Is whitening toothpaste safe for dental health?: RDA-PE method

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The relative dentin abrasivity-profilometry equivalent values were compared using non-contact profilometry with three subtypes of regular toothpaste and two subtypes of whitening toothpaste containing sodium bicarbonate and 35% hydrogen peroxide. Bovine dentin specimens were assigned to six groups: regular toothpaste (R): R1 (BAMBOO SALT GUM OINTMENT); R2 (MEDIAN TARTAR ORIGINAL); R3 (PERIOE Alpha), Reference slurry: RS (calcium pyrophosphate), whitening toothpaste (W): W1 (NET. WT); W2 (Vussen 28 WHITENING). Relative dentin abrasion–profilometry equivalent (RDA-PE) was determined by brushing 10,000 times (n=5). The pH of the toothpaste was measured (n=8) and the abrasive constituents of the toothpaste was analyzed by FE-SEM and EDS. The RDA-PE values ranged from 26 to166, and the pH level ranges were 4.928–9.153. The RDA-PE value of the whitening toothpaste containing hydrogen peroxide was not high compared with that of the regular toothpaste. The RDA-PE values of whitening toothpaste could vary depending on the mechanism and ingredients of the whitening agents.

Keywords: RDA-PE, Regular toothpaste, Whitening toothpaste, Hydrogen peroxide, Sodium bicarbonate

INTRODUCTION

Structural loss of teeth is an intraoral phenomenon that brings about a combination of physical, chemical, and biological factors on the surface of the teeth³. The physical factors include attrition, abrasion, and abfraction. Attrition occurs through mastication (occlusion) and bruxism. Abrasion is caused by friction when abrasive material from outside of the mouth comes into contact with the surface of the teeth. Lastly, abfraction results from the microfracture of vulnerable parts of the teeth as the compressive and tensile stresses of the bite force act as stress on the teeth. A chemical factor is an erosion, which causes strong acidic substances (food, beverage, gastric juice, etc.) to demineralize enamel and exposed dentin, thereby softening and dissolving the surface of the teeth²⁰. The biological factors include the pH level of individual saliva and the amount of saliva²⁶.

In particular, abrasion of teeth is mainly caused by toothbrushing in the oral cavity⁶,⁷. Toothbrushing is a relatively inexpensive and efficient means of maintaining oral health. It should have sufficient cleaning power to remove food residue and plaque in the mouth⁸,⁹. Factors that lead to tooth abrasion due to tooth brushing include the types of toothpaste and toothbrush used and brushing habits⁴,²⁰. Toothpaste consists of between 0 and 50% abrasives and the rest of the ingredients are humectants, purified water, detergents, bonding agent, and so on¹¹. Abrasives are used as active ingredients of toothpaste such as calcium carbonate, silica, sodium bicarbonate, and alumina¹². Studies have reported that the amount of tooth abrasion was negligible, with less than 0.1 μm of loss when brushing with only water without the active ingredient of toothpaste abrasive¹³,¹⁴. These results indicate that the active ingredient of toothpaste plays an important role in tooth abrasion¹⁵. Although toothbrush and brushing habits might be less damaging to the teeth than toothpaste¹⁶, factors that lead to tooth abrasion include the shape, thickness, and stiffness of the bristles, as well as the strength, and method of brushing²⁷-²⁹.

Tooth abrasion is often more likely to occur in older people than in younger people due to the aging processes. Moreover, dentin shows more abrasion than enamel owing to the difference in their surface hardness⁴,²⁰. In particular, highly abrasive toothpaste incurs a structural loss of teeth in the area of the cervical region with the thinnest enamel, causing non-caries cervical lesion (NCCL) and exposure to a dentinal tubule. As a result, it causes dentin hypersensitivity and toothache²¹,²². The NCCL causes C or V-shaped lesions on the tooth surface, resulting in unfavorable aesthetic changes and increase risk of tooth fracture²³-²⁵. Therefore, it is important for the consumer or patient to select the appropriate toothpaste for their oral condition.

Indicators that consumers can refer to when choosing a toothpaste are the relative dentin abrasivity (RDA) and relative enamel abrasivity (REA) which uses a radioactivity detector. Also there are relative dentin abrasion–profilometry equivalent (RDA-PE) and relative enamel abrasion–profilometry equivalent (REA-PE) which are determined by profilometry²⁶. Both the indicators represent relative values after measurement according to the International Organization for Standardization (ISO) 11609 by comparing the amount of abrasion through the reference material (calcium pyrophosphate, silica or chalk) and each toothpaste. The values of REA and RDA of reference materials are 10...
and 100 respectively, with their limits corresponding
to 40 and 250 respectively. RDA is more commonly used than
REA because the hardness of the abrasive contained in
toothpaste is lower or higher than the surface hardness
of dentin and dentin is more susceptible to abrasion
than enamel.

Recently, whitening toothpaste containing various
ingredients has become increasingly popular. It reflects
the increased consumer's interest in teeth whitening
or hygiene. It is easy and convenient to improve the
aesthetics of teeth at home. However, there is some
concern that whitening toothpaste may adversely affect
the surface of dental hard tissue in previous studies.

In using whitening toothpaste, the composition of
toothpaste differs depending on the manufacturer.
RDA and REA values of each toothpaste also vary.
Furthermore, there is scant information on the effect
of whitening toothpaste on dental hard tissue. Therefore,
it is necessary to further investigate its effect on teeth.
The purpose of this study is to compare the RDA-PE
values of regular and whitening toothpaste using non-
contact profilometry.

**MATERIALS AND METHODS**

**Specimen preparation**

A total of 48 bovine dentin specimens were prepared.
A flawless bovine incisor was extracted from the
bovine mandibular arch to prepare dentin specimens.
Caries, fractured, and microdont teeth were excluded
from extraction. After tooth extraction, the remaining
soft tissues of the tooth were removed with a scalpel,
immersed in 0.1% thymol solution, and stored in a
refrigerator (4°C). The extracted teeth were penetrated
to a diameter of 8 mm using a bench drilling machine
(YDM-13mm, Yongsoo Precision, Daegu, Korea) with
a cylindrical diamond core drill bit (outer diameter
10 Ø×inner diameter 8 Ø) while supplying water.
Donut-shaped acrylic molds (outer diameter 30 Ø×inner
diameter 12 Ø×thickness 4 mm), which have three
grooves to distinguish the positions were attached to
the OHP film and double-sided tape. The teeth were placed
in the center of the acrylic mold with the labial side of the
enamel facing the floor. A self-curing resin (Vertrex Self-
Curing, Vertex, Zeist, The Netherlands) was injected
into an acrylic mold to fix the teeth, and sufficiently
polymerized for 24 h. Specimens were polished using a
polishing machine (LaboPol-5, Struers, Copenhagen,
Denmark) with Silicon carbide paper (#220, 600, and
1200 SiC paper, R&B, Daejeon, Korea) for the removal
of lingual enamel and flattening. The thickness of the
specimens was polished in parallel by adjusting using
a custom polishing jig (Insert holder 30 mm, R&B). The
thickness of the specimens was measured with a digital
vernier calliper (CD67-S15PM, Mitutoyo, Kawasaki,
Japan), and was set to 3.0±0.1 mm (Fig. 1A). The final
specimens were magnified at 5× with a stereoscopic
microscope (KS-200, Korealabtech, Seongnam-si, Korea)
to confirm the state of the specimens. Defective or
dented specimens were excluded from the study.

**Fig. 1** Specimens and toothbrush used in the study.
(A) Completely prepared specimen (until final polishing). Also shown is position discrimination by three grooves. (B) Three-row flat-bristle toothbrush (material, nylon; bristle diameter, 178μm).

A Vickers hardness tester (HMV-2, Shimadzu,
Kyoto, Japan) was used to verify the Vickers hardness
of the specimens. Tester diamond tip was loaded with a
force of 300 g (2.942 N) and indented on each specimen
for 15 s. After measuring 5 points per specimen at 40×
magnification, the average value was determined as the
Vickers hardness. Specimens with Vickers hardness
values outside the range of 30 to 70 (dentin range) were
excluded. Finally, 48 specimens with a Vickers hardness
range of 40 to 50, which is the middle range among
the Vickers hardness ranges of dentin were adopted.
Specimens were refrigerated at 100% relative humidity
before the test.

**Preparation of reference and toothpaste slurries**

The five kinds of toothpaste used in this study were
selected as easily available toothpaste in the market.
Three subtypes of regular toothpaste (R1, R2, and
R3) were chosen with calcium carbonate and silica-
based abrasives, respectively (control group), where R
means regular toothpaste. In addition, two subtypes
of whitening toothpaste were selected as toothpaste
containing sodium bicarbonate (W1) and hydrogen
peroxide (W2) as well as silica as a basic abrasive (test
group), where W means whitening toothpaste. Sodium
bicarbonate and hydrogen peroxide are known as
whitening or plaque removal effects. The details of the
toothpaste are described in Table 1. The 48 specimens
were randomly assigned to reference slurry (RS) and
five-toothpaste (n=8).

To prepare a 400 mL reference dilution, 20 mL
of glycerin (99.5%, Shanghai Aladdin Biochemical
Technology, Shanghai, China) and 2 g of carboxymethyl
cellulose (CMC, Sigma-Aldrich, St, Louis, USA) were
stirred using a magnetic stirrer (MS300HS, Coretech
Korean, Hwaseong-si, Korea) at 60°C until homogeneous.
20 mL of 60°C glycerin was added and stirred for 1 h.
Three hundred-sixty milliliters distilled water added
after transferring the solution to a 500 mL lab bottle
(0.5% CMC and 10% glycerine solution). The solution
was stirred slowly for 12 h. It was used after 12 h for
viscosity stabilization. The reference abrasive was used
Table 1  Detail of the toothpaste used in the study, with their compositions and manufacturers

<table>
<thead>
<tr>
<th>Code*</th>
<th>Product name/Manufacturer</th>
<th>Composition</th>
<th>Fluoride (ppm)</th>
<th>Lot</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>BAMBOO SALT GUM OINTMENTa</td>
<td>Centella Titrated Extract, Bamboo Salt, Sodium fluoride, Dipotassium glycyrrhiza, Dental type silica, Sodium copper chlorophyllin, Sodium lauryl sulfate, Amorphous sorbitol solution 70%, Saccharin sodium hydrate, Titanium dioxide, Xanthan gum, Purified water, Carboxymethylcellulose sodium salt, Polyethylene glycol 300, Flavor</td>
<td>1,000</td>
<td>G101E</td>
</tr>
<tr>
<td>R2</td>
<td>MEDIAN TARTAR ORIGINALb</td>
<td>Green tea extract, Sodium monofluorophosphate, Sodium pyrophosphate, Dental type silica, Methylcyclohexanol, Saccharin sodium hydrate, Titanium dioxide, Cellulose gum, Sodium lauryl sulfate, Sorbitol, Sucralose, Purified water, Zeolite silica, Ground calcium carbonate, Flavor</td>
<td>1,000</td>
<td>DGN057F</td>
</tr>
<tr>
<td>R3</td>
<td>PERIOE Alphaa</td>
<td>Sodium monofluorophosphate, Calcium carbonate, Glycerin, Sodium lauryl sulfate, Polyoxyethylene sorbitan monooleate, Amorphous sorbitol solution 70%, Saccharin sodium hydrate, Disodium dihydrogen pyrophosphate, Zinc Acetate dihydrate, Xylitol, Purified water, Carboxymethylcellulose sodium salt, Silicic acid (TIXOSIL 43K), Flavor</td>
<td>1,000</td>
<td>F061D</td>
</tr>
<tr>
<td>W1</td>
<td>NET. WT. c</td>
<td>Sodium fluoride, Sodium pyrophosphate, Sodium bicarbonate, Hydrated silicon dioxide, Glycerin, Sodium lauryl sulfate, Saccharin sodium hydrate, Titanium dioxide, Sodium lauryl sarcosinate 30%, Sorbitol solution 70%, Purified water, Carboxymethylcellulose sodium salt, Flavor (containing eugenol)</td>
<td>995</td>
<td>LL8137</td>
</tr>
<tr>
<td>W2</td>
<td>Vussen 28 Whiteningd</td>
<td>Hydrogen peroxide 35% (containing 2.8 wt%), Colloidal silicon dioxide, Glycerin, Sodium lauryl sulfate, Sodium metaphosphate, Saccharin sodium hydrate, Citric acid, 1-Menthol, Purified water, Poloxamer 407, Polyethylene glycol 1500, Flavor, Hydroxyethylcellulose</td>
<td>—</td>
<td>19H005</td>
</tr>
</tbody>
</table>

*R=regular toothpaste, W=whitening toothpaste

a LG Household & Health Care, Cheongju-si, Korea
b AMOREPACIFIC, Daejeon, Korea
c Church & Dwight, Ewing, NJ, USA
d Vussen, Ansan-si, Korea

as a calcium pyrophosphate (99.95%, Strem Chemicals, Newburyport, MA, USA). The reference slurries (RS) were mixed with 10 g of calcium pyrophosphate with 50 mL of reference dilution.

The toothpaste slurries were prepared by stirring a mixture of 40 mL distilled water and 25 g of toothpaste. Reference and toothpaste slurries were each prepared in 100 mL lab bottles for ease of mixing and to prevent precipitation. All slurries were stirred again before use.

**Toothbrushing process**

Before toothbrushing, specimens were masked with a 25 μm polyester tape (162.H421.25B, HaeSung Tape Ind., Daejeon, Korea) for creating a window measuring 5×20 mm (width×height) to obtain an unbrushed reference surface. A three-row flat-bristle toothbrush (Name Brush T21, Guardian Angel, Suwon-si, Korea) was used with a bristle’s diameter of 178 μm and bristles were made of nylon material (Fig. 1B). The toothbrush was soaked in distilled water for 24 h before the toothbrushing. A new toothbrush was used for each test. The toothbrushing was performed in an automatic toothbrush machine (RB118, R&B) with six slots. Specimens, which assigned by the table of random numbers were fixed in six toothpaste baths. The toothbrush heads were in contact with the center of the specimens, and a load of 150 g was applied. Each slurry was poured into a toothpaste bath and brushed 10,000 strokes. The toothbrushing rate was 170 strokes/min. It was re-checked 8 times during the toothbrushing process and was stirred with a brush to prevent precipitation of the slurry (per 1,250 strokes). After completion of toothbrushing, the tape was removed.
Table 2 Mean and standard deviation of Vickers hardness in used specimens

<table>
<thead>
<tr>
<th>Toothpaste*</th>
<th>Vickers Hardness (HV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R3</td>
<td>46.4 (2.3)*</td>
</tr>
<tr>
<td>W1</td>
<td>46.1 (3.0)*</td>
</tr>
<tr>
<td>R1</td>
<td>44.5 (3.0)*</td>
</tr>
<tr>
<td>RS</td>
<td>44.2 (3.1)*</td>
</tr>
<tr>
<td>R2</td>
<td>45.9 (3.1)*</td>
</tr>
<tr>
<td>W2</td>
<td>46.5 (3.0)*</td>
</tr>
</tbody>
</table>

Code*: R1 (BAMBOO SALT GUM OINTMENT); R2 (MEDIAN TARTAR ORIGINAL); R3 (PERIOE Alpha); RS (Reference Slurry); W1 (NET WT.); W2 (Vussen 28 WHITENING).

Different letters imply significant difference between groups (p<0.05, n=8).
Fig. 2 Dentin abrasivity of three subtypes of regular toothpaste and two subtypes of whitening toothpaste as determined by noncontact profilometry. The 0 on the Y-axis represents the reference line. The average depth of abrasion was calculated using a software program after 10,000 strokes of brushing under flat conditions, where the left and right reference surfaces are within 10 μm. Code: R1 (BAMBOO SALT GUM OINTMENT); R2 (MEDIAN TARTAR ORIGINAL); R3 (PERIOE Alpha); RS (Reference Slurry); W1 (NET WT.); W2 (Vussen 28 WHITENING).

Table 3 Means and standard deviation of RDA-PE value and average depth of abrasion

<table>
<thead>
<tr>
<th>Toothpaste*</th>
<th>RDA-PE value</th>
<th>Average depth of abrasion (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R3</td>
<td>166 (57)a</td>
<td>54.31 (18.77)a</td>
</tr>
<tr>
<td>W1</td>
<td>124 (21)ab</td>
<td>40.62 (6.97)ab</td>
</tr>
<tr>
<td>R1</td>
<td>102 (14)bc</td>
<td>33.38 (4.53)bc</td>
</tr>
<tr>
<td>RS</td>
<td>100 (33)bc</td>
<td>32.72 (10.69)bc</td>
</tr>
<tr>
<td>R2</td>
<td>66 (20)d</td>
<td>21.72 (6.40)d</td>
</tr>
<tr>
<td>W2</td>
<td>26 (2)bc</td>
<td>8.62 (0.72)bc</td>
</tr>
</tbody>
</table>

Code*: R1 (BAMBOO SALT GUM OINTMENT); R2 (MEDIAN TARTAR ORIGINAL); R3 (PERIOE Alpha); RS (Reference Slurry); W1 (NET WT.); W2 (Vussen 28 WHITENING). Different letters imply significant difference between groups (p<0.05, n=8).

However, the other four toothpaste has a lower RDA-PE value compared with those of R3 according to the post-hoc comparison (p<0.05). W2 containing hydrogen peroxide showed the lowest value. There was a statistically significant difference from other groups except for R2 (p<0.05). The comparisons of the average...
Table 4  Mean and standard deviation of pH value

<table>
<thead>
<tr>
<th>Toothpaste*</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2</td>
<td>9.153 (0.010)</td>
</tr>
<tr>
<td>R3</td>
<td>8.850 (0.026)</td>
</tr>
<tr>
<td>W1</td>
<td>8.116 (0.018)</td>
</tr>
<tr>
<td>RS</td>
<td>7.098 (0.025)</td>
</tr>
<tr>
<td>R1</td>
<td>6.748 (0.022)</td>
</tr>
<tr>
<td>W2</td>
<td>4.928 (0.016)</td>
</tr>
</tbody>
</table>

Code*: R1 (BAMBOO SALT GUM OINTMENT); R2 (MEDIAN TARTAR ORIGINAL); R3 (PERIOE Alpha); RS (Reference Slurry); W1 (NET WT.); W2 (Vussen 28 WHITENING).

The mean and standard deviation of the pH measurements are shown in Table 4. The pH ranges were from 4.928 to 9.153.

FE-SEM and EDS

The abrasive particles contained in the toothpaste had irregular shapes such as round, oval, rectangular, and polygonal shapes in the FE-SEM image (Fig. 3). In all groups except R2, large and small abrasives within 50 μm were observed. The zeolite silica contained in R2 was observed to be several hundred micrometers in size.

EDS analysis indicated the elements contained in the abrasives of each toothpaste (Fig. 3), and the elements of the main abrasives were matched by color (mapping). RS and W2 showed a single abrasive element, and the remaining groups showed results that included abrasive and other elements. All groups except RS contained silica (green color). R2, R3, and RS contained calcium (purple color). R2 containing zeolite included sodium (red color), barium (yellow color), strontium (brown color), and aluminum (blue color) as well as silica and calcium. The large bead-shaped zeolite (Fig. 3, green arrow) contained all six elements. W1 was observed as silica and some agglomerated sodium (Fig. 3, yellow arrows). Trace amounts of titanium concentration were present in R1, R2, and W1.

DISCUSSION

In the present study, the RDA-PE value and average depth of abrasion were determined using non-contact profilometry after brushing 10,000 strokes each of regular toothpaste and whitening toothpaste on the dentin surface. Our results showed RDA-PE value in the range of 26–166 and an average depth of abrasion dentin in the range of 8.62–54.31 μm (Table 3). Interestingly, the W2 with hydrogen peroxide had the lowest value for both measurements. It is also noteworthy that there is a difference between the two subtypes (i.e. W1 and W2) of whitening toothpaste according to the result of the post-hoc comparison. In addition, the values of W2 were lower than those of R1 and R3 (p<0.05). On the other hand, the value of W1 is the second-highest but we could not find any statistical significance when comparing the values of R3, R1, and RS.

Studies have reported that whitening toothpaste was evaluated based on RDA or abrasion values (μm) of human or bovine teeth compared to regular toothpaste32-37). The abrasion values of whitening toothpaste were not higher than that of regular toothpaste in some studies 32,35,36). On the other hand, other studies have demonstrated that whitening toothpaste has higher abrasion values than regular toothpaste33,34,37). These similarities or discrepancies in outcomes indicate that abrasion value may vary depending on the difference in the abrasive and whitening ingredients included in toothpaste. The RDA-PE value of all toothpaste did not exceed the 250 which is defined as the limit value in ISO 11609. This finding indicates that regular and whitening toothpaste can be safe to use on the hard tissues of the teeth.

The radioactivity measurement method was used as the ‘gold standard’ for the evaluation of abrasivity. The profilometry measurement method was developed due to errors in weighing, color change of specimens, variability of values, and regulation of radioactive equipment5,15). It is currently used as an alternative to radioactivity measurement. In a previous study, there was no statistical difference when comparing the RDA and RDA-PE values between the two methods29), and it showed a strong correlation (R^2=0.71)38). Profilometry measurement methods are divided into contact and non-contact methods. Both methods can quantify the amount of abrasion through the reference and the abrasion surface. The contact profilometry method may damage the surface of the specimen because it measures the surface of the specimen by scraping it using stylus tips. Moreover, there is a limitation that the abrasion area smaller than the diameter of the stylus tips cannot be measured. However, the non-contact profilometry method does not damage the surface of the specimen and can observe the surface information more effectively.
Fig. 3 Image visualization and compositional analysis of abrasives by FE-SEM and EDS. The white scale bar of 50 μm represents a magnification of 1,000×, whereas the white scale bar of 100 μm represents a magnification of 500×. EDS and mapping detected the components of each abrasive and matched the main components. Elements and colors at the bottom left of the mapping image of EDS indicate the corresponding element in the FE-SEM image. The green arrow indicates zeolite silica in the R2 group, which contains six elements. The yellow arrow indicates some residual agglomerated sodium in the W1 group. Code: R1 (BAMBOO SALT GUM OINTMENT); R2 (MEDIAN TARTAR ORIGINAL); R3 (PERIOE Alpha); RS (Reference Slurry); W1 (NET WT.); W2 (Vussen 28 WHITENING)
than other methods\textsuperscript{39}.

In this study, dentin from bovine incisors was used to determine the RDA-PE value of toothpaste. Bovine teeth do not pose ethical problems, have fewer defects, easy to obtain a flat surface, and have the advantages of relatively large size compared to human teeth\textsuperscript{40}. However, due to differences in the biological properties (physical/chemical) of dentin, there has been controversy when using it as an alternative material\textsuperscript{39,41,42}. In a previous study, there was no significant difference in RDA values when comparing four types of laboratory toothpaste with different RDA values in human and bovine dentin, respectively\textsuperscript{43}. In addition, studies showed similar properties when compared by physical/chemical methods between human teeth and bovine teeth\textsuperscript{40,41,43}. These data suggest that bovine teeth can be used as a substitute for human teeth in determining the RDA-PE value of toothpaste. Dentin has wide biological variability and is less homogeneous than enamel, so the experimental results show high deviation\textsuperscript{39}. In our study, we tried to minimize the error in the results by controlling the hardness of the specimen to be the median value of the dentin range (Table 2).

The frequency and time of brushing are some other factors that affect dentin abrasion along with toothpaste\textsuperscript{23}. In general, RDA-PE value after 4,000 strokes using RS is defined that of 100 in as indicated by ISO 11609\textsuperscript{39}. However, the RDA-PE value after 10,000 strokes using RS was considered that of 100 in this study. Ten thousand strokes correspond to the number of strokes completed in 12 months, assuming that you brush your teeth ten times per tooth and three times a day\textsuperscript{44,45}. We decided to evaluate the effects of 10,000 strokes rather than 4,000 strokes, which corresponds to about five months, to determine long-term real effects. In addition, a higher number of strokes is more advantageous in evaluating abrasion in the case of toothpaste exhibiting significantly low abrasivity. RDA-PE value depends on the performance of non-contact profilometry and inaccurate values were obtained in the pilot study when measuring the case of toothpaste with significantly low abrasivity.

Whitening toothpaste is known to make the inside or outside of the tooth visually brighter\textsuperscript{46}. Currently, it has a complex composition with various whitening agents as well as abrasives added for efficacy such as brightening and tartar removal (anti-plaque)\textsuperscript{46,47}. The ingredient list in the toothpaste packaging often does not contain information about the exact ingredient content, RDA or RDA-PE.

Consumers primarily choose toothpaste based on the product’s name, manufacturer’s advertisement, and the efficacy indicated on the packaging. However, the choice can potentially increase the abrasion of hard dental tissue and worsen the condition especially in patients suffering from non-curious cervical lesion. In addition, the scanty information can make difficult for dental professionals to recommend a suitable toothpaste for a patient’s oral condition. ISO 11609 provides only the limit (250) for safe toothpaste of RDA-PE, and there is no detailed classification standard. Authors suggest different classification ranges, and often it can be suggested that the range of low-abrasive toothpaste is less than 70, medium abrasive toothpaste is 70 to 150, and high-abrasive toothpaste is 151 or more\textsuperscript{5,15,48}. Based on the classification range, R2 and W2 can be classified as low-abrasive, R1 and W1 as medium-abrasive, and R3 as high-abrasive.

Whitening toothpaste with hydrogen peroxide may also contain abrasives to remove stains and reinforce the cleaning effect\textsuperscript{49}. The experiments showed that the RDA-PE value of W2 was 2.5 to 6.4 times lower than the values of R1, R2, and R3 as well as 4.8 times lower than the value of W1, which is also a whitening toothpaste (Fig. 2 and Table 3). These findings suggest that the combined action of 35% hydrogen peroxide with other ingredients did not have a detrimental effect on dentin in terms of the RDA-PE value. One previous study showed that the amount of dentin loss when brushing with 35% hydrogen peroxide gel for 30 min did not differ compared with when brushing with distilled water\textsuperscript{50}. The result also supports our observation that the use of 35% hydrogen peroxide alone does not seem to cause substantial abrasion on dentin surface. However, it is not prudent to conclude that the 35% hydrogen peroxide does not have any detrimental effect on the tooth surface, because the only RDE-PE was evaluated in the present study. There could be many other factors affecting the result of dentin loss. For example, the pattern of abrasion might differ from toothpaste and tooth paste depending on the whitening mechanism. Furthermore, exact composition and amount of abrasives were not specified on the toothpaste package. They may be the main factors affecting the value of RDE-PE rather than the hydrogen peroxide. Further studies should be warranted considering the above factors.

Zeolite silica is widely used in the medical field and is sometimes called a magic stone\textsuperscript{50}. Structurally, zeolite silica is a porous solid containing silica and aluminum. It also includes alkali ions sodium, calcium, barium, and strontium\textsuperscript{40}. The pH value of R2 containing zeolite silica was 9.153. However, the current result could not find an association between RDA-PE and pH value, which is in line with one previous study\textsuperscript{50}. Zeolite silica has an adsorption function and ion exchange, so it can effectively remove calculus and help hemostasis\textsuperscript{50}. Meanwhile, clinical studies have demonstrated the plaque removal effects of zeolite\textsuperscript{55,54}. However, the effect of zeolite silica on the dentin surface is unknown. Here, zeolite silica was observed as a large particle size of several hundred micrometers compared to other groups (Fig. 3). The relatively large particle abrasive could be related to high abrasivity\textsuperscript{55}, but the present study did not find a higher RDE-PE value of R2 compared to other toothpaste without the zeolite silica.

The present study compared the long-term effect of whitening toothpaste and regular toothpaste through in vitro experiments. The influence of variables was minimized compared to in vivo experiments by controlling factors such as the amount of toothpaste, number of
brushing, and pressure. Continuous brushing was performed for about 1 h (10,000 strokes) to determine the RDA-PE value in this study. There is a limitation that it may not sufficiently reflect the clinical situation compared to in vivo experiments. In a further study, it is necessary to evaluate the additional factors such as acidity, ingredients, abrasives of type and shape.

**CONCLUSION**

This study compared the RDA-PE values of two subtypes of whitening toothpaste and three subtypes of regular toothpaste. The RDA-PE value of the whitening toothpaste containing hydrogen peroxide was not high compared with that of the regular toothpaste. All toothpaste tested in the present study had an RDA-PE value that did not pose any hazard to the dentin surface. Our results suggest that the RDA-PE values of whitening toothpaste could vary depending on the mechanism of the whitening agents.

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