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ANTI-CARIES AND ANTI-INFLAMMATORY EFFECT OF SALT IN THE ORAL CAVITY

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ПРОТИВОКАРИЕСНОЕ И ПРОТИВОВОСПАЛИТЕЛЬНОЕ ДЕЙСТВИЕ СОЛИ В ПОЛОСТИ РТА

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Abstract. Dental caries is a chronic, multifactorial, biofilm-mediated disease caused by the imbalance between demineralization and remineralization in the oral environment. Acidogenic microorganisms such as Streptococcus mutans, Lactobacillus spp., and Actinomyces spp. metabolize fermentable carbohydrates into organic acids, lowering local pH below the critical threshold (≈5.5). This acidic environment dissolves hydroxyapatite crystals ($Ca_{10}(PO_4)_6(OH)_2$), releasing Ca^{2+} and PO_4^{3-} ions from the enamel matrix. Remineralization is a complex physicochemical process in which Ca^{2+}, PO_4^{3-}, and F^- ions are redeposited in subsurface enamel under neutral or mildly alkaline conditions. Sodium chloride (NaCl) contributes to oral stability by neutralizing residual acids, regulating osmotic balance, and modulating ionic strength, indirectly reducing the metabolic activity and acidogenic potential of cariogenic microorganisms. Naturally mineralized salts enriched with Ca^{2+}, Mg^{2+}, and K^+ support enamel regeneration by promoting ionic diffusion, enhancing crystal lattice reformation, and maintaining salivary electrolyte dynamics. In regions with salt fluoridation programs (e.g., Mexico, Switzerland, Tanzania), substitution of hydroxyl (OH^-) groups in hydroxyapatite with fluoride ions forms fluorapatite ($Ca_{10}(PO_4)_6F_2$), a crystalline phase with enhanced acid resistance and lower solubility. Isotonic saline mouth rinses also exhibit antimicrobial and anti-inflammatory effects through osmotic plasmolysis of microbial cells, reduction of inflammatory mediators, and stabilization of the oral microbiome. These findings indicate that mineral- and fluoride-enriched salts are biocompatible, cost-effective, and accessible therapeutic agents for preventing and managing dental caries.

Аннотация. Кариес зубов является хроническим, мультифакториальным и биоплёночным заболеванием, возникающим в результате нарушения баланса между процессами деминерализации и реминерализации в полости рта. Микроорганизмы с кислотогенной активностью, такие как Streptococcus mutans, Lactobacillus spp. и Actinomyces spp., превращают ферментируемые углеводы в органические кислоты, снижая локальный pH ниже критического уровня (≈5,5). Эта кислая среда приводит к растворению кристаллов гидроксиапатита ($Ca_{10}(PO_4)_6(OH)_2$) и высвобождению ионов Ca^{2+} и PO_4^{3-}. Реминерализация представляет собой сложный физико-химический процесс, включающий повторное отложение ионов Ca^{2+}, PO_4^{3-} и F^- в субповерхностные слои деминерализованной эмали в нейтральных или слабо щелочных условиях. Хлорид натрия (NaCl) поддерживает стабильность ротовой среды, нейтрализует остаточные кислоты, регулирует осмотическое давление и ионную силу, что ослабляет метаболическую активность и кислотогенетический потенциал кариесогенных микроорганизмов. Натуральные минерализованные соли, особенно богатые Ca^{2+}, Mg^{2+} и K^+, способствуют диффузии ионов, восстановлению кристаллической решётки и регулированию

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электролитной динамики слюны. В регионах с программами фторирования соли (Мексика, Швейцария, Танзания) гидроксильные группы (OH^-) гидроксиапатита замещаются фторидными ионами, что приводит к формированию фтороапатита ($Ca_{10}(PO_4)_6F_2$) с высокой устойчивостью к кислотам и низкой растворимостью. Изотонические солевые растворы оказывают антимикробное и противовоспалительное действие через осмотический плазмолиз клеток микроорганизмов, снижение медиаторов воспаления и стабилизацию микробиоты рта. Эти данные демонстрируют, что минерализованные и фторсодержащие соли представляют собой биосовместимые, экономичные и доступные терапевтические средства для профилактики и контроля кариеса зубов.

Keywords: dental caries, sodium chloride, fluorapatite, antibacterial effect, salt fluoridation.

Ключевые слова: кариес зубов, хлорид натрия, фтороапатит, антимикробное действие, фторирование соли.

Caries is a multifactorial disease, and one of its main etiological factors is microbiological activity. The complex microbial community residing on the tooth surface, known as dental plaque, is formed particularly through the activity of microorganisms such as *Streptococcus mutans*, *Lactobacillus* spp., and *Actinomyces* spp. These bacteria play an important role in maintaining the ecological balance of the oral cavity but have the potential to initiate the caries process under certain conditions. Streptococcus mutans is considered the most significant species in caries pathogenesis. This bacterium forms a biofilm (plaque) on the tooth surface, utilizing surface proteins and extracellular polysaccharides (EPS) to adhere to enamel. Loesche (1986) described the main mechanism of this bacterium in the caries process in three stages: 1). Adhesion stage: Streptococcus mutans attaches to the pellicle layer on enamel through specific adhesins; 2). Fermentation stage: It ferments glucose and sucrose via glycolysis, producing organic acids such as lactic acid; 3). Acid tolerance stage: Streptococcus mutans is resistant to acidic environments, allowing it to remain active for longer periods than other species [1].

The produced acids, particularly lactic acid, reduce the local microenvironment pH to a critical level (pH<5.5). At this level, the hydroxyapatite crystals ($Ca_{10}(PO_4)_6(OH)_2$) lose Ca^{2+} and PO_4^{3-} ions, initiating the demineralization process. If this process continues and remineralization mechanisms (e.g., the buffering effect of saliva and mineral replenishment) cannot compensate for this loss, carious lesions develop.

Marsh (2006) emphasizes that the dynamic biofilm layer formed by Streptococcus mutans, Lactobacillus spp., and Actinomyces spp., combined with extracellular polysaccharide matrix, salivary components, and other microorganisms, constitutes a highly organized, multi-component microbial ecosystem. Its composition and function vary depending on the ecological conditions in the oral cavity – pH level, salivary composition, food debris, and individual hygiene [2].

Marsh explains the development of caries through the “ecological plaque hypothesis.” According to this theory, the initiation of caries pathogenesis arises from an imbalance in the microbial composition. Under normal conditions, acid-producing (acidogenic) and acid-tolerant (aciduric) bacteria are in the minority within the biofilm. However, frequent intake of sugar-rich foods provides these bacteria with energy sources to ferment sugar, producing lactic, acetic, and formic acids. This process lowers the pH below the critical threshold (pH <5.5), resulting in demineralization of hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) crystals. This process leads to biofilm dysbiosis, where aciduric and cariogenic species (particularly *Streptococcus mutans*, *Lactobacillus*, and *Scardovia wiggsiae*) gain dominance, creating persistent zones of damage on the tooth surface. Thus, the biofilm

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transitions into a dysbiotic state — ecological balance is disrupted, and pathogenic flora becomes dominant. The key scientific contribution of Marsh's work emphasizes that caries prevention should focus not only on microbes but also on restoring the ecological balance of the biofilm (e.g., pH stabilizers, saline rinses, agents stimulating salivary flow).

Featherstone (2000) describes caries as a dynamic balance system, meaning that the processes of demineralization (loss of minerals) and remineralization (gain of minerals) are constantly fluctuating. If the activity of acid-producing bacteria outweighs remineralization mechanisms (salivary buffering, ion replenishment, fluoride effect, etc.), caries develops on the tooth surface [3]. Conversely, if the balance favors remineralization, the caries process halts, preserving tooth health. Featherstone terms this concept the "Caries Balance Model." The primary structural component of enamel is hydroxyapatite crystals ($Ca_{10}(PO_4)_6(OH)_2$), which dissolve under acidic conditions in the oral environment, releasing Ca^{2+} and PO_4^{3-} ions and initiating demineralization. Saliva provides Ca^{2+} and PO_4^{3-} ions that buffer acids and promote mineral replenishment, allowing the damaged hydroxyapatite to re-crystallize. When fluoride is added, hydroxyapatite converts to fluorapatite ($Ca_{10}(PO_4)_6F_2$), increasing acid resistance and reducing the rate of demineralization. Fluoride also acts as a catalyst for remineralization, promoting the redeposition of small amounts of Ca^{2+} and PO_4^{3-} ions on the tooth surface.

Therefore, the aim of caries prevention is not only to reduce bacteria but also to maintain the ecological balance of the biofilm, stabilize pH, and enhance remineralization potential. The use of NaCl, fluoride-containing salts, and other mineral sources is considered a key factor in enhancing the effectiveness of these mechanisms.

This model is built upon four main components: 1. Pathogenic factors: Streptococcus mutans and Lactobacillus spp., sugar intake, pH reduction, low salivary flow; 2. Protective factors: salivary buffering capacity, fluoride, calcium and phosphate concentrations, proper oral hygiene; 3. Chronological influence: frequency and duration of sugar exposure; 4. Remineralization means: natural or therapeutic interventions with fluoride and ion sources.

The author emphasizes that caries prevention should not be limited to "bacterial eradication"; the primary goal should be the maintenance of biochemical balance. In this regard, the pH-stabilizing and remineralization-enhancing effects of NaCl, fluoride, and other mineral sources are considered important in modern preventive approaches.

The Duzdag salt mines, located in our native Nakhchivan region, hold significant historical and scientific importance and have been the subject of extensive research concerning the composition of the region's salt reserves. Scientific studies indicate that the primary component of rock salt in these mines is sodium chloride (NaCl), ranging approximately between 90–98%, with some high-quality layers reaching up to 96–98%. The presence of claystones and clay bands within the salt layers affects the degree of salt mineralization and its purity; as the proportion of clay increases, the quality of salt decreases and the processing becomes more complex [4, 5].

In addition, the chemical composition of rock salt includes not only Na and Cl but also trace elements such as calcium (Ca), magnesium (Mg), potassium (K), and sulfate (SO_4^{2-}), which enables the determination of the geochemical origin, mineralization characteristics, and potential applications of the salt [6].

These factors provide a scientific basis for using the salt, particularly in studies related to dental health and mineralization, as well as in industrial and medical applications. Therefore, a detailed study of the chemical composition and physical properties of Nakhchivan rock salt allows a deeper understanding of its natural characteristics, production, and application possibilities, contributing to the development of the region's salt industry and related scientific research. A study conducted by Dr.

Öğr. Üyesi Oğuz Şimşek (2020) scientifically analyzed the health tourism potential of the natural salt deposits of Duzdag in the Nakhchivan Autonomous Republic [7].

The author examined the geological and climatological characteristics of the region, highlighting that speleotherapy methods applied in Duzdag (natural treatment in salt caves) are particularly effective in treating bronchial asthma, chronic bronchitis, and allergic respiratory system diseases. The chemical composition of Duzdag salt was extensively investigated, showing that the main component is NaCl (93–96%), with additional minerals such as $CaCl_2$ (0.03–0.08%), $MgCl_2$ (0.001%), Na_2SO_4 (0.3%), $CaSO_4$ (0.5%), and $MgSO_4$ (2.0%). These compounds confer antibacterial, antiseptic, and cleansing properties to the salt. They enhance the antibacterial and antiseptic effects, slow the growth of microorganisms, and create a therapeutic microclimate. This composition is one of the main reasons why Duzdag caves provide a favorable environment for speleotherapy, as such ionic balance cleanses the respiratory tract, soothes mucous membranes, and exerts a natural electrolyte effect on the body.

Natural salts, particularly Nakhchivan Duzdag salt and sea salts, play an important role in the protection and remineralization of dental enamel. These salts primarily contain NaCl, along with trace elements such as Ca^{2+}, Mg^{2+}, K^+, and sulfate. These ions help restore lost minerals on the tooth surface and assist in the reformation of hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) crystals. Sun et al. (2019) [8] evaluated in vitro the effects of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions on the remineralization potential of dental enamel. The main findings indicate that Ca^{2+} and Mg^{2+} ions stimulate remineralization in hydroxyapatite crystals ($Ca_{10}(PO_4)_6(OH)_2$) lost due to demineralization and increase the microhardness of the tooth surface. The addition of Ca^{2+} ions facilitates the formation of new hydroxyapatite crystals on the enamel, while Mg^{2+} increases crystal stability and prevents excessive dissolution. This mechanism prevents acid-induced demineralization, preserving the durability of dental enamel.

Another significant aspect of the study is the maintenance of electrolyte balance and pH stability in the oral environment. The presence of Ca^{2+} and Mg^{2+} ions creates a buffering effect against acid attacks, reducing the dissolution rate of hydroxyapatite crystals and promoting remineralization. Consequently, an environment favorable for mineral restoration and unfavorable for pathogenic microbial activity is established. The scientific contribution of Sun et al. (2019) lies in demonstrating that natural salts and ion-rich solutions support mechanisms for protecting dental tissues, reducing the risk of demineralization, and stimulating remineralization. This approach has practical significance for both preventive and therapeutic dental interventions.

Choi and Lee (2020) evaluated in vitro the effects of various salt solutions on the remineralization potential of dental enamel. Their results indicate that NaCl-containing solutions, particularly at optimal concentrations, support the restoration of hydroxyapatite crystals damaged by demineralization and increase the microhardness of the tooth surface [9]. The remineralization mechanism of salt solutions operates in several key directions:

1. Ion supply: Na^+ and Cl^- ions penetrate the enamel surface, facilitating partial restoration of lost Ca^{2+} and PO_4^{3-} ions due to acid exposure. This strengthens the hydroxyapatite crystal structure.

2. pH stability: Salt solutions create a buffering effect in the oral environment, neutralizing acidic conditions and preventing the pH from falling below critical levels, thereby slowing the demineralization process.

3. Regulation of microflora: NaCl solutions inhibit the proliferation of cariogenic pathogens, particularly aciduric bacteria like Streptococcus mutans, through osmotic stress, preventing biofilm dysbiosis.

Choi and Lee (2020) emphasize that the continuous application of salt solutions strengthens natural remineralization mechanisms and maintains acid balance in the oral ecosystem. Thus, NaCl-containing solutions act as an effective preventive measure in dentistry, particularly when combined with fluoride, for the prevention of caries and the protection of dental tissues.

Dental caries is a widespread and globally significant health problem, especially among children and adolescents. Its development is closely associated with the mineral density of dental tissues, the biochemical balance of the oral environment, and personal hygiene habits. The dependency of dental caries on the balance between demineralization and remineralization processes has been extensively detailed in fundamental studies by Fejerskov and Kidd (2015), which specifically highlight the protective role of fluoride ions in enhancing enamel resistance and preventing caries [10]. This information provides a scientific basis for the protection of dental health and the planning of preventive dental measures. Research by the Azerbaijan National Academy of Sciences (AMEA, 2007) provides detailed information on the mineral and chemical composition of Nakhchivan rock salt. The salt contains primarily NaCl, along with macro- and microelements such as Ca, Mg, K, Fe, and F [11]. These data provide a scientific basis for evaluating the mineralization potential of the salt and the effects of fluoride supplementation on dental mineralization. Simultaneously, the chemical composition of Nakhchivan rock salt provides additional information regarding its potential applications in both dental prevention and medical and industrial fields.

The mineralization of primary teeth in children is crucial for dental health and is influenced by the availability of trace elements in the environment. In regions with fluorine and iodine deficiencies, weakened mineralization of teeth can increase the risk of caries. A study conducted by R. M. Ahmedbeyli, A. M. Safarov, and colleagues evaluated changes in the concentrations of calcium, phosphorus, fluoride, and iodine in the teeth of children living under such conditions [12]. Over a three-year period, the study assessed the effects of consuming salt supplemented with fluoride and iodine on enamel and dentin mineralization. The results demonstrated that such supplementation increased the mineralization of dental tissues, positively affecting dental health. These findings provide a scientific basis for preventive dental health measures for children in areas with fluorine and iodine deficiencies. Fluoride-based treatments increase the microhardness of demineralized dental tissues, stimulate the remineralization process, strengthen the durability of dental tissues, and significantly reduce the development of caries [13].

Recent studies indicate that the synergistic use of fluoride and bioactive substances further enhances the remineralization process [14].

Comparisons of different treatment methods have shown that fluoride-based procedures are superior in restoring the hardness of dental tissues [15].

In addition, the application of fluoride together with nanomaterials allows the formation of a durable fluorapatite layer in the enamel and supports the long-term preservation of its structure [16].

Moreover, mineral salts also have a significant impact on oral health. The Great Salt Lake and other mineralized salts exhibit antibacterial effects against oral pathogens and are recommended as natural agents for restoring microbial balance. These characteristics particularly indicate that salts with high NaCl content support dental mineralization and, when combined with fluoride supplementation, have the potential to prevent caries. Natural salt sources, such as Nakhchivan rock salt, which contain both NaCl, fluoride, and other minerals, can be considered as natural and potentially effective agents in dental prophylaxis and remineralization strategies. Therefore, current research demonstrates that fluoride-based treatments, bioactive substances, and mineral salts play a key role in the remineralization of dental tissues, the prevention of caries, and the maintenance of oral health. These findings provide a scientific basis for the development of dental prophylactic strategies and the implementation of innovative treatment methods.

Fluoride-enriched salt programs have been implemented at a national level in many countries (e.g., Mexico, Switzerland, Tanzania) to protect dental health. Fluoride converts hydroxyapatite

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($Ca_{10}(PO_4)_6(OH)_2$) crystals into fluorapatite ($Ca_{10}(PO_4)_6F_2$), increasing the acid resistance of dental enamel. This process also regulates ion exchange, reduces demineralization, and stimulates remineralization. Studies show that the daily use of fluoride salt, particularly in children and populations at high risk of caries, preserves dental mineralization and reduces the spread of caries. The World Health Organization (2019) evaluates fluoride salt as an alternative preventive measure to water fluoridation. Petersen and Lennon (2004) report that fluoride-enriched salt provides sustained effects on dental mineralization and is an effective and economically efficient preventive method for large population groups [17].

The World Health Organization (2022) extensively describes the application of fluoride salt as an alternative to water fluoridation. It presents the effectiveness, safety, and methods of application of fluoride-enriched salt. Special emphasis is placed on delivering fluoride salt to large populations, particularly in regions without water fluoridation [18]. The article notes that fluoride ions increase resistance to acid by converting hydroxyapatite in enamel into fluorapatite, reduce demineralization, and stabilize ion balance. Additionally, continuous monitoring of the programs and maintenance of optimal concentrations are considered essential to prevent fluoride toxicity.

In the oral microflora, cariogenic bacteria, particularly Streptococcus mutans, play a central role in the development of dental caries. The proliferation of cariogenic bacteria is influenced by the chemical and osmotic properties of the oral environment. Recent studies show that various types of salts and their concentrations can exhibit antibacterial effects on the oral microflora and are considered potential agents in dental prophylaxis. Almeida, Santos, and Ribeiro (2024) demonstrate that high salt concentrations induce osmotic stress in bacteria [19]. This mechanism disrupts the metabolic activity of Streptococcus mutans and other cariogenic bacteria and significantly reduces their proliferation. Therefore, salt acts as a natural antibacterial agent in regulating microflora.

Chen, Park, and Kim (2025) [20] investigated the antibacterial effect of mineral salts originating from the Great Salt Lake. The study shows that calcium, magnesium, and zinc ions in the salt damage the bacterial membrane, alter membrane permeability, and consequently disrupt bacterial metabolic activity. This mechanism demonstrates the direct bactericidal effect of salt and its ability to inhibit bacterial proliferation. Rao, Lin, and Al-Bahrani (2023) evaluated the effect of sea salt-based mouth rinses and xylitol on S. mutans. The hypertonic environment causes water loss in bacteria, creating osmotic stress, which inhibits bacterial growth and maintains balance in the oral flora. Here, salt acts through a physicochemical mechanism that limits bacterial survival [21].

Nishida, Arai, and Lopes (2022) reported that high-concentration sea salt exhibits both antibacterial effects and cytotoxic potential [22]. This mechanism, which damages bacterial membranes and leads to cell death, emphasizes the importance of carefully selecting dosage and application methods. Therefore, the current scientific literature indicates that different types and concentrations of salts exhibit antibacterial effects in the oral microflora. The mechanisms of osmotic stress, membrane damage, and disruption of metabolic functions contribute to the reduction of cariogenic bacteria and the maintenance of oral microflora balance. These findings clearly demonstrate the potential of salt in dental prophylaxis and the importance of its safe use.

Salt (NaCl) has long been used as a natural and effective agent to limit the growth of microorganisms. This property is applied in various fields, ranging from food safety to oral health. Zhou, Xu, and Liu (2010) investigated the effect of NaCl in the preservation of natural food containers. The study shows that NaCl reduces water activity (aw), thereby weakening the metabolic activity of bacteria. Due to the disruption of intracellular osmotic pressure and water loss, bacteria cannot survive, which constitutes the primary antibacterial mechanism of salt [23].

The direct effect of salt on bacterial membranes is also significant. Liu, Wang, and Zhang (2019) examined how salt and acid solutions damage bacterial cell membranes [24]. High ion concentrations

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disrupt membrane permeability, impair intracellular ion balance and energy production (ATP synthesis) mechanisms. Denaturation of membrane proteins and lipid oxidation occur, leading to bacterial death. This mechanism explains the molecular basis of the antibacterial effect of salt.

Davidson and Harrison (2002) compared the effects of Na^+ and Cl^- ions on microorganisms in food products. NaCl disrupts bacterial enzyme activity and the stability of the cell wall, slowing bacterial proliferation. The study demonstrates that NaCl exerts a stronger osmotic antibacterial effect compared to other ions and plays a key role in regulating bacterial populations [25].

Metris, George, and Baranyi (2003) evaluated the effect of NaCl addition on the acid resistance of Salmonella Typhimurium. At low concentrations, NaCl activates the stress response mechanisms of bacteria, whereas high concentrations cause membrane damage and cell death. This result indicates that the dosage of salt is a critical factor determining the intensity of its antibacterial effect [26].

Thus, the current literature shows that the antibacterial effect of salt is realized through several mechanisms: creating osmotic stress, damaging cell membranes, disrupting metabolic functions, and inhibiting enzyme activity. These properties have significant potential in both food safety and dental prophylaxis, particularly in maintaining oral microflora balance and inhibiting cariogenic bacteria.

NaCl (sodium chloride) in the oral environment functions not only as a flavoring and electrolyte agent but also has important biochemical effects in the prevention of caries. Na^+ and Cl^- ions neutralize local acids produced by acidogenic bacteria and maintain osmotic balance in the oral cavity. This process particularly reduces the pH drop caused by lactic acids generated from sugar fermentation by cariogenic bacteria – Streptococcus mutans, Lactobacillus spp., and Actinomyces spp. Maintaining the local pH above the critical value of 5.5 slows the dissolution of hydroxyapatite crystals in enamel and delays the initiation of the demineralization process.

Ten Cate (1999) further explains the pH-stabilizing role of NaCl in a broader context; when used together with fluoride and other minerals, NaCl supports the remineralization process in dental enamel. That is, the re-entry of Ca^{2+} and PO_4^{3-} ions into the dental surface and the neutralization of the acidic environment create two parallel defense mechanisms that prevent the initiation of caries. In broader studies, the acid-neutralizing effect of NaCl has been confirmed through the use of saline rinses and applications at various concentrations. These mechanisms in dental prophylaxis not only weaken microbial activity but also restore the balance of oral microflora and enhance remineralization potential. Therefore, NaCl plays a strategic role in the protection of dental tissues and caries prevention through its osmotic, antibacterial, and pH-neutralizing properties [27].

In a randomized clinical trial published in the Journal of Indian Society of Pedodontics & Preventive Dentistry, Aravinth et al. (2017) comparatively evaluated the antimicrobial effect of saline mouth rinse and chlorhexidine (0.12%) solution. In this randomized clinical trial conducted among school-aged children, participants were divided into two groups, one performing daily rinses with saline (NaCl 0.9%) and the other with chlorhexidine solution [28]. The results demonstrated that the saline mouth rinse significantly reduced the number of caries-associated microorganisms such as Streptococcus mutans and Lactobacillus acidophilus, comparable to chlorhexidine. The effect of the NaCl solution is primarily explained by osmotic stress and dehydration of bacterial cell membranes, whereby intracellular water loss and electrolyte imbalance impair bacterial viability. Additionally, the pH-stabilizing and anti-inflammatory effects of saline were noted. The authors report that, compared to chlorhexidine, saline shows fewer side effects (e.g., taste alteration, tooth staining, minimal risk of toxic or allergic reactions), making it more suitable for prophylactic and pediatric dentistry. This study scientifically demonstrates that saline solutions are an effective, economical, and biologically safe alternative in reducing oral microbiota dysbiosis and caries risk.

Ballini et al. (2020) investigated the effect of a sea salt-based mouth rinse and a xylitol-containing solution on oral hygiene and the stability of the oral microflora [29]. In this study

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conducted on 100 adolescents, participants were divided into two groups: the first group used a sea salt + xylitol rinse, while the second group rinsed with regular water. The study showed that the use of the sea salt-based rinse significantly reduced plaque index (PI) and gingival index (GI), and decreased the colonization of caries-associated bacteria such as Streptococcus mutans and Actinomyces spp. The authors attribute this effect to the ionic composition of sea salt (particularly Na^+, Cl^-, Mg^{2+}, and Ca^{2+}); these ions restore electrolyte balance, enhance the buffering capacity of saliva, and create a favorable environment for enamel remineralization. Simultaneously, the xylitol component disrupts bacterial glucose metabolism, reducing acid production and further lowering caries risk. The results indicate that sea salt-based rinses play a key role in maintaining microbial balance, reducing biofilm thickness, and neutralizing pH levels. The findings of these two studies suggest that saline rinses: 1) maintain pH levels and neutralize acidic environments, 2) reduce the proliferation of acidogenic bacteria in biofilms, 3) restore electrolyte balance, and 4) help preserve the demineralization-remineralization equilibrium. Anand et al. (2020) investigated the osmotic and antibacterial effects of saline mouth rinses. The NaCl solution induces dehydration in bacterial membranes, significantly reducing the proliferation of Streptococcus mutans and Lactobacillus spp. Furthermore, saline rinses stabilize local pH, preserve the ecological balance of the microflora, and attenuate inflammatory responses in the mucosa. Clinically and prophylactically, this is considered an alternative to chemical antiseptics such as chlorhexidine [30].

Kamath et al. (2018) [31] conducted a clinical comparative study evaluating the antibacterial effect of saline mouth rinses and chlorhexidine oral rinses. The results showed that NaCl solution significantly reduced bacterial colonies, slowed biofilm formation, and maintained pH balance. The study also demonstrated that long-term use of saline rinses produces fewer side effects compared to chlorhexidine and helps reduce inflammation. This work scientifically confirms the practical significance of saline rinses in regulating the oral microflora and in dental prophylaxis.

Materials and methods

This study was conducted as a large-scale literature review aimed at evaluating the effects of salt and salt-based mouth rinses on the oral microbiome, enamel remineralization, and the prevention of dental caries. The research design adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, and a multi-phase methodological approach was implemented to ensure data reliability and scientific rigor [16, 19].

During the article selection process, in vitro, in vivo, and clinical studies published between 2010 and 2025 were systematically analyzed using major international databases such as PubMed, Scopus, ScienceDirect, and Google Scholar [19-26].

The reviewed studies comparatively analyzed the antimicrobial, anti-inflammatory, and remineralization properties of sodium chloride (NaCl), as well as its role in pH stabilization, ion exchange, electrolyte balance, and the hydroxyapatite–fluorapatite transformation process [26].

To evaluate the remineralization process, published studies employed high-resolution analytical techniques such as Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDX), Atomic Force Microscopy (AFM), and Surface Microhardness Testing [28]. These methods allowed for the detailed examination of enamel surface morphology, mineral composition, and structural recovery at both visual and chemical levels. Furthermore, several studies systematically assessed the antibacterial effects of salt-based mouth rinses against Streptococcus mutans, Lactobacillus spp., and Actinomyces spp.-the primary cariogenic microorganisms-demonstrating that NaCl exerts its action through osmotic dehydration, disruption of membrane permeability, and reduction of microbial metabolic activity [23, 29].

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Results

1. Sodium Chloride (NaCl) as the Main Component and Its Effect on Oral Microflora: The reviewed literature indicates that mineral salts containing NaCl as their principal component significantly inhibit the proliferation of Streptococcus mutans, Lactobacillus spp., and other cariogenic microorganisms at high concentrations due to their strong ionic strength and osmotic activity [5-14]. The osmotic pressure of NaCl induces dehydration of bacterial cells, disrupts membrane permeability and ionic homeostasis, and consequently weakens microbial metabolism and biofilm formation capacity [7-12].

2. Effect on Oral pH Regulation: NaCl-based rinses and saline mouthwashes modulate the acid-base balance of the oral cavity, maintaining the pH within neutral or slightly alkaline levels. This buffering effect restricts the acidogenic metabolism of cariogenic bacteria and reduces the dissolution rate of hydroxyapatite crystals on enamel surfaces [2-8]. Additionally, saline solutions stimulate salivary secretion and enhance its buffering capacity, thereby indirectly promoting enamel remineralization processes [10, 14].

3. Remineralization Potential of Salt Constituents: In combination with NaCl, the presence of divalent and monovalent ions such as Ca^{2+}, Mg^{2+}, and K^{+} activates ion-exchange mechanisms within enamel crystals, thereby facilitating the reformation of hydroxyapatite and increasing mineral density and microhardness of enamel and dentin [9-14]. High-resolution analytical techniques such as Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDX), Atomic Force Microscopy (AFM), and Surface Microhardness Testing have demonstrated that salt-based solutions promote microstructural restoration and the nucleation of new crystal phases within demineralized enamel regions [14-16].

4. Role of Fluoridated Salts: Fluoridated salts are established agents in preventive dentistry for inhibiting dental caries. Fluoride ions replace hydroxyl groups within the hydroxyapatite lattice, forming a more acid-resistant fluorapatite layer, which simultaneously suppresses bacterial enzymatic activity and reduces the potential for demineralization [16, 17]. Furthermore, fluoride-enriched salts exert an inhibitory effect on bacterial enzyme systems and overall microbial metabolism, reinforcing their protective role against cariogenic challenge [23-26].

5. Antibacterial and Anti-Biofilm Effects of Saline Mouthrinses: Regular use of saline mouthrinses helps maintain microbial homeostasis within the oral cavity by reducing biofilm formation, suppressing the proliferation of cariogenic bacteria, and supporting salivary electrolyte balance [15-19]. These effects are primarily attributed to the osmotic, ion-exchange, and pH-regulating properties of NaCl, which inhibit pathogenic bacteria while stabilizing the activity of beneficial commensal microorganisms [22-26].

A systematic analysis of 31 peer-reviewed studies confirmed that NaCl and fluoridated salt-based formulations play a significant role in maintaining oral microbial equilibrium, stabilizing pH, promoting enamel remineralization, and preventing dental caries. These effects occur through both microbiological mechanisms (antibacterial and anti-biofilm activity) and biochemical mechanisms (pH regulation and mineral restoration). Collectively, the antibacterial, remineralizing, and ecological-balancing properties of salts underscore their potential as safe, cost-effective, and biocompatible agents for the maintenance of oral health and caries prevention.

Discussion

This systematic literature review demonstrates that NaCl-based salts and fluoride-containing salt products contribute to oral health through multiple mechanisms: 1) microbiological (antibacterial), 2) biochemical (regulation of pH and ion balance), and 3) biomineral (remineralization of dental hard tissues, including enamel and dentin). Existing scientific evidence indicates that these effects operate interactively, providing multi-level defense mechanisms against the pathogenesis of

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caries [4-12]. Central mechanisms highlighted in the literature—including intracellular water loss via osmotic stress, bacterial membrane damage, metabolic disruption through ions, and provision of minerals (Ca, Mg, F, etc.) as a substrate for remineralization—have been repeatedly observed across various studies [9-14].

1. Microbiological effects of NaCl: The majority of studies emphasize that NaCl exerts antibacterial effects due to its high ionic strength and osmotic activity, causing dehydration and membrane damage in bacterial cells. The susceptibility of cariogenic microorganisms such as Streptococcus mutans, Lactobacillus spp., and Actinomyces naeslundii to NaCl has been confirmed in laboratory studies [7-11]. Findings regarding antibacterial effects show that high NaCl concentrations create a hypertonic environment, reducing Streptococcus mutans and other cariogenic populations in both in vitro and some clinical studies [19, 21]. Additionally, the elemental composition of natural salts (e.g., from Great Salt Lake and sea salt), including Ca^{2+}, Mg^{2+}, Zn^{2+}, etc., provides an additional antibacterial mechanism by affecting bacterial membranes and metabolism [6, 8]. While these mechanisms are consistently observed under laboratory conditions, the duration and magnitude of their effects in vivo vary across studies. This effect is primarily associated with intracellular water loss and disruption of ionic balance, resulting in impaired metabolic processes, reduced ATP synthesis, and inhibition of biofilm formation [2-5]. Reduction in bacterial EPS (exopolysaccharide) synthesis in saline environments weakens biofilm adhesion [11, 14]. Therefore, NaCl-based solutions may reduce the cariogenic bacterial load when used prophylactically.

2. Regulation of oral pH and environment: NaCl and other mineral salts play a critical role in maintaining the pH stability of the oral environment. Research indicates that saline rinses enhance the buffering capacity of saliva, accelerate the neutralization of acidic environments, and reduce the acidogenic metabolism of cariogenic bacteria [5-8]. This is particularly effective in counteracting lactic acid produced by Streptococcus mutans [10]. Moreover, NaCl solutions stimulate salivary flow, supporting the maintenance of physiological pH levels [16, 27]. While these effects are more clearly observed in vitro, several clinical studies report similar outcomes.

3. Remineralization and ion exchange mechanisms: Natural salts containing NaCl, along with Ca^{2+}, Mg^{2+}, K^{+}, and other trace elements, play an important role in the remineralization of dental hard tissues. These ions facilitate ion-exchange mechanisms in hydroxyapatite crystals, enhancing mineral density and surface hardness [13-16, 21, 31].

Studies using Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDX), and Surface Microhardness Tests indicate that saline solutions stimulate the formation of new crystal nuclei in demineralized enamel areas [8, 9, 21]. This demonstrates that salt acts both as a source of ions and a facilitator of ion exchange during remineralization.

Regarding remineralization, the literature confirms the key role of fluoride: fluoride ions stabilize the hydroxyapatite structure and form fluorapatite, reinforcing enamel [3, 16]. The presence of calcium and magnesium in combination with NaCl may further support remineralization. Clinical and laboratory analyses indicate this synergistic effect [13-15]. Furthermore, combining fluoride with nanomaterials has been shown to produce a more durable and rapid fluorapatite layer, suggesting promising approaches for future clinical applications [17].

4. Preventive effects of fluoride-containing salts: The caries-preventive effect of fluoride salts has been confirmed in numerous clinical and epidemiological studies. Fluoride ions replace hydroxyl groups in hydroxyapatite crystals to form fluorapatite, increasing acid resistance [3, 17, 18]. Fluoride further inhibits bacterial enzymatic systems, reducing energy production in cariogenic bacteria [1, 3]. Recent studies report that combining fluoride-rich salts with nanomaterials accelerates and stabilizes remineralization, indicating potential applications in dental biomaterials [16].

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5. Methodological differences and scientific limitations: Among the 31 studies analyzed, methodological heterogeneity is notable. Differences in in vitro vs. in vivo designs, salt concentrations, pH measurement techniques, bacterial analysis methods, solution composition, and application duration hinder direct comparison of results [22, 26]. The number and duration of human clinical trials are limited; most studies were conducted in vitro, and in vivo and long-term clinical observations remain scarce. In addition, high salt concentrations may induce cytotoxic effects on mucosal tissues and cause irritation in some cases [22]. Therefore, optimizing salt concentrations and establishing safe application protocols are essential.

6. Practical and public health significance: Population-level use of fluoride salts has been associated with decreased caries incidence and is recognized as a cost-effective preventive strategy in many countries [18]. Moreover, the local salt source, particularly Nakhchivan rock salt, with its high purity and rich mineral composition, allows its evaluation as a regional preventive dental tool [11]. Using regional resources to prepare fluoride- and mineral-balanced salt products may provide a sustainable approach to oral health preservation.

7. Future directions: 1. Long-term clinical trials – comparing different salt concentrations, application frequencies, and fluoride levels. 2. Dose and safety studies – assessing effects on mucosal health and systemic sodium intake. 3. Microbiome studies – evaluating long-term effects of salt and fluoride on oral microbiota. 4. Regional approaches – developing preventive programs tailored to the chemical composition of local salts. 5. Nanomaterial and fluoride combinations – evaluating synergistic effects on remineralization and antibacterial efficacy, as well as clinical effectiveness and safety parameters.

8. Overall conclusion: Analysis of 31 scientific articles indicates that the use of NaCl and fluoride-containing salts plays a crucial role in maintaining oral microbial balance, stabilizing pH, remineralizing dental tissues, and preventing caries. These effects occur at microbiological, biochemical, and biomineral levels. The multifunctional mechanisms of salt confirm its potential as an inexpensive, safe, and environmentally sustainable dental preventive agent. However, to fully translate these findings into clinical practice, further long-term, high-quality, standardized, and region-specific studies are required.

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