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Whitening Efficacy of Chewing Gum Containing Sodium Metaphosphate on Coffee Stain: Placebo-controlled, Double-blind *In Situ* Examination

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Clinical Relevance

Chewing gum containing sodium metaphosphate is useful for whitening after eating colored food.

SUMMARY

This study aimed to evaluate the ability of chewing gum containing sodium metaphosphate (SMP) to remove coffee stains from enamel *in situ*. This was a double-blind (subjects, evaluators), parallel-group, crossover, randomized clinical trial with 30 healthy adult volunteers. Each participant held an appliance with a hydroxyapatite (HA) pellet on the lower lingual side of his or her mouth for two hours to allow pellicle formation. The appliances were subsequently immersed in coffee solution at 37°C for 48 hours. The color of the HA pellet before and after coffee immersion was measured using a spectrophotometer. The participant set the appliance and chewed two pieces of test gum, which contained 7.5 mg of SMP per piece, or control gum without SMP. Each cycle included five minutes of exposure to chewing

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gum, after which the appliances were placed in 100% relative humidity at room temperature for a 30-minute incubation. This cycle was repeated five times for each gum type. The color of the HA pellet was measured after each chewing cycle using the spectrophotometer. In addition, ΔE* values, which indicate the change in pellet color after each chewing cycle compared with after coffee immersion, were calculated. Data were analyzed using the paired *t*-test with Bonferroni adjustment to compare ΔE* values of control and test gum after each chewing cycle. The ΔE* values of test gum were significantly higher than those of control gum after all chewing cycles, excluding the first cycle ($p<0.05$). This finding indicates that test gum containing SMP was more effective at removing coffee stains from the HA pellet than control gum. We conclude that chewing gum containing SMP can effectively remove coffee stains from HA pellets. Thus, SMP is a promising agent to be further explored in tooth-cleaning studies.

INTRODUCTION

The teeth are always seen during conversation, and a smile furnished with a set of beautiful, white teeth positively adds to a person's overall appearance. The formation and accumulation of dental stains have become some of the most important esthetic problems for many patients. Therefore, bleaching, stain removal, or other therapies that whiten the teeth are crucial concerns. The deposition of a coloring substance from coffee, red wine, smoking, and some foods and drinks onto the dental pellicle corresponds to an extrinsic dental stain. It can be difficult to avoid such staining, even when maintaining good oral hygiene. Therefore, both physical and chemical methods to remove the stain are often needed to improve such situations.[1]

Hydrogen peroxide and urea peroxide have been commonly used in professional tooth bleaching.[2,3] However, they are associated with adverse side effects or complications.[4-6] As peroxides are known to damage the teeth and cause hyperesthesia at high concentrations, they have not been approved for home use or as an addition to dentifrices by the Japanese Ministry of Health, Labour, and Welfare from a safety viewpoint.

In contrast, condensed phosphate, which is used as a component of many dentifrices and a food additive, has been shown to safely exert a whitening effect on the tooth.[7] Sodium metaphosphate (SMP) has a number of uses. It is commonly applied as a food additive owing to its water-retentive, buffering, and washing actions. It is also used in cosmetics and as a quasi-drug in medicine to maintain the blood concentration of antibiotics. Recent studies reported that SMP can prevent periodontal disease and caries and enhance bone formation.[8-13] SMP has a potential high affinity for hydroxyapatite (HA) and may exhibit stronger binding to the tooth than a stain. Thus, it is considered that SMP competes with the stain to bind to HA, and the stain is removed from the tooth during this process. Since chewing gum is well accepted by both adults and children and can be frequently used with ease, SMP-containing chewing gum may aid in removing dental stains.

Therefore, the purpose of this study was to evaluate the efficacy of a chewing gum containing SMP in removing coffee stains from HA pellets in a double-blind *in situ* clinical trial. The null hypothesis tested was that there is no difference in the ability to remove coffee stains between gum containing SMP and control gum without SMP.

METHODS AND MATERIALS

Participants

This study was a double-blind (subjects, evaluators), parallel-group, randomized clinical trial including adult volunteers. Volunteers were recruited at the hospital associated with our university (staff and students). The study was approved by the university's ethics oversight committee and was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments (reference 8/2014). Informed consent was obtained from all participants included in the study. Inclusion and exclusion criteria are indicated in Table 1. The participants were between 26 and 58 years old. All selected subjects agreed to refrain from using whitening products or procedures and to avoid the use of any dentifrices and toothbrushes other than those assigned for use during the study. The participants were also free from oral diseases or diseases with oral symptoms and did not use prostheses and orthodontic appliances. Moreover, they had the required number of teeth to retain the appliances used in this study and were not sensitive to SMP-containing chewing gum. In addition, they were available for the total five-day experimental period, able to chew gum five times per day and able to comply with the rules and instructions of the study. The participants were not pregnant or lactating women, were not smokers and did not use dentifrices for tooth whitening or chlorhexidine for

Table 1: *Inclusion and Exclusion Criteria*
Inclusion Criteria
Willing to sign a consent form
Between 26 and 58 years old
Free from any disease with oral effects
Haas sufficient teeth to support an intraoral device (appliance)
Available for a total of five days for the experiment and able to chew gum five times per day
Able to comply with the rules and instructions of the study
Exclusion Criteria
Gross pathology in the oral cavity
Presence of oral prostheses or orthodontic appliances
Underwent or undergoing surgery for periodontal disease
Pregnant or lactating woman
Smoker
Using dentifrices for tooth whitening and chlorhexidine for gargling
Dry mouth
Food and metal allergies
Eating disorder

gargling. All participants received the same supply of a toothbrush and a dentifrice (Clear Clean, KAO, Tokyo, Japan) without SMP. They were asked to use them from a week before the start of this trial until the end of this trial.

Chewing Gum Tested

Test gum containing SMP and control gum without SMP (Lotte, Tokyo, Japan) were used and put in bags marked "P" or "Q." All individuals involved in the experiment, except for the manufacturer, were not informed as to which bag contained test gum and which bag contained control gum until the end of the study. The composition of the chewing gum is indicated in Table 2. Test gum contained 7.5 mg SMP per piece as an additional ingredient; otherwise, it was identical to control gum in taste, shape, weight, and color. Participants were given gum labeled "P" or "Q" and were blinded to the experiment until all data were collected for analysis.

Table 2: *Gum Composition (One Piece)*		
Components	**Control Gum (% Weight)**	**Test Gum (% Weight)**
Xylitol	39	39
Maltitol	35	35
Gum base	20	20
Sodium metaphosphate	0	0.5
Essence	3	3
Others	3	2.5

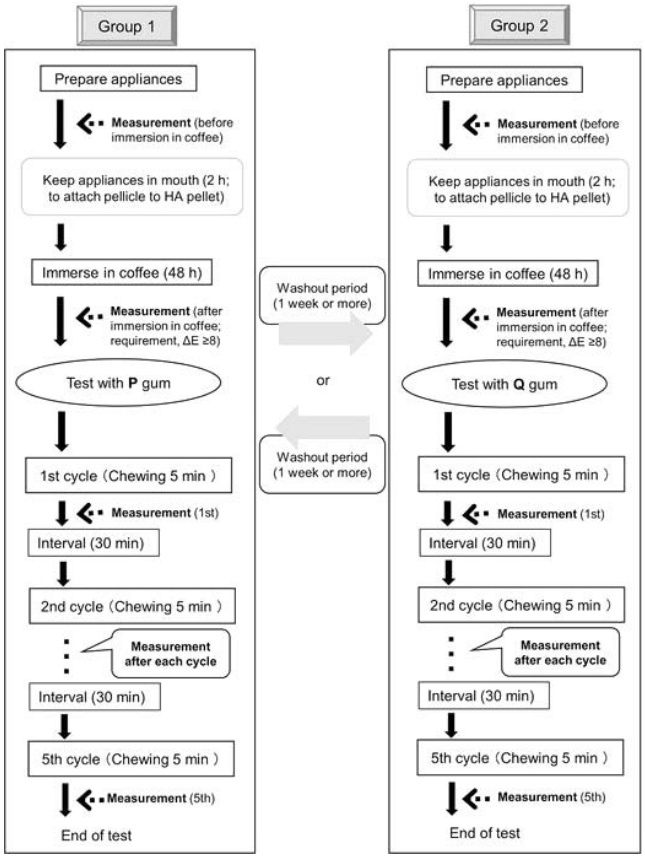


Figure 1. *Experimental design.*

Appliance

Impressions were taken from the mandible of all participants, and appliances were made on cast models. An HA pellet (10×10×2 mm; APP-100, Cosmo Bio, Tokyo, Japan) was attached to the lower lingual side of each appliance with resin (Palapress vario, Heraeus Kulzer, South Bend, IN, USA).[14] Before attachment, 4-META/MMA-TBB resin (opaque ivory; Super Bond, Sun Medical, Shiga, Japan) was applied on the back of the pellet to ensure uniform visibility of color beneath the pellet. Then, wires (φ=0.9 mm) were used to hold the appliances on teeth. Each participant was supplied with two appliances (one for each chewing gum). The surface of the HA pellet was polished using #400 waterproof silicon carbide paper (Sankyo Chemical, Saitama, Japan).

Protocol and Color Measurement

We adopted a crossover design protocol. The flowchart of the experimental process is shown in Figure 1. Thirty participants (10 women and 20 men) between the ages of 26 and 58 years (mean age, 31 years) were equally and randomly distributed into

groups 1 and 2. The method used to generate the random allocation sequence was simple randomization. Group 1 participants used P gum first and then Q gum after a ≥1-week washout period, while group 2 participants used Q gum first and then P gum after a ≥1-week washout period.

The color of HA pellets before coffee immersion was evaluated using a spectrophotometer (CM 2600d, Konica Minolta, Osaka, Japan) with the CIE L*a*b* color space system. The conditions of color evaluation were as follows: D65 standard light, specular component included, and 2° observed angle. All participants kept the appliances in their mouth for two hours to form a pellicle on the HA pellets. The appliances were then immersed in 1.4% coffee solution (AGF, Maxim, Tokyo, Japan.) at 37°C for 48 hours and the color of HA pellets was again measured. The ΔL*, Δa*, Δb*, and ΔE* values (before and after coffee immersion) were calculated, and pellets with ΔE* values <8.0 were excluded from the experiment.

After coffee immersion, the participants kept the appliance in their mouth and were asked to chew on the molar side of the appliance without consuming food or drink during the five-minute chewing cycle. After the chewing cycle, the CIE L*a*b* value was estimated again. The appliances were then placed in 100% relative humidity at room temperature for 30 minutes. This cycle was repeated five times for each gum type. After the fifth measurement, a sufficient washout period was given to allow for the elimination of the influence of SMP (one week or more). Thereafter, a new experimental row with a new appliance and different chewing gum type was conducted (Figure 1).

To evaluate cleaning efficacy of test and control gum, ΔL*, Δa*, Δb*, and ΔE* were calculated from the color of the pellets after immersion in coffee and after each chewing cycle as follows:

$$\Delta L^* = L^*_{(\text{each chewing cycle})} - L^*_{(\text{after coffee immersion})}$$

$$\Delta a^* = a^*_{(\text{each chewing cycle})} - a^*_{(\text{after coffee immersion})}$$

$$\Delta b^* = b^*_{(\text{each chewing cycle})} - b^*_{(\text{after coffee immersion})}$$

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

Statistical Analysis

All data (ΔL*, Δa*, Δb*, and ΔE*) were statistically analyzed using the paired *t*-test with Bonferroni adjustment to compare control gum with test gum after each chewing cycle. Statistical analyses were performed using IBM SPSS Statistics, Version 20.0 (IBM Japan, Ltd, Tokyo, Japan).

RESULTS

Participants

All participants completed the study and none reported health problems linked to SMP exposure.

Color Change by Coffee Immersion

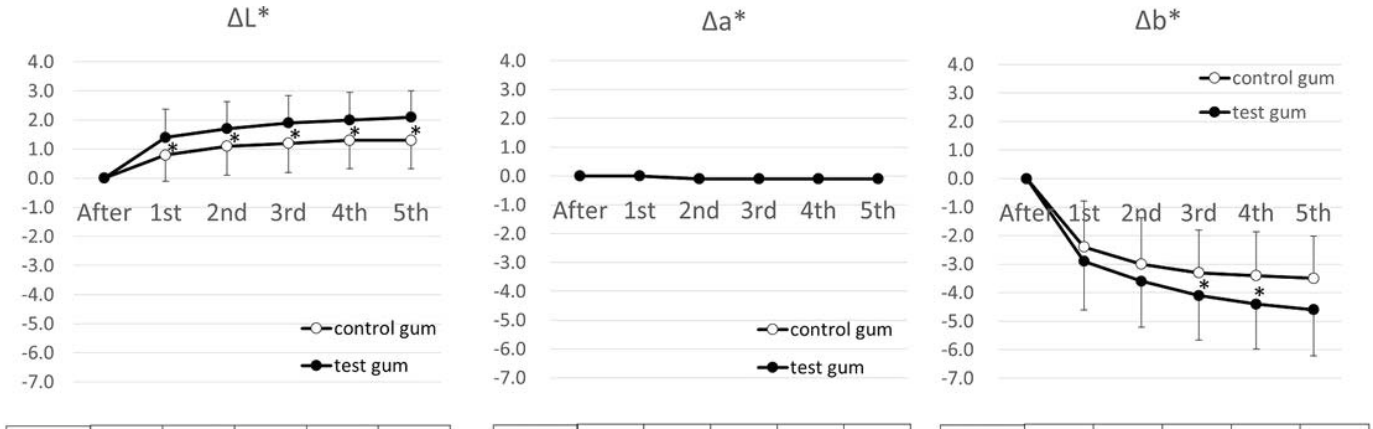
Color change (ΔL*, Δa*, Δb*) by coffee immersion was −5.0, 0.1, and 9.1 for test gum and −4.7, 0.1, and 8.6 for control gum, respectively. Hence, the color of the HA pellet became darker and more yellowish, though the amount of redness showed almost no change following coffee immersion. The shift in color differences (ΔE*) by coffee immersion was >8.0 in all subjects. The mean (±standard deviation) ΔE* values of test and control gum were 10.4 (±1.7) and 9.8 (±1.4), respectively, which were not statistically significant (paired t-test: $p>0.05$). Hence, all HA pellets were sufficiently stained.

Change of ΔL*, Δa*, and Δb* by Gum Chewing

Figure 2 shows mean ΔL*, Δa*, and Δb* values after chewing both gum types in comparison with the color coordinates of HA pellets after coffee immersion. The change in ΔL* values after chewing both gum types showed a tendency to increase with the number of chewing cycles. In contrast, the change in Δb* values after chewing both gum types indicated a tendency to decrease with the number of chewing cycles. Δa* values after chewing both gum types remained relatively unchanged. Comparisons between test and control gum demonstrated ΔL* values of test gum were significantly higher than those of control gum after all chewing cycles ($p<0.05$), whereas Δb* values of test gum were significantly lower than those of control gum after the third and fourth chewing cycles ($p<0.05$). However, Δa* values were not significantly different between gum types for all chewing cycles.

Change of ΔE* by Gum Chewing

The change in ΔE* values after chewing each gum type is shown in Figure 3. For control gum, mean ΔE* values between baseline (after immersion in coffee) and after each chewing cycle were 2.6, 3.2, 3.5, 3.7, and 3.8, respectively. For test gum, mean ΔE* values were 3.2, 4.1, 4.5, 4.8, and 4.9, respectively. Comparisons between test and control gum



test	1.4(1.0)	1.7(0.9)	1.9(0.9)	2.0(1.0)	2.1(0.9)
control	0.8(0.9)	1.1(1.0)	1.2(1.0)	1.3(1.0)	1.3(1.0)

test	0.0(0.2)	-0.1(0.2)	-0.1(0.2)	-0.1(0.2)	-0.1(0.2)
control	0.0(0.2)	-0.1(0.2)	-0.1(0.2)	-0.1(0.2)	-0.1(0.2)

test	-2.9(1.7)	-3.6(1.6)	-4.1(1.6)	-4.4(1.6)	-4.4(1.6)
control	-2.4(1.6)	-3.0(1.6)	-3.3(1.5)	-3.4(1.5)	-3.5(1.5)

Figure 2. *Change of ΔL*, Δa*, and Δb* by gum chewing, Mean ΔL*, Δa*, and Δb* values after chewing both gum types are shown in comparison with the color coordinates of HA pellets after coffee immersion. Asterisks (*) at each chewing cycle indicate a significant difference between control and test gum (p<0.05). ΔL*, Δa*, and Δb* values at each chewing cycle are also given in tables below the graphs. The values in parentheses indicate standard deviation.*

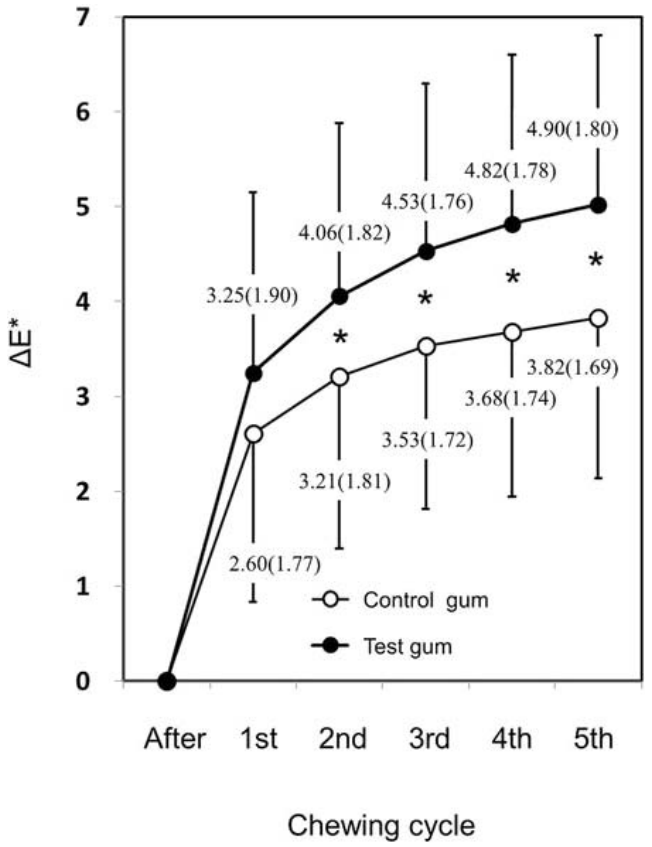


Figure 3. *Change of ΔE* by gum chewing. The ΔE* values of control and test gum after each chewing cycle are shown in comparison with the color of HA pellets after coffee immersion. Asterisks (*) at each chewing cycle indicate a significant difference between control and test gum (p<0.05). The values in parentheses indicate standard deviation.*

after each chewing cycle indicated that ΔE* values of test gum were significantly higher than those of control gum after all chewing cycles, excluding the 1st cycle ($p<0.05$).

DISCUSSION

To our knowledge, this is the first double-blind clinical study to compare the efficacy of gum containing SMP and SMP-free gum to reduce dental stains. The chemical formula of metaphosphate is expressed by the general formula for condensed phosphates, $M^{I}_{n}(PO_3)_n$. A condensed phosphate is chemically produced by heating orthophosphoric acids (H_3PO_4) and is classified by structure into polyphosphate, metaphosphate, and ultraphosphate. SMP is listed as a safe food additive by the US Food and Drug Administration and as a safe cosmetic additive by the US Cosmetic Ingredient Review. SMP is used as a food additive to retain moisture and maintain food shape and texture. In addition, condensed phosphate has recently been used for stain removal.[15] Adding condensed phosphate to a dentifrice is safe and convenient to use. In this study, stain removal efficacy of SMP was evaluated using chewing gum.

The result of our clinical study revealed a decreasing L* value and increasing b* value after immersing the appliance in coffee solution, though the a* value showed almost no change. The HA pellet changed in color from nearly white to yellowish and grayish color during the immersion process. Interestingly, we found that the L* value tended to increase and the b* value tended to decrease, though

the a* value remained almost unchanged, after chewing test gum containing SMP. This finding suggests that the color shift from grayish and yellowish color to white occurred before coffee immersion, to some extent. Regarding ΔE*, the mechanism of color change clearly increased after each subsequent cycle until the fifth chewing cycle, and ΔE* values of test gum were significantly higher than those of control gum after all chewing cycles except for the first cycle ($p<0.05$; Figure 3). One potential explanation for this finding may be different chemical and molecular mechanisms of the destaining action. With control gum, the stain was cleaned to some degree by rinsing with saliva and friction with soft tissue, such as the tongue and gum itself. However, with test gum, chemical destaining likely occurred in addition to the rinsing and mechanical cleaning effect of mastication. Because SMP was the only component that differed in the composition of control and test gum, the difference in ΔE* values between control and test gum after each chewing cycle must be derived from the chemical destaining effect of SMP. Therefore, the null hypothesis—there is no difference in the efficacy of removing coffee stains between gum containing SMP and control gum without SMP—was rejected. Therefore, chewing gum containing SMP appears to be effective at removing coffee stains, which have high acidity and easily permeate the enamel.[2,16-19]

Several studies have evaluated the use of condensed phosphates for decreasing stain formation or stain removal.[20-22] Baig and others[20] stated that the effect of sodium hexametaphosphate is likely to decrease stain formation due to the higher affinity of sodium hexametaphosphate to tooth calcium ions than to tea chromogens. In addition, they showed that sodium hexametaphosphate can prevent deposition and decrease staining using HA pellet powder as a substrate to adsorb tea chromogens. They discuss that binding of the phosphate group to calcium on the enamel surface is the thermodynamic affinity of enamel apatite. The adsorbed pellicle protein is removed while the condensed phosphate is simultaneously adsorbed. In other words, the stain adsorbed on the surface of enamel apatite or stain attached to the surface of the pellicle is replaced by condensed phosphate.[20] Thus, the whitening effect of SMP observed in our study might be explained by a higher affinity between condensed phosphate and HA pellets than between the stain and HA pellets.

Koyasu and others[21] suggested that ultraphosphate binds to the glass ionomer cement slice and can replace stains that are bound to its surface. They investigated the influence of temperature on stain removal by ultraphosphate and found significantly greater stain removal at 37°C than 20°C.[21] In the present study, test gum containing SMP was kept in the human oral cavity, which is approximately 36°C to 37°C. We speculate that the higher temperature of the oral cavity in comparison with room temperature enhanced the chemical action of SMP, thereby resulting in the significant difference in stain removal between test and control gum.

In addition, Porciani and others[22] conducted a double-blind clinical study of chewing gum containing a condensed phosphate as a cleaning agent. Participants chewed gum with or without 1% sodium tripolyphosphate for 10 min/d for six weeks to remove stains. The authors observed decreased staining following the use of chewing gum containing the tripolyphosphate.[22] In the present study, there was a significant difference even within a short period of five times a day for five minutes. Thus, the stain removal ability of SMP may have further increased over time. It is not clear whether there is a difference in the stain removal effect of SMP according to the period of SMP activity and the properties of coloring substances. It is difficult to simulate mastication to investigate stain removal ability in an *in vitro* study. Therefore, additional clinical studies are necessary. Further studies are also needed to evaluate the effect of acidity, hydrophobicity, or solubility on the stain removal ability of SMP and differences according to period of SMP activity.

CONCLUSIONS

Chewing gum containing SMP can effectively remove coffee stains from HA pellets. Thus, SMP is a promising agent to be further explored in tooth whitening studies.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Hokkaido University Dental Hospital. The approval code for this study is: # 8/ 2014.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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