According to Dadamio et al. [1], every fourth person has a problem with persistent breath odor. In most cases, the origin of this condition is hidden in the oral cavity, or to be more precise, on the surface of the tongue, which is a reservoir of halitogenic bacteria. Zürcher et al. [2] define halitosis as an increased and unpleasant, offensive breath, regardless of the reason. Just as in the case of the prevention or treatment of caries or periodontal disease, the basis for any action in regard to halitosis is elimination of bacteria responsible for all three problems. Mechanical dispatching of bacteria, by means of brushing teeth, flossing and tongue hygiene, never allows for a complete elimination of the pathogenic microorganisms [3–5]. Hence, chemical compounds of antimicrobial activity are used as an adjunctive measure. In the case of halitosis, these molecules can also bind to the volatile sulphur compounds released as a result of bacterial metabolism, including hydrogen sulphide, thioles (formerly called mercaptanes), dimethyl sulphide [6, 7], and other chemical compounds responsible for foul breath. An example of such molecule of a multi-directional activity...
is stannous fluoride (SnF₂). The dyad stannous ions, when reacting with salivary anions, such as PO₄³⁻ and CO₃²⁻, form barely soluble salts. These salts precipitate on the surface of exposed dentin, decreasing its hypersensitivity by forming kind of protective layer, securing it from the effects of irritating factors of both chemical and mechanical nature [8, 9]. A similar protective layer forms on the enamel surface while brushing teeth with the use of a toothpaste containing stannous fluoride, as the anions, bound by tin, form insoluble salts, serving as an inorganic matrix. The ability to chelate stannous ions using organic ligands has equipped the stannous-organic complexes with ease of penetrating into the bacteria responsible for periodontal disease and halitosis. Once inside, they block bacterial metabolism, for example at the level of biochemical red-ox systems.

The Mechanisms of the Antibacterial Activity of Sn²⁺ Ions Employed in Halitosis Treatment

Stannous ions act as a bactericidal, but also inhibit the formation of bacterial biofilm [10]. Both mechanisms can suppress halitosis symptoms. The earliest research on the antibacterial activity of stannous ions and their use in dentistry comes from the 1970s. Initially the studies, led in vivo [11] and in vitro [12], compared the stannous fluoride to previously-used sodium fluoride. The researchers described the much higher antibacterial activity of stannous fluoride. The preponderance of SnF₂ as compared to sodium fluoride in relation to the decrease of gingival index (GI) has also been reported by Niedermann [13] in his literature review. Initially the studies focused on a bacterial strain of Streptococcus mutans, due to the expected anti-caries effect. Gradually they were extended to include the effectiveness of stannous ions in the prevention and treatment of periodontal diseases and halitosis. The new formula introduced to toothpastes, combining stannous fluoride with sodium hexametaphosphate, has initiated new research on the efficiency of this combination. The studies conducted have proven [14]: 1. the high antibacterial activity, leading to the death of 90–99% of salivary bacteria 16 hours after exposure; 2. the inhibition of the biofilm forming rate as well as decreased acid production in glycolytic processes, as compared to the standard toothpaste, based on sodium fluoride (as assessed after 15 and 45 minutes); 3. the high rate of tin infiltration into the bacterial cells and the long-lasting maintenance of an increased concentration of soluble stannous ions, exceeding the minimal level to inhibit bacterial metabolic activity even 12 hours after exposure.

Studies on the Effectiveness of Stannous Ions (Sn²⁺) in Halitosis

Donovan-Brand [15] has compared the effectiveness of stannous ions in halitosis treatment to triclosan and essential oils, finding stannous ions to be more effective. Parallel usage of toothpaste and mouthwash enriched with stannous ions has also led to significant plaque index reduction, while toothpaste alone did not exhibit such the activity. Feng et al. [16] have published a meta-analysis of four studies, comparing the effectiveness of toothpaste containing stannous fluoride (0.454% SnF₂) to sodium fluoride based toothpaste (negative control), in regard to the decrease of the level of volatile sulphur compounds (VSC). The inclusion criteria included baseline VSC level above 100 ppb. Altogether, the meta-analysis involved 100 patients.

All the studies were conducted according to the crossover design, with 2 therapeutic regimens applied in 3 or 4 cycles and at least 2 days of wash-out period between them. The patients brushed their teeth with the toothpastes assigned, using soft manual toothbrushes, supervised by the researchers. During the study, the patients desisted flossing and tongue cleaning.

Every cycle included four halimeter measurements: the first two measurements took place in the morning of the first day: before toothbrushing and 3–4 hours after toothbrushing for two minutes. In the evening of the same day, patients brushed their teeth again using the assigned toothpaste for 2 minutes, without supervision. The next two halimeter measurements were conducted on the following day: in the morning, before brushing (24 hours from the beginning of the cycle, “morning breath”) and after the third brushing (27–28 hours from the beginning). On the basis of the studies conducted, the authors reported that SnF₂ is significantly more effective in VSC level reduction at all the timepoints (p < 0.047). The difference between groups increased with every brushing (24.5% in the fourth measurement). Another study analyzed the efficacy of aminofluoride (AmF) with SnF₂ in 7-day periods. The patients were subjected to professional cleaning. After the procedure, they rinsed only, without toothbrushing, for 7 days. Three differ-
ent formulas were used: 1. chlorhexidine in an alcohol solution (CHX-Alc); 2. chlorhexidine + cetylpyridinium + zinc lactate; 3. AmF/SnF₂ (mouth rinse or toothpaste slurry). VSC levels were assessed in the morning on days 0, 3 and 7. On the basis of this study, the authors described a significant decrease of microorganisms level in the saliva and on the tongue surface as well as a decrease in VSC level in all the groups, despite the lack of toothbrushing. Blom et al. [17] performed a systematic literature review, analyzing the efficiency of mouth rinses in malodor reduction. The endpoints chosen by the authors included a volatile sulphur compound assessment and organoleptic evaluation as well as tongue coat quantity. 12 papers, based on the clinical trials satisfying these criteria, were found. The studies included were divided into short-term (below 3 weeks) and long-term observations (3 weeks and more).

On the basis of the literature review, the authors stated that nearly all of the active solutions exerted a positive effect on the reduction of oral malodor, both in short-term and in long-term observations. The most studied compound, with the best quality of evidence, was chlorhexidine. The best efficiency profile in relation to halitosis was exhibited by the combination of cetylpyridinium chloride and chlorhexidine. None of the studies has proven a positive effect on tongue coating.

**Sn²⁺ Ions in Oral Hygiene Products**

Due to the *in vitro* and *in vivo* studies as well as the clinical confirmation of stannous fluoride efficiency, this compound has become a common ingredient in oral hygiene products. This refers both to the everyday use, preventive products and to those dedicated to specific oral problems. Tin compounds can be found in toothpastes and mouth rinses. The toothpastes available on the market contain stabilized stannous fluoride or stannous fluoride in conjunction with sodium hexametaphosphate (HMP), which are meant especially to prevent and treat halitosis. There are also other toothpastes, containing the complex ingredient AmF/SnF₂, that exhibit antibacterial properties, inhibiting the metabolism of the anaerobic G(−) bacteria responsible for halitosis. Metal ions, such as Zn²⁺ and Sn²⁺, exhibiting an affinity to sulphur, form insoluble metal sulphides, neutralizing VSC and inactivating thiole-dependent enzymes. The addition of OMC compounds (neutralizing oral malodor) prevents VSC release by inhibiting enzymatic reactions, converting amino acids into VSC.

Many papers, based on the comparative studies of different formulations, can be found in the literature. Some of these formulations were commercially available oral hygiene products, others were experimental formulas. For example, a mouth rinse containing chlorhexidine and cetylpyridinium chloride was compared to a mouth rinse based on stannous fluoride [18]. The aim of another study was to assess the influence of commercially available oral hygiene products (containing NaF, SnF₂ + HMP and triclosan with copolymer) on the microbial activity of oral bacteria [19]. In the first case, the authors achieved a significantly higher efficiency of chlorhexidine with cetylpyridinium chloride in oral malodor reduction, while in the second one a similar observation was made in regard to triclosan with copolymer. At this point we should mention the fact that long-term use of chlorhexidine not only leads to discolorations of the teeth and restorations, but also to bacterial resistance. On the other hand, triclosan degradation can lead to dioxin production and environment pollution. That is why this compound has been listed on the hazardous chemicals list. The counter-argument to the above-mentioned reports is recent, short-term *in vivo* research, led by Wigger-Alberti et al. [20], who have investigated the effect of mouth rinses with active ingredients (see below) on the decrease in OR and VSC. The authors have used following formulas: I – containing SnF₂ with zinc lactate, II – containing chlorhexidine with cetylpyridinium chloride, III – containing chlorhexidine and IV – containing water. No statistically significant differences were found between the efficiency of solutions I to III. Yet the SnF₂-containing formula was found to cause fewer side effects as compared to chlorhexidine. Given the comparable efficiency, this observation is in favor of mouth rinses containing SnF₂.

**Summary**

The literature review shows that regular use of a stannous fluoride toothpaste significantly increases the efficiency of halitosis prevention and treatment, due to the long-lasting high tin bioavailability. It appears that the combination of stannous fluoride, sodium hexametaphosphate and stannous chloride exhibits a higher efficiency in halitosis treatment, as compared to other ingredients used in the form of toothpastes. This effect results from the bactericidal activity, the ability to disturb bacterial metabolism, the inhibition of biofilm formation and the chemical neutralization of unpleasant-smelling compounds.
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