3, 17]. Research suggests a notable decline in a certain element's levels in the human aorta with age, potentially affecting arterial blood vessel integrity in older adults [7]. By 2030, it's projected that 20% of the population will be over 65, with 40% of deaths attributed to CVD.

Pathological changes in aging cardiovascular tissues include hypertrophy, altered LV diastolic function, reduced LV systolic reserve capacity, increased arterial stiffness, and compromised endothelial function [3].

Compromised proteostasis is a hallmark of both aging and neurodegenerative disorders [17]. Disruptions in proteostasis prompt cellular adaptation, leading to accumulated DNA damage in neurons as repair mechanisms decline. This heightened oxidative stress and inflammation contribute to neuron death and neurodegeneration, notably in conditions like Alzheimer's disease, which becomes more prevalent with age [3, 17].

Numerous scientific reports, including those referenced in this study, underscore the significant potential of OSA in addressing various age-related conditions such as atherosclerosis, bone and joint issues, diabetes, and Alzheimer's disease, among others. Given its demonstrated benefits in these specific health concerns, OSA holds promise for use in the aging population. However, further research is warranted to thoroughly evaluate its effectiveness, safety profile, and potential risks associated with silicate formulations. Such investigations have the potential to enhance the well-being of elderly individuals and contribute substantially to public health initiatives.

Conclusions

Research presented in this paper sheds light on the promising therapeutic potential of orthosilicic acid in addressing various age-related disorders. From enhancing bone health and cardiovascular function to potentially mitigating the progression of neurodegenerative diseases like Alzheimer's, silicon supplementation emerges as a multifaceted approach to promoting healthy aging.

The findings discussed underscore the importance of considering silicon supplementation as a viable strategy in geriatric care. However, it's imperative to recognize the need for further research to validate these findings and elucidate the optimal dosages, formulations, and safety profiles of silicon supplements. Ultimately, harnessing the health-promoting effects of silicon supplementation has the potential to not only enhance the quality of life for elderly individuals but also alleviate the burden of age-related diseases on healthcare systems worldwide.

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Conflict of interest

The authors declare no conflict of interest.

Supplementary material

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