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The Impact of Zinc Supplementation on the Course of Infections

Justyna Woźniak

Independent Public Healthcare

Institution of the Ministry of Interior and Administration

Kronikarza Galla 25, 30-053 Kraków

justynawozniak512@gmail.com

https://orcid.org/0009-0009-7785-4665

Ewelina Kopczyńska

Gromkowski Regional Specialist Hospital

Koszarowa 5, 51-149 Wrocław

ewekop13@gmail.com

https://orcid.org/0009-0006-5665-6043

Piotr Kulej
Regional Specialist Hospital in Wrocław
Research and Development Center
H. M. Kamieńskiego 73a, 51-124 Wrocław
piotrek.kulej@gmail.com
https://orcid.org/0009-0004-6655-6877

Wiktor Biesiada
Gromkowski Regional Specialist Hospital
Koszarowa 5, 51-149 Wrocław
wiktor122333@gmail.com
https://orcid.org/0009-0002-2662-5300

Justyna Weronika Kmieć
Gromkowski Regional Specialist Hospital
Koszarowa 5, 51-149 Wrocław
kmiecjustyna12345@gmail.com
https://orcid.org/0009-0001-0570-9575

Anna-Mariia Chernysh
Regional Specialist Hospital in Wrocław
Research and Development Center
H. M. Kamieńskiego 73a, 51-124 Wrocław
annamaria.chernysh@gmail.com
https://orcid.org/0009-0008-6900-1593

Aleksandra Dusińska
Uniwersity Clinical Medical Hospital in Wrocław
Borowska 213, 50-556 Wrocław
oladusinska1@gmail.com
https://orcid.org/0000-0001-5197-9683

Jakub Waszczyński

PCK Marine Hospital in Gdynia

Powstania Styczniowego 1, 81-519 Gdynia

waszczynski.jakub@gmail.com

https://orcid.org/0009-0003-4156-2253

Kamila Fuczyło

Lower-Silesian Center of Oncology
Pulmonary and Hematology in Wrocław
pl. Hirszfelda 12, 53-413 Wrocław
kamilafuczylo@gmail.com
https://orcid.org/0000-0002-3443-8663

Karolina Stankevič

Lower-Silesian Center of Oncology
Pulmonary and Hematology in Wrocław
pl. Hirszfelda 12, 53-413 Wrocław
karolina.stan97@gmail.com
https://orcid.org/0009-0008-3572-1066

Correspondence: justynawozniak512@gmail.com

ABSTRACT

Introduction: Zinc plays a vital role in immune function, enhancing defense mechanisms and reducing infection duration and severity.

Purpose of Research: This study aimed to assess the impact of zinc on immune function, its role in preventing and treating infections, particularly in vulnerable populations such as the elderly, and its interactions with vitamins D and C. Additionally, the research explored zinc's effects on microbial cell membranes, gut microbiome balance, and immune modulation, focusing on age-related immune decline and infection susceptibility.

Materials and Methods: The study utilized a comprehensive approach, combining literature reviews, clinical trials, experimental studies, and microbiota analyses to investigate zinc's role in immune function, infection management, and antimicrobial resistance.

Results: Zinc was found to modulate the immune system, influencing T lymphocytes, B lymphocytes, macrophages, and natural killer cells. Deficiency weakened immune responses, increasing infection risk. Zinc supplementation, especially with vitamins D and C, improved immune function, shortened infection duration, and alleviated symptoms. Zinc and vitamin D enhanced antimicrobial peptide production and epithelial barrier function, while zinc and vitamin C reduced oxidative stress and enhanced neutrophil activity. Zinc also destabilized microbial membranes, inhibiting bacterial and viral replication, including multi-drug-resistant strains. Furthermore, zinc supplementation improved gut microbiome composition, promoting beneficial bacteria and reducing pathogenic growth. Clinical studies confirmed its effectiveness in reducing respiratory infections, improving vaccine responses, and decreasing complications in vulnerable individuals.

Keywords: zinc, supplementation, immune system, infections, vitamin D, vitamin C, antimicrobial peptides, biofilm formation, viral infections, bacterial infections, oxidative stress, phagocytosis, neutrophil activity, immune response, zinc deficiency, therapeutic benefits, synergistic effects

Introduction

Zinc plays a crucial role in the functioning of the immune system, influencing the body's defense mechanisms and the course of infections. Its deficiency increases susceptibility to infectious diseases, while zinc supplementation can shorten the duration of infections and alleviate their severity, especially when combined with vitamins D and C. Zinc affects immune cells, such as lymphocytes, macrophages, and neutrophils, supporting their functions, including phagocytosis, antibody production, and inflammatory responses. Additionally, zinc stabilizes the cell membranes of microorganisms, reducing their ability to survive and replicate. In combination with vitamins D and C, zinc exhibits a synergistic effect, enhancing the immune response, increasing the production of antimicrobial peptides, and supporting the reduction of oxidative stress. Clinical studies show that zinc supplementation, particularly when combined

with these vitamins, effectively aids the treatment of bacterial and viral infections, shortening the duration of symptoms and reducing the risk of complications. This article aims to present the current state of knowledge regarding the mechanisms of zinc's action in the context of infections and its potential clinical benefits.

Zinc and the Immune System

Zinc plays a crucial role in regulating the immune response. Its deficiency leads to dysfunction of T cells and decreased activity of natural killer (NK) lymphocytes. Zinc supports the maturation of lymphocytes in the thymus and regulates the production of pro-inflammatory cytokines, such as interleukin-6 (IL-6) and tumor necrosis factor α (TNF-α) [1,2].

Zinc also affects the function of macrophages, key immune cells responsible for phagocytosis of pathogens and initiating the immune response. Zinc deficiency disrupts their antigen presentation capability, which can result in a reduced response of the adaptive immune system [3,4]. Zinc's influence on reducing the production of reactive oxygen species (ROS) by macrophages helps minimize the risk of host tissue damage during infection [5].

Another important aspect of zinc's action is its role in maintaining B lymphocyte homeostasis, which are responsible for antibody production. Studies have shown that zinc supplementation can increase the production of immunoglobulins, significantly supporting protection against bacterial and viral pathogens [6]. Zinc also plays a role in mechanisms of immune tolerance, preventing excessive autoimmune responses [7].

Clinical studies have demonstrated that zinc supplementation reduces the risk of infections in immunocompromised patients, including the elderly and children. A randomized controlled trial showed that administering zinc at therapeutic doses can reduce the incidence of respiratory tract infections [8]. A meta-analysis published in 2020 indicated that zinc supplementation shortens the duration of infection symptoms by an average of 33%, suggesting potential benefits for its use in prevention and treatment [9].

Zinc and Microbial Cell Membranes

Zinc plays a significant role in destabilizing the cell membranes of microorganisms, resulting in the disruption of their vital functions. This mechanism primarily involves interference with the integrity of the lipid membrane, which is crucial for maintaining cellular homeostasis in bacteria and viruses. Through its interactions, zinc increases the permeability of the cell membrane, making it difficult for microorganisms to maintain ion gradients and transport nutrients [10,11].

One of zinc's mechanisms of action is its ability to chelate ions essential for the function of transmembrane proteins. These proteins, responsible for substance transport and maintaining membrane potential, lose their functionality in the presence of zinc, preventing microorganisms from effectively adapting to environmental conditions [12]. In vitro studies have shown that zinc acts as an inhibitor of certain metalloproteins that are important for the metabolic processes of pathogens. The blockage of these enzymes leads to the inhibition of microorganism growth and increased susceptibility to damage [13].

In the context of viral infections, zinc affects the membranes surrounding virions, preventing them from effectively entering host cells. Additionally, zinc disrupts the functions of viral capsids, which are essential for protecting the virus's genetic material and its integration with the host genome. This mechanism has been described in the context of RNA viruses, such as coronaviruses, where zinc supplementation significantly reduced the virus's ability to replicate [12].

In bacteria, zinc has the ability to limit biofilm formation, which are protective structures that allow bacteria to survive in unfavorable environmental conditions. Zinc disrupts the expression of genes responsible for producing the intercellular substance of the biofilm, reducing the bacteria's ability to adhere and colonize surfaces [13]. As a result, bacteria become more susceptible to the action of phagocytes and antibiotics. Studies conducted on pathogens such as *Pseudomonas aeruginosa* have shown that zinc, at therapeutic concentrations, reduced biofilm development by more than 60% compared to control groups [13].

It is also worth mentioning the antibacterial properties of zinc in the context of its interactions with the cell membranes of multi-drug-resistant bacterial strains. Zinc destabilizes their membranes, leading to cell lysis, particularly in Gram-positive microorganisms, whose thick cell wall generally makes them more resistant to the action of other host defense mechanisms [11,13]. The effectiveness of this mechanism has also been documented in supportive therapy, where the use of zinc increased the effectiveness of standard antibiotics.

In conclusion, zinc plays an essential role in disrupting the function of microbial cell membranes, which is crucial for limiting their ability to proliferate and colonize. This mechanism, supported by the synergistic action with the immune system, makes zinc a promising element in adjunctive therapy for treating bacterial and viral infections.

Combination of Zinc and Vitamin D

Vitamin D is not only a regulator of calcium-phosphate balance but also a key element in modulating the immune response. Its deficiency, particularly common in the general population,

can lead to impaired defense mechanisms in the body. Zinc, like vitamin D, is essential for the proper functioning of the immune system, and their synergistic action presents a promising strategy for supporting the treatment of infections.

One of the important mechanisms behind the combined action of zinc and vitamin D is the increased production of antimicrobial peptides, such as defensins and cathelicidins. These peptides are capable of destroying a wide range of pathogens, including bacteria, viruses, and fungi, by disrupting their cell membranes. Studies have shown that vitamin D stimulates the expression of genes encoding these peptides, while zinc enhances their activity by stabilizing molecular structures and supporting enzymatic processes [14,15].

Meta-analyses involving patients with acute respiratory infections have shown that supplementation with vitamin D combined with zinc significantly reduced the risk of hospitalization and shortened the duration of symptoms. This mechanism can be explained by the reduction of inflammation through the modulation of pro-inflammatory cytokines, such as interleukin-6 (IL-6) and tumor necrosis factor α (TNF-α) [16]. Additionally, the synergistic action of these two components improved the integrity of the epithelial barrier in the respiratory tract, which limited the penetration of pathogens into deeper tissue layers.

Randomized clinical trials conducted between 2020 and 2023, including during the COVID-19 pandemic, highlighted the significant role of vitamin D and zinc supplementation in reducing the risk of severe viral infections, including coronavirus infections [15]. In patients receiving both components, better immunological parameters were observed, such as increased T lymphocyte counts and macrophage activity, compared to groups receiving a placebo or monotherapy with one of the components.

Combination of Zinc and Vitamin C

Vitamin C, primarily known for its antioxidant properties, plays a key role in reducing oxidative stress and supporting immune function. In combination with zinc, it can exhibit synergistic effects that improve the control of infection progression. Vitamin C neutralizes free radicals produced during inflammation, while zinc protects immune cells from oxidative damage, ensuring optimal function of the defense mechanisms [17,18].

One of the mechanisms behind the combined action of these components is the support of phagocytosis and neutrophil activity. Vitamin C enhances the chemotaxis of neutrophils to the site of infection, while zinc supports their ability to destroy pathogens through reactive oxygen species (ROS)-dependent mechanisms. Clinical studies have shown that supplementation of

both substances leads to an increase in interferon α production, which plays a crucial role in combating RNA viruses, such as the flu virus and cold viruses [19].

Meta-analyses of randomized controlled trials involving patients with viral infections have shown that supplementation with zinc and vitamin C resulted in a reduction of infection duration by an average of 1.5–3 days and a decrease in the severity of symptoms such as fever, cough, and muscle aches [18,19]. Furthermore, this combination reduced the incidence of infection-related complications, such as secondary bacterial infections.

The combination of vitamin C and zinc also shows potential in preventing infections in individuals at higher risk, such as the elderly, patients with chronic respiratory diseases, or immunosuppressed individuals. Regular supplementation of these components can strengthen the epithelial barrier of mucous membranes, reducing the likelihood of pathogen penetration [17]. Additionally, vitamin C combined with zinc exhibits antiviral activity by inhibiting virus replication in host cells.

In summary, the synergistic action of vitamin C and zinc supports key defense mechanisms in the body, reduces oxidative stress, and decreases the intensity of inflammatory processes, making this combination an effective tool in supporting the treatment of bacterial and viral infections [19]. In light of the latest evidence from randomized trials, using this combination appears to be justified both in the treatment and prevention of infectious diseases [13]

Based on available evidence, zinc supplementation, especially in combination with vitamins D and C, can be an effective way to support infection treatment. Zinc plays a key role in reducing inflammation, modulating the immune response, and improving overall body immunity [2]. Its combination with vitamin D strengthens the epithelial barrier and increases the production of antimicrobial peptides, which is crucial in preventing respiratory infections [9]. Vitamin C, on the other hand, supports the antioxidant action of zinc, leading to a reduction in oxidative stress and an increase in the activity of immune cells such as macrophages and T lymphocytes [19].

The recommended daily doses of zinc range from 20 to 40 mg, but the dosage should be adjusted to the individual needs of the patient, depending on their age, health condition, and risk of deficiency (Prasad, 2010; Chiu et al., 2021). In the elderly and patients with chronic diseases, zinc supplementation combined with vitamins D and C may significantly reduce the risk of severe infection, including viral infections [5]. However, it is important that supplementation is conducted under medical supervision to avoid potential side effects from excessive zinc intake, such as copper imbalance [13].

Clinical studies have shown that zinc supplementation combined with vitamins D and C enables more effective support for the treatment of viral infections, shortening the duration of illness

and reducing its severity[12]. Patients using such supplementation reported a faster recovery and lower risk of complications [16]. Future studies should focus on identifying optimal doses and supplementation regimens for different patient groups, which will allow for more precise use of this potential [20].

The Relationship Between Zinc Levels, Gut Microbiota, and Susceptibility to Infections

Zinc plays a crucial role in immune system function, and its deficiency is associated with a weakened immune response, increased susceptibility to infections, and reduced ability to combat pathogens. Increasing evidence suggests that the gut microbiota plays an essential role in regulating immune responses, and zinc levels can influence its composition and function, which in turn affects susceptibility to infections.

Recent studies indicate that zinc can modify the composition of the gut microbiota, affecting microbial diversity and their functions. A 2022 study demonstrated that zinc supplementation increased the numbers of beneficial bacteria such as *Lactobacillus* and *Bifidobacterium*, which positively influence gut health and immune function. Conversely, zinc deficiency promotes the growth of pathogens like *Clostridium difficile* and *Escherichia coli*, which are associated with gastrointestinal infections [20].

The gut microbiota also significantly influences zinc metabolism. Gut bacteria can produce zinc-chelating compounds, affecting its bioavailability and absorption. Therefore, an imbalanced gut microbiota, caused by factors such as a low-fiber diet, can lead to zinc deficiency, thereby increasing susceptibility to infections [21].

The Role of Zinc in Preventing Infections in Older Adults

Older adults are particularly vulnerable to zinc deficiency due to changes in metabolism, reduced absorption of the element from the digestive tract, and decreased consumption of zinc-rich foods. Zinc deficiency in older adults can weaken the immune system, increasing susceptibility to infections, particularly respiratory, urinary, and gastrointestinal infections.

Zinc supplementation in older adults has been shown to have a positive impact on immune function by improving T lymphocyte activity and cytokine production, both of which are crucial for immune response. Studies indicate that older adults who took zinc had a lower risk of respiratory infections and recovered more quickly from colds and the flu. A 2021 study showed that zinc supplementation reduced the number of respiratory infections by 35% in people over 65 years of age [22].

Additionally, zinc helps maintain the integrity of the gut barrier, which is vital in preventing infections. In older adults who have a reduced ability to maintain this barrier, zinc can support its function, reducing pathogen penetration through the intestinal wall. Zinc supplementation can also enhance the response to vaccines, particularly the flu vaccine, improving its efficacy among older adults [1].

Zinc and Antibiotic Resistance: Modern Therapeutic Approaches

Antibiotic resistance is one of the most significant challenges in modern medicine, leading to increased mortality and complications associated with bacterial infections. Given the rising antibiotic resistance, exploring alternative therapeutic approaches is essential. One promising direction involves the use of zinc, which interacts with bacterial resistance mechanisms and affects their ability to develop resistance.

Zinc can impact bacteria by inhibiting the activity of beta-lactamase enzymes, which are responsible for breaking down many commonly used antibiotics. Studies suggest that zinc supplementation can restore bacterial susceptibility to antibiotics, including penicillin and cephalosporins, which may offer a novel approach for treating bacterial infections resistant to standard therapies [23].

Moreover, zinc is essential for proper immune system functioning, and its role in fighting antibiotic-resistant bacterial infections may involve supporting the body's immune response. Zinc affects the activity of neutrophils, macrophages, and lymphocytes, which are key players in fighting infections. Additionally, zinc exhibits anti-inflammatory properties, reducing inflammation caused by infections, which can improve the effectiveness of therapy in patients with antibiotic resistance [24].

Modern therapeutic approaches also involve combining zinc with other substances, such as probiotics, to improve the effectiveness of bacterial infection treatments. Research suggests that combining zinc with probiotics can enhance gut health and increase the efficacy of antibacterial therapies, especially in cases of antibiotic-resistant infections [25].

Conclusions

The article discusses many important aspects regarding the role of zinc in infections, its impact on the immune system, the gut microbiome, and interactions with other nutrients such as vitamins D and C. Zinc plays a key role in the functioning of the immune system by supporting the body's defense mechanisms, including the activity of lymphocytes, macrophages, and neutrophils. Its deficiency increases susceptibility to infections, while zinc supplementation can

contribute to shortening the duration of infections and reducing their severity. Zinc also acts on the cell membranes of microorganisms, destabilizing them and decreasing their ability to survive, which is particularly important in the treatment of bacterial and viral infections.

The combination of zinc with vitamins D and C shows synergistic effects. Vitamin D supports the production of antimicrobial peptides, while zinc enhances their activity, improving the immune response and strengthening the epithelial barrier of the respiratory tract. Vitamin C, on the other hand, acts as an antioxidant, supporting the action of zinc in reducing oxidative stress and improving immune system function, especially in the context of viral infections.

Additionally, studies indicate that zinc can influence the gut microbiome by modifying the composition of microorganisms and supporting gut health. Zinc deficiency promotes the growth of pathogens, which increases the risk of infections.

Zinc is also important in the prevention and treatment of infections in older adults, who are particularly susceptible to zinc deficiencies. Zinc supplementation supports their immune system, improving the response to infections, including respiratory infections, and enhancing the effectiveness of vaccines.

In the context of rising antibiotic resistance, zinc may offer an alternative therapeutic approach by supporting the action of antibiotics through its interaction with bacterial resistance mechanisms, which may help combat antibiotic-resistant infections.

The article emphasizes the importance of zinc supplementation, especially in combination with vitamins D and C, as an effective support in treating infections and improving immune system function. Recommendations regarding dosing should take into account the individual needs of the patient, and supplementation should be carried out under medical supervision to avoid side effects associated with excessive zinc intake.

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Author's contribution:

Conceptualization: Justyna Woźniak, Wiktor Biesiada, Justyna Weronika Kmieć

Methodology: Justyna Woźniak, Wiktor Biesiada,Justyna Weronika Kmieć

Software: Ewelina Kopczyńska, Jakub Waszczyński

Check: Kamila Fuczyło

Formal Analysis: Piotr Kulej, Anna-Mariia Chernysh, Karolina Stankevič

Investigation: Justyna Woźniak, Wiktor Biesiada,Justyna Weronika Kmieć, Ewelina Kopczyńska, Jakub Waszczyński, Kamila Fuczyło, Karolina Stankevič, Anna-Mariia Chernysh, Piotr Kulej, Aleksandra Dusińska Resources: Aleksandra Dusińska, Justyna Woźniak, Piotr

Kulej, Wiktor Biesiada

Data Curation: Karolina Stankevič, Kamila Fuczyło

Writing-Rough Preparation: Justyna Woźniak, Wiktor Biesiada,Justyna Weronika Kmieć, Ewelina Kopczyńska, Jakub Waszczyński, Kamila Fuczyło, Karolina Stankevič, Anna-Mariia Chernysh, Piotr Kulej, Aleksandra Dusińska

Writing-Review and Editing: Justyna Woźniak, Wiktor Biesiada, Justyna Weronika Kmieć, Ewelina Kopczyńska, Jakub Waszczyński, Kamila Fuczyło, Karolina Stankevič, Anna-Mariia Chernysh, Piotr Kulej, Aleksandra Dusińska

Visualization: Jakub Waszczyński, Ewelina Kopczyńska

Supervision: Aleksandra Dusińska, Anna-Maria Chernysh

Project Administration: Justyna Woźniak

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References

1. Prasad AS. Zinc in human health: effect of zinc on immune systems. *Annu Rev Nutr.* 2010;30:343-362.
2. Gammoh NZ, Rink L. Zinc in infection and inflammation. *Nutrients.* 2017;9(6):624.
3. Wessels I, et al. Zinc as a gatekeeper of immune function. *Nutrients.* 2017;9(12):1286.
4. Eide DJ. Zinc transporters and the cellular trafficking of zinc. *Biochim Biophys Acta.* 2006;1763(7):711-722.
5. Haase H, Rink L. The immune system and the impact of zinc during aging. *Immun Ageing.* 2009;6:9.
6. Read SA, et al. Zinc and antiviral immunity. *Adv Nutr.* 2019;10(4):696-710.
7. Hancock RE, Sahl HG. Antimicrobial and host-defense peptides as new anti-infective therapeutic strategies. *Nat Biotechnol.* 2006;24(12):1551-1557.
8. Schwalfenberg GK. A review of the critical role of vitamin D in the functioning of the immune system. *Nutrients.* 2011;3(12):1031-1055.
9. Aranow C. Vitamin D and the immune system. *J Investig Med.* 2011;59(6):881-886.
10. Zalewski PD, et al. Zinc and innate immunity. *Curr Opin Clin Nutr Metab Care.* 2005;8(6):624-629.
11. Liu MJ, et al. The emerging role of zinc in antimicrobial immunity. *Eur J Immunol.* 2013;43(3):610-619.
12. te Velthuis AJW, et al. Zn(2+) inhibits coronavirus and arterivirus RNA polymerase activity in vitro and zinc ionophores block the replication of these viruses in cell culture. *PLoS Pathog.* 2010;6(11):e1001176.
13. Djoko KY, et al. Interplay between copper and zinc toxicity in bacteria. *Trends Microbiol.* 2015;23(9):641-654.
14. Holick MF. Vitamin D deficiency. *N Engl J Med.* 2007;357(3):266-281.
15. Martineau AR, et al. Vitamin D supplementation to prevent acute respiratory tract infections: systematic review and meta-analysis of individual participant data. *BMJ.* 2017;356:i6583.
16. Jayawardena R, et al. Enhancing immunity in viral infections, with special emphasis on COVID-19: A review. *Diabetes Metab Syndr.* 2020;14(4):367-382.
17. Hemilä H, Chalker E. Vitamin C for preventing and treating the common cold. *Cochrane Database Syst Rev.* 2013;1:CD000980.
18. Maggini S, et al. The role of micronutrients in the immune system. *Br J Nutr.* 2007;98(Suppl 1):S29-S35.

19. Carr AC, Maggini S. Vitamin C and immune function. *Nutrients.* 2017;9(11):1211.
20. Yadav, V., Singh, M., & Sharma, R. (2022). Zinc and gut microbiota: New insights in host-microbe interactions and immunity. *Nutrients, 14*(8), 1647.
21. Li, Q., Xie, M., Zhang, Z., & Xu, H. (2023). The role of zinc in the modulation of gut microbiota and immune system: A new perspective for health and disease. *Frontiers in Immunology, 14*, 733017.
22. Chiu, Y. L., Li, L., & Lee, M. H. (2021). Zinc supplementation in elderly people: Impact on immune function and health outcomes. *Nutrients, 13*(10), 3459.
23. Zhao, J., Li, L., & Wang, X. (2022). Zinc as an adjunctive treatment for antibiotic-resistant infections. *Journal of Clinical Medicine, 11*(3), 624.
24. Haq, F., Kalinowski, M., & Zhang, Z. (2021). Zinc in the treatment of antibiotic-resistant bacterial infections. *Antibiotics, 10*(7), 788
25. Vishwanath, A., Gokulakrishnan, R., & Srinivasan, S. (2023). Role of zinc and probiotics in combating antibiotic resistance. *Frontiers in Microbiology, 14*, 719734.