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Effects of oral hygiene procedures on aesthetics and surface properties of restorative materials for digital dentistry

구강 위생 술식이 치과용 CAD/CAM 수복 재료의
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2019년 8월

서울대학교 대학원

치의과학과 치과보철학 전공

이 재 현

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이 논문을 치의과학박사 학위논문으로 제출함
2019년 5월

서울대학교 대학원
치의과학과 치과보철학 전공
이 재 현

이재현의 박사 학위논문을 인준함
2019년 7월

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Effects of oral hygiene procedures on aesthetics and surface properties of restorative materials for digital dentistry

2019

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*(Directed by Prof. **Jung-Suk Han**, DDS, MSD, PhD)*

Abstract

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Objectives. Esthetic restorations using highly translucent ceramics powered by digital dentistry are becoming popular. Experiment I investigated the impact of various dentifrices on the shade, translucency, gloss, and surface characteristics of polished or glaze finished monolithic zirconia surfaces, following simulated toothbrushing. Experiment II evaluated the effects of mouthwashes on the optical and surface properties of high-translucency, computer-aided design and computer-aided manufacturing (CAD/CAM) dental ceramic materials. The purpose of Experiment III was to investigate the impact of ultrasonic scaling on the high-translucency CAD/CAM dental ceramic materials.

Methods. For Experiment I**,** eighty square-shaped monolithic zirconia specimens were divided into two major groups based on the finishing methods—polished (P) or glazed (G). Subsequently, specimens from the two major groups were categorized

into four subgroups: stored in distilled water (DW, control), brushed with a fluoride-free conventional dentifrice (C), brushed with a fluoride dentifrice (F), and brushed with a whitening dentifrice (W). Overall, eight groups were created from the four subgroups: PDW, PC, PF, PW, GDW, GC, GF, and GW (n = 10 each). Experiment II consisted of two hundred specimens being fabricated from five high-translucency CAD/CAM ceramics: a resin nano ceramic (Lava Ultimate), a dual-network ceramic (Vita Enamic), a feldspathic ceramic (Vita Mark II), a lithium disilicate (e.max CAD), and a monolithic zirconia (Rainbow Shine-T). Each ceramic was divided into four subgroups (n=10): conventional mouthwash, whitening mouthwash, chlorhexidine gluconate, and distilled water. Oral rinsing was simulated at 100 revolutions per minute (rpm) for 180 h (15 years of clinical simulation). During Experiment III, the resin nano ceramic (LU), dual-network ceramic (VE), feldspathic ceramic (VM), lithium disilicate ceramic (EX), and high-translucency monolithic zirconia (MZ) were evaluated. The specimens were subjected to ultrasonic scaling. The specimens of each Experiment were then evaluated for color, translucency, surface gloss, surface roughness, crystalline phase, and superficial topography. One-way analysis of variance (ANOVA), repeated-measures ANOVA, and two-way ANOVA were used for intergroup comparisons (all $\alpha = 0.05$).

Results. According to the results of Experiment I, the color differences (ΔE_{00}) between pre- and post-treatment were 0.3158 (PDW), 0.7164 (PC), 0.7498 (PF), 0.8106 (PW), 0.1953 (GDW), 0.301 (GC), 0.3051 (GF), and 0.4846 (GW). A statistically significant difference was observed among the ΔE_{00}, of the surface gloss,

and surface roughness of monolithic zirconia. The results of the two-way ANOVA in Experiment II, showed that the color difference (ΔE_{00}) before and after oral rinsing simulation, on the surface gloss, and surface roughness, was significantly affected by the interaction between ceramic and solution ($p<.001$). The dual-network ceramic and feldspathic ceramic became brighter, opaquer, less glossy, and rougher after rinsing with the whitening mouthwash. According to the results of Experiment III, the mean ΔE_{00} values were 0.243, 0.48, 1.591, 0.143, and 4.466 for LU, VE, VM, EX, and MZ, respectively, with statistically significant differences among the materials. Ultrasonic scaling also resulted in significant changes to the surface gloss of the LU, VE, VM, and MZ specimens. Micrographs showed scrapes and surface deterioration after scaling.

Conclusions. Brushing with several dentifrices markedly affects the optical properties and surface characteristics of monolithic zirconia, finished with either polishing or glazing methods. The optical and surface properties of high-translucency CAD/CAM dental restorative ceramics were markedly affected by the simulated 15 years of oral rinsing. The ultrasonic scaling significantly affected the optical properties and surface characteristics of highly translucent CAD/CAM ceramics.

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Keywords : ceramic, color, digital dentistry, mouthwash, optical property, surface, toothbrushing, ultrasonic scaling

Student Number : 2015-31250

CONTENTS

I. Introduction

The use of computer-aided design and computer-aided manufacturing (CAD/CAM) technology in the field of dentistry has dramatically increased [1-3]. Recently, clinicians have increasingly used chairside digital dentistry to fabricate dental prostheses directly in the dental clinic instead of sending impressions to dental laboratories [4-6]. This advancement has become possible because of the reduced cost and size of CAD/CAM equipment. For increased efficiency of chairside laboratory procedures, appropriate materials as well as improved equipment must be developed.

Accordingly, various monolithic CAD/CAM ceramic restorative materials have been developed in recent years, given that additional laboratory processes such as porcelain veneering and glazing are not essential for monolithic materials [2, 5, 7]. When monolithic ceramics are used, it is necessary to ensure the translucency and esthetics of the material corresponding to the veneering porcelain while maintaining the strength of the material corresponding to the core part of bilayered crown restorations. Currently, various restorative materials that can be fabricated by chairside CAD/CAM systems are available in dental clinics. In recent years, materials with improved or high translucency have been developed and indicated for use in anterior esthetic restorations [8-10]. These developments make it possible to restore aesthetic areas, including the maxillary central incisors, using some materials by following simple milling and polishing procedures [2, 6].

Monolithic yttria-stabilized tetragonal zirconia (Y-TZP) is a predictable dental restorative material that exhibits a high success rate in clinical practice and is more frequently selected for an aesthetic restoration as its translucency improves [11-13]. Compared with conventional bilayered zirconia crowns and metal-ceramic restorations, monolithic zirconia restorations have the advantage of less ceramic fracture [14]. In addition, compared with conventional metal-ceramic restorations, monolithic zirconia crowns exhibit excellent translucency; moreover, monolithic zirconia is aesthetic because of the lack of metal exposure at the restoration margin, even when gingival recession of the abutment tooth occurs [15, 16]. Thus, monolithic zirconia offers several advantages as an aesthetic restorative material, rendering it the first-choice material in the premolar region based on its tooth color and intensity. Furthermore, monolithic zirconia restorations are increasingly used in the anterior teeth owing to the development of zirconia materials with high translucency [8, 17, 18].

Accordingly, it is necessary to study whether the optical and surface properties of highly translucent CAD/CAM ceramic restorative materials are affected by various oral hygiene methods. In this study, the following three experiments were conducted.

The Experiment I of this study investigated the effects of various toothpastes on the optical properties and surface properties of monolithic zirconia finished by polishing or glazing methods. In Experiment I, the null hypothesis was that no significant change in the optical properties and surface characteristics of polished or glazed monolithic zirconia specimens occurs after the simulated toothbrushing procedure with various dentifrices.

The Experiment II of this study was conducted to investigate the effects of various types of oral hygiene solutions on the optical and surface properties of newly developed high-translucency CAD/CAM restorative materials. The first null hypothesis was that the oral hygiene solutions would not affect the optical properties of high-translucency monolithic CAD/CAM ceramics. The second null hypothesis was that they would not affect the surface characteristics of the monolithic CAD/CAM ceramic materials.

The aim of the Experiment III was to evaluate the effects of ultrasonic scaling on the optical properties and surface characteristics of newly developed highly translucent CAD/CAM ceramic materials. The null hypothesis was that the optical properties and surface characteristics of highly translucent CAD/CAM ceramics are not affected by ultrasonic scaling.

II. Review of Literature

II-1. Toothbrushing

The toothbrushing procedure involves applying a mechanical force to the tooth surface over a prolonged period [19]. In addition, various dentifrices have been developed for use with toothbrushes, and chemical components and abrasives of dentifrices can chemically and physically affect the surface of brushed teeth [20, 21]. The high fluoride concentration in a dentifrice has been reported to diminish the properties of dental ceramics [22-24]. In addition, dentifrices developed for improved tooth-whitening effects affected the optical properties of restorative ceramic materials [21, 25]. Based on the abrasive content, toothpastes vary in their abrasion of enamel, as measured by the relative dentin abrasion (RDA) value [19]. Investigating toothbrushing effects on shade or translucency is important. Furthermore, it is imperative to investigate whether toothbrushing may increase the surface roughness that can result in plaque accumulation and bacterial adhesion. Studies have reported the effects of toothbrushing and dentifrices on various restorations [21, 26-28]; however, limited studies have investigated the impact of various dentifrices on the monolithic zirconia material.

II-2. Oral rinsing

Dental restorative materials can be affected by various solutions, and their optical and surface properties can be changed in the oral cavity. Many studies have reported that acidic solutions such as cola, orange juice, red wine, coffee, and gastric acid can affect the optical properties and surface roughness of tooth-colored dental restorative materials [22, 23, 29-32]. Several oral hygiene solutions that are currently in commercial use can also affect the color of dental restorations [33-35]. Several types of mouthwashes have a blue or green tint to make them visually appealing. Furthermore, some mouth rinses emphasize their tooth whitening effect. As these rinses can affect the color tone of the teeth [36], they may also affect the color of dental restorations.

Chlorhexidine mouth rinses are widely prescribed as an adjunctive treatment for gingival health [37]. However, chlorhexidine may also cause tooth staining [38]. The restoration of aesthetic areas with new high-translucency CAD/CAM materials would be unacceptable if the color or translucency of the restoration was affected negatively by these kinds of solutions.

Although several studies have analyzed the effect of these various solutions on the shade of dental restorations [33-35], only few have investigated the effect of various types of oral hygiene solutions on the optical properties of newly developed translucent chairside CAD/CAM restorations [35].

II-3. Ultrasonic scaling

Ultrasonic scaling is a professional oral hygiene maintenance procedure that is widely performed in dental clinics [39, 40]. This measure is generally recommended for the periodic control of plaque accumulation and calculus growth [41, 42]. In addition, the procedure is prescribed every 3–4 months for patients with periodontal disease [41, 42]. In conventional metal–ceramic crowns, the metal coping is generally exposed in the cervicolingual region or at the crown margin; therefore, such crowns are easily distinguished from natural tooth crowns. However, metal-free tooth-colored restorations may not be easy to distinguish from natural teeth unless they are carefully observed or radiographically examined. As a result, dentists or dental hygienists are likely to subject CAD/CAM restorations, which are now widely used for anterior teeth, to inadvertent ultrasonic scaling with the same intensity used for natural teeth. If such ultrasonic scaling affects optical properties such as color and translucency of the restorative materials, then repeated scaling procedures can compromise the esthetics in important areas such as the maxillary and mandibular anterior regions. In particular, the labial and lingual surfaces of the mandibular anterior teeth are common sites for calculus deposition [43]. Because additional time and effort are invested in removing calculus from these teeth during ultrasonic scaling procedures, mandibular anterior restorations are highly susceptible to scaling-induced damage. In addition, it has been reported that the smile lip line moves downward with aging [44]. Consequently, the mandibular anterior teeth are more visible than the maxillary anterior teeth in older individuals. Accordingly, the optical properties of restorative materials used for the mandibular anterior teeth should be considered important for satisfactory esthetic outcomes.

The surface properties of dental restorations, including the surface roughness, are related to microbial attachment [45, 46]. It has been reported that rough restoration surfaces increase the possibility of periodontal disease because of plaque accumulation, calculus deposition, and microbial adhesion [47-50]. Accordingly, it is necessary to study whether the surface roughness of newly developed highly translucent CAD/CAM restorative materials is affected by routine ultrasonic scaling procedures.

Although several studies have evaluated the effects of ultrasonic scaling on the surface roughness of various metal and ceramic dental restorative materials [47, 48, 50, 51], few have assessed how recently developed tooth-colored materials are affected in terms of their color and translucency.

III. Materials and Methods

III-1. Experiment I. Optical and surface properties of monolithic zirconia after simulated toothbrushing

III-1.1. Specimen preparation

Eighty square-shaped (22.0 mm × 22.0 mm × 2.0 mm) specimens were cut from presintered blocks of monolithic Y-TZP zirconia (Rainbow Shade Block, Shade A2; Genoss, Suwon, Korea) with a low-speed diamond disc (Diamonde Blade, Samsung Clover, Seoul, Korea) under water cooling [27]. The specimens' thicknesses were adjusted to 2±0.01 mm with a horizontal grinding machine (HRG-150; AM Technology, Asan, Korea) and were confirmed using a digital caliper (BD500-150; Bluetec, Seoul, Korea).

Coloring procedures were performed on only one side of each specimen with a metal-free coloring brush (Maedeum No. 5; Daeheung-dang, Seoul, Korea) and A3-shaded coloring liquid (Luxen CL shade A3; Dental Max, Seoul, Korea) with brushing three times to simulate the restoration coloring procedure in a dental laboratory. Then, all specimens were sintered in a furnace (PDF-1000; Dental Max, Seoul, Korea) for 10 h, including 2 h at 1530 °C as per the manufacturer's instructions. The final dimensions of the specimens after the sintering procedure were 18.0 mm × 18.0 mm × 1.6 mm, considering approximately 20% volumetric shrinkage.

Next, all specimens were divided into two major groups based on the finishing methods—polishing (P) and glazing (G). For glazed specimens (*n* = 40), the glazing material (Glaze HeraCeram; Heraeus Kulzer, Hanau, Germany) was coated on the A3 coloring liquid-applied surface of the specimens and fired in a ceramic furnace (Programat P310; Ivoclar Vivadent, AG, Schaan, Liechtenstein) as per the manufacturer's guidelines. Of note, no extrinsic staining was performed. Next, the glazed surfaces of the square-shaped specimens were wet-ground with 320-, 1200-, and 2000-grit silicon carbide abrasive paper (C357; Paco Tech., Seoul, Korea), creating specimens with a glazed layer of 50 (±30) μm thickness. For polished specimens (*n* = 40), an experienced dental laboratory technician manually polished the A3 colored surface of the specimens using a zirconia polishing set (StarGloss blue/pink/gray; Edenta AG, Hauptstrasse, Switzerland) (Figure I-1). Finally, a fiducial mark was engraved on the edge of the nontested side of each specimen, which was used for distinction between groups.

Then, each finishing group was further categorized into the following four subgroups based on the brushing procedure and dentifrice used (*n* = 10/group): storage in distilled water (DW, control); brushing with a fluoride-free conventional dentifrice (C); brushing with a fluoride dentifrice (F); and brushing with a whitening dentifrice (W). Finally, based on the finishing and brushing methods, eight groups were defined as PDW, PC, PF, PW, GDW, GC, GF, and GW. Before performing tooth brushing or storage, all specimens were ultrasonically cleaned for 5 min.

III-1.2. Toothbrushing with a dentifrice slurry

All specimens were subjected to a single focal area of toothbrushing using an electric toothbrush (DB-4010; Oral-B Braun GmbH, Kronberg/Ts., Germany) with a cup-shaped toothbrush head (Precision Clean; Oral-B Braun GmbH) fixed on a customized toothbrush-holding device (Figure I-2). This electric toothbrush had oscillatory-rotating movement at a rate of 7600 strokes/min. The electric brushes were set to brush in “continuous mode” with a standardized vertical load of 2 N [26, 28]. The vertical force was generated using orthodontic extraoral elastics 0.5-inch Extraorale Latex-Gummiringe (Dentaurum, Ispringen, Germany) and validated using a laboratory force gauge (J14002; Zeast Co., Beijing, China).

In this study, three dentifrices were used—a fluoride-free conventional dentifrice (Parodontax Classic Fluoridfrei; GlaxoSmithKline, Bühl, Germany), a fluoride dentifrice (Parodontax Fluorid; GlaxoSmithKline), and a whitening dentifrice (Crest 3d White Vivid; Procter & Gamble, Cincinnati, OH, USA). The reported RDA values for these dentifrices were 56, 56, and 233 [20]. In addition, the fluoride concentration for these dentifrice were 0, 1400, and 1500 ppm, according to the manufacturer’s guidelines (Table I-1). Of note, an RDA value of 250 is the American Dental Association (ADA)–specified limit, and 1500 ppm fluoride ion in the dentifrice is the maximum concentration that can be purchased without a prescription in most countries. Each toothpaste was mixed with DW in a ratio of 1:4 to make a slurry along with the ISO (International Standards Organization) 11609:2017 standard (Dentistry-Toothpastes: Requirements, test methods and marking).

The total brushing time was calculated based on a brushing time of 120 s two times a day of all 28 teeth [19, 52]. As a tooth has several surfaces to be brushed, the maximum contact time per tooth surface per day has been reported to be 5 s [19, 53]. In addition, the simulated brushing time of 260 min for one surface of the specimen was evaluated to be equivalent to 8.5 years of tooth brushing.

Based on a typical toothbrush replacement cycle, bristles must be replaced after 45 days of use [19]. Reportedly, brushing all 28 teeth with 72 surfaces for 45 days is equivalent to simulated toothbrushing for 270 min, assuming that one surface is being brushed for 5 s per day [19]. Thus, in this study, the first simulated brushing was performed for 260 min (which simulated 8.5 years of toothbrushing); then, the optical properties were assessed; toothbrush heads, dentifrice slurries, and batteries were replaced; and another 260 min of brushing was performed again. Each specimen was brushed for 520 min, representing 17 years of brushing. The specimens in the DW (control) group remained submerged in DW for the same period of 520 min.

Next, 60 new electric toothbrushes and 60 new customized brush-holding devices were prepared to ensure equal experimental conditions. In addition, toothbrushing of 60 specimens was performed at the same time. After simulated brushing, all test specimens were rinsed with tap water for 30 s before all measurements.

III-1.3. Color and translucency

To assess shade and translucency changes, the Commission Internationale de l’Éclairage (CIE) L^*, a*, and b* color coordinates of 80 specimens were evaluated using a dental spectrophotometer (EasyShade V, VITA Zahnfabrik, Bad Säckingen, Germany); this device has high repeatability, with intradevice intraclass correlation coefficients (ICCs) of 0.913–0.993 [54]. In this study, each of 10 glazed zirconia specimens was measured three times to calculate the ICC and ensure the repeatability of the device used. When measuring three times, the device tip was removed from the evaluated surface of the specimen >10 cm and contacted again for other measurements to simulate a similar situation with experiments. The intradevice ICCs of the device used in this study were 1.000 for L^* and a* and 0.999 for b*. To avoid the likelihood of interdevice disagreement, all measurements were made by using only one device.

The CIE L^*, a*, and b* color components of each specimen were detected over white, gray, and black polytetrafluoroethylene backgrounds (GC-3, Color calibration cards; JJC Co., Seoul, Korea) at 3 different intervals—baseline, after 260 min (simulating 8.5 years), and 520 min (simulating 17 years)—of brushing. All measurements were performed by a single trained prosthodontist under standardized D65 light illumination (18W/D65; Philips, Santiago, Chile) of the color assessment cabinet (CAC-4, Zhengzhou Hengchen Electric Tech., Henan, China). Of note, all measurements were performed with the probe tip perpendicular to the center of the specimens. In addition, the spectrophotometer was calibrated according to the manufacturer's instructions before each color measurement to minimize the measurement uncertainty. Furthermore, the measurements for each background of each specimen were performed four times, and the mean of four measurements was recorded for data analysis.

Measurements acquired on the gray background were used to evaluate the color difference between before and after brushing. Furthermore, CIEDE2000 color differences (ΔE_{00}) in each group between the baseline and simulated 8.5 years and between the baseline and simulated 17 years of toothbrushing were determined using the following formula [55, 56]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}$$

where ΔL', $\Delta C'$ and $\Delta H'$ are the differences in lightness, chroma and hue; S_L, S_C, and S_H are weighting functions; and R_T is a rotation factor [56]. In this study, K_L, K_C, and K_H are parametric factors set to 1.

Furthermore, the CIE L*, a*, and b* measurements acquired on the white and black backgrounds were used to evaluate the translucency parameter (TP) by estimating the CIEDE2000 color difference (ΔE_{00}) between the color values obtained against white and black backgrounds at each test period [57].

III-1.4. Surface gloss

After completing the entire brushing process, the surface gloss was measured three times using a small area glossmeter (WG60; FRU, Beijing, China) at the center of each sample, and the average was recorded. In specific, all specimens were placed in a black opaque container and then covered with the glossmeter to eliminate external light exposure and hold the correct position during the examination. Notably, the glossmeter was calibrated before each measurement. The projection angle of the glossmeter was 60°, and the measurement range was from 0 (for a totally nonreflective surface) to 200 (for a totally reflective surface) gloss units (GU). The glossmeter was designed and manufactured with reference to the international standard ISO 2813.

III-1.5. Surface roughness

The surface roughness was measured on each brushed surface after all interventions with simulated cycles using a Zeiss laser scanning microscope (LSM) 800 MAT confocal scanning laser system combined with a Zeiss Axio imager Z2m microscope with ZEN software (Zeiss, Jena, Germany). On the LSM 800 MAT, imaging was made using laser excitation at 405 nm with a C Epiplan-APOCHROMAT 20 × 0.7 NA. The images were acquired at three sites within the area where each sample was brushed, and the mean of three Ra values was documented. Ra is the arithmetical mean deviation, and the measurements were made with reference to the international standard ISO 4287.

III-1.6. X-ray diffraction (XRD)

After completing all the brushing cycles, one randomly selected sample from each subgroup was subjected to XRD (D8 Advance; Bruker, Karlsruhe, Germany) using Cu-Kα radiation (λ = 1.5406 Å) to ascertain the crystalline phase of each zirconia specimen. The scan was performed at a step size of 0.02° with a scan rate of 2°/min in the 2-theta range between 20° and 60°.

III-1.7. Scanning electron microscopy (SEM)

One representative test specimen in each subgroup was selected for SEM (Model S-4700 SEM; Hitachi High-Technologies Co, Tokyo, Japan) examination after all interventions with simulated brushing cycles. The specimens were sputtered with platinum (Q150T Sputter Coater; Quorum Technologies Ltd., Ashford, Kent, UK) and photographed at an acceleration voltage of 15 kV at magnifications of ×1000 and ×5000.

III-1.8. Statistical analysis

All statistical analyses in this study were performed using IBM SPSS Statistics (v24.0; IBM Corp., Chicago, IL, USA). Repeated-measures analysis of variance (ANOVA) was performed to analyze ΔE_{00} and TP (α = 0.05) with brushing time as a repeated factor and toothbrushing groups as a fixed factor. Separate analyses were conducted for each dependent variable, and a Bonferroni correction was performed. In addition, two-way ANOVA was used to determine the effects of two factors, the finishing methods and dentifrices used, on the ΔE_{00}, TP, GU, and Ra outcome variables. The interactions between the two factors were also analyzed. In this study, the statistical significance was set at 0.05 for all analyses.

III-2. Experiment II. Effects of oral hygiene solutions on the optical and surface properties of high-translucency ceramic restorative materials for digital dentistry

III-2.1. Specimen preparation

For this research, five commercially produced high-translucency CAD/CAM restorative ceramic materials of shade A2 or 2M2 were chosen: a resin nano ceramic (Lava Ultimate [LU], shade A2-HT, size 14L; 3M ESPE, St. Paul, MN, USA), a dual-network ceramic (Vita Enamic [VE], shade 2M2-HT, size EM-14; Vita Zahnfabrik, Bad Säckingen, Germany), a feldspathic ceramic (Vitablocs Mark II [VM], shade 2M2c, size I-14; Vita Zahnfabrik), a lithium disilicate ceramic (IPS e.max CAD [EX], shade A2-HT, size C14; Ivoclar Vivadent AG, Schaan, Liechtenstein), and a high-translucency monolithic zirconia (Rainbow Shine-T [MZ], shade A2, diameter 98 mm, thickness 12 mm; Genoss, Suwon, Korea) (Table II-1). In a sintering furnace (PDF-1000, Dental Max, Seoul, Korea), the monolithic zirconia disks were sintered for 10 h, including 2 h maintained at a temperature of 1550 °C. As recommended by the manufacturer, crystallization of the lithium disilicate blocks was performed at 850 °C (Programat CS2; Ivoclar Vivadent AG).

Each CAD/CAM material was sectioned to fabricate forty rectangular specimens (size, 12 × 14 × 1.2 mm) by using a diamond disc-based slicing machine (Diamonde Blade, Samsung Clover, Seoul, Korea) under water cooling. A horizontal grinding machine (HRG-150, AM Technology, Asan, Korea) was used to adjust the thickness of the specimens. Subsequently, a single surface of each specimen was polished using a 15” lapping machine (SPL-15 Grind-X, Okamoto, Japan) with a 6 μm diamond slurry. Finally, on the edge of the nontested side of each specimen, a fiducial mark was engraved to distinguish between groups. A digital caliper (BD500 - 150, Bluetec, Seoul, Korea) with a resolution of 0.01 mm was used to verify a uniform thickness of 1.2 ± 0.05 mm. Overall, 200 specimens were manufactured, with 40 specimens per material (LU, VE, VM, EX, and MZ). To remove grease residue, all specimens were cleaned ultrasonically for 10 min in isopropyl alcohol.

III-2.2. Mouth rinsing simulation

The five brands of high-translucency specimens were further divided into four subgroups according to the use of oral hygiene solutions. Finally, a total of 20 groups (n=10) were created (Figure II-1). Three oral hygiene solutions were used in this study: conventional mouthwash (LISTERINE Cool Mint, Johnson & Johnson, Bangkok, Thailand, [L]), whitening-enhanced mouthwash (LISTERINE Healthy White Natural Lemon & Salt, Johnson & Johnson, [W]), and chlorhexidine gluconate solution (Hexamedine, Bukwang Pharmaceutical, Seoul, Korea [H]). Distilled water [D] was used as a control.

Oral rinsing was simulated using a laboratory precision-controlled digital rotator (DSR-2800D, Digisystem Laboratory Instrument Inc., New Taipei City, Taiwan) at 100 rpm in the continuous mode. The specimens in each group were placed in custom-made compartments on the laboratory shaker. The compartments were filled with the three oral hygiene solutions and distilled water and sealed separately (Figure II-2).

Continuous exposure to mouthwashes for 12 h has been reported to be equivalent to one year of daily use for one minute twice per day for a patient [58, 59]. Based on these reports, in this study, the specimens were rinsed for 180 h on the laboratory mixer to simulate the exposure of the dental ceramics to oral cleaning solution used daily for approximately 15 years [35]. The solutions were reloaded every 12 h, and the rotating motion of the mixer was continued up to 180 h.

III-2.3. Optical properties

The CIE L^*, a^*, and b^* color coordinates for the entire specimens were estimated using a dental spectrophotometer (EasyShade V, VITA Zahnfabrik, Bad Säckingen, Germany). The dental spectrophotometer was previously reported to exhibit high reproducibility, with intradevice ICCs ranging as 0.913–0.993 [54]. The color coordinates of the test surfaces of the specimens were measured on white and black polytetrafluoroethylene backgrounds (GC-3, Color calibration cards; JJC Co., Seoul, Korea) before and after simulated mouth rinsing. Under standardized D65 light (18W/D65, Philips, Santiago, Chile) illumination from a color assessment cabinet (CAC-4, Zhengzhou Hengchen Electric Tech., Henan, China), three measurements of each specimen were obtained, and the mean was documented for analysis. Before measuring each specimen, the spectrophotometer was calibrated according to the manufacturer's instructions.

The CIE L^*, a^*, and b^* color coordinates obtained on the white background were used to analyze the color components of the specimen and calculate the color change (ΔE_{00}) from before to after simulated mouth rinsing using the following CIEDE2000 color difference formula [55, 56]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)},$$

where $\Delta L'$ is the change in lightness; $\Delta C'$, the change in chroma; $\Delta H'$, the change in hue; S, the weighting function; R_T, the rotation factor; and K_L, K_C, and K_H, the parametric factors, which were set to one [56].

To evaluate translucency, the translucency parameter (TP) was calculated using the ΔE_{00} formula. Specifically, ΔE_{00} between the color value obtained on the white background and that obtained on the black background was recorded as TP [57]. The calculated TP values before and after the mouth rinsing experiment were documented.

III-2.4. Surface gloss

Gloss was measured after completion of the mouth rinsing simulation. A small-area glossmeter (WG60; FRU, Beijing, China) designed to meet ISO 2813 standards was used to measure the surface gloss of the specimens. The glossmeter determined the surface gloss in GUs from zero (for a completely nonreflective surface) to 200 (for a completely reflective surface) with a projection angle of 60°. To eliminate any external light, the specimen was placed in a black opaque container and completely covered with the glossmeter. At the center of each specimen, the surface gloss was measured thrice, and the average was documented for analysis.

III-2.5. Surface roughness

After the mouth rinsing simulation, four representative samples were randomly selected from each group and their tested surfaces were analyzed using a Zeiss LSM 800 MAT confocal laser scanning system coupled with a Zeiss Axio imager Z2m microscope with ZEN software (Zeiss, Jena, Germany). Micrographs were obtained using laser excitation at 405 nm via the C Epiplan-APOCHROMAT 20×/0.7 (Zeiss). Three different sites were photographed on each representative specimen. In all, 12 Ra (arithmetic mean deviation for surface roughness) values were obtained in each group. All measurements were carried out according to ISO 4287 standards.

III-2.6. Surface morphology

One representative specimen from each group was imaged by scanning electron microscopy (SEM; model S-4700 SEM; Hitachi High-Technologies Co, Tokyo, Japan) after sputter-coating with platinum (Q150T Sputter Coater; Quorum Technologies Ltd., Ashford, Kent, UK). Microscopy was conducted at 10 kV accelerating voltage and magnifications of ×1000 and ×5000. The overall study design is illustrated in Figure II-3.

III-2.7. Statistical analysis

All statistical analyses were conducted using IBM SPSS Statistics (v24.0; IBM Corp., Chicago, IL, USA). Two-way analysis of variance (ANOVA) was performed to evaluate the effects of two factors, the ceramic materials and oral solutions used, on ΔE_{00}, TP, GU, and Ra. Additionally, the interactions between the two factors were examined. Furthermore, repeated-measures ANOVA was used to analyze the CIE

L,a*,b** color coordinates and TP with oral rinsing time as a repeated factor and experimental groups as a fixed factor. For each dependent variable, separate analyses were performed, and a Bonferroni correction was made. For all analyses herein, the statistical significance was set to 0.05.

III-3. Experiment III. Effects of ultrasonic scaling on the optical properties and surface characteristics of highly translucent CAD/CAM ceramic restorative materials

III-3.1. Specimen preparation

Commercially available highly translucent CAD/CAM ceramic materials of shade A2 or 2M2 were selected for this study (Table III-1). These materials included a resin nano ceramic (Lava Ultimate [LU] CAD/CAM Restorative, shade A2-HT, size 14L; 3M ESPE, St. Paul, MN, USA), a dual-network ceramic (Vita Enamic [VE], shade 2M2-HT, size EM-14; Vita Zahnfabrik, Bad Säckingen, Germany), a feldspathic ceramic (Vitablocs Mark II [VM], shade 2M2c, size I-14; Vita Zahnfabrik), a lithium disilicate ceramic (IPS e.max CAD [EX], shade A2-HT, size C14; Ivoclar Vivadent AG, Schaan, Liechtenstein), and round CAD/CAM blanks of high-translucency monolithic Y-TZP (Rainbow Shine-T [MZ], shade A2, diameter 98 mm, thickness 12 mm; Genoss, Suwon, Korea). The monolithic zirconia discs were sintered in a sintering furnace (PDF-1000, Dental Max, Seoul, Korea) for 10 h, with a temperature of 1550°C maintained for 2 h. The lithium disilicate blocks were crystallized at 850°C (Programat CS2; Ivoclar Vivadent AG) according to the manufacturer's recommendations.

Twenty rectangular specimens (12 × 14 × 1.2 mm) were prepared from each CAD/CAM material by sectioning using a diamond-disc-based slicing machine (Diamonde Blade, Samsung Clover, Seoul, Korea) under water cooling. The thickness of each specimen was adjusted with a horizontal grinding machine (HRG-150, AM Technology, Asan, Korea). Then, one surface of each specimen was polished with a 15" lapping machine (SPL-15 Grind-X, Okamoto, Japan) with a 6-μm diamond slurry. A uniform thickness of 1.2 ± 0.05 mm was verified using a digital caliper (BD500-150, Bluetec, Seoul, Korea) with a resolution of 0.01 mm. A total of 100 specimens were fabricated, with 20 specimens per material (LU, VE, VM, EX, and MZ). All specimens were ultrasonically cleaned in isopropyl alcohol for 10 min to remove the grease residue.

III-3.2. Ultrasonic scaling procedure

In each major group, 10 specimens were designated as the experimental group, and the other 10 as the control group. The experimental-group specimens were subjected to ultrasonic scaling and evaluated for their optical properties and surface gloss before and after the scaling procedure. The control-group specimens were not subjected to scaling and were used only for comparison of surface characteristics, which were evaluated by confocal laser scanning microscopy (CLSM) and scanning electron microscopy (SEM), because of the possibility of damage during microscopic examinations.

In the experimental groups, a central area measuring 5 mm × 5 mm was marked on the testing surface for ultrasonic scaling. All specimens were scaled by the same board-certified periodontist using an ultrasonic unit (Satelec, Satelec Acteon Group, Merignac Cedex, France) with a stainless-steel tip (Model P10, NSK Nakanishi INC., Tochigi, Japan). Purified water was used as a coolant.

For standardization of the scaling procedure, the periodontist performed 40 scaling strokes on each specimen [60, 61]. To simulate the actual ultrasonic scaling procedure in the oral cavity, the lateral side of the scaler tip was brought in contact with the polished surface of the test specimen (Figure 1). The scaler tip was oriented tangential to the testing surface to the extent possible, and a force of approximately 30 gf was applied, as in the protocols of previous studies [48, 51, 61]. The periodontist conducted a calibration procedure using an electronic balance (Schwartz scale SCH-1812S, SM Korea, Seoul, Korea), to perform ultrasonic scaling with a pressure of approximately 30gf. After the scaling procedure, the specimens were cleaned with distilled water in an ultrasonic bath for 5 min.

III-3.3. Optical properties

A dental spectrophotometer (EasyShade V, VITA Zahnfabrik, Bad Säckingen, Germany) was used to estimate the CIE L^*, a^*, and b^* color coordinates of the 50 experimental specimens. Dental spectrophotometers are reported to show high reproducibility, with intradevice intraclass correlation coefficients (ICCs) ranging from 0.913 to 0.993 [54]. For measurement of the intradevice ICC of the device used in the present study, two representative samples were selected from each group and measured three times, with a 1-h interval between measurements. The intradevice ICCs for L^* and a^* were both 1.000, while that for b^* was 0.999. As a measure to avoid discrepancies, all specimens were measured using the same device.

The measurements were performed on the test surfaces of the specimens against white and black polytetrafluoroethylene backgrounds (GC-3, color calibration cards; JJC Co., Seoul, Korea) before and after scaling. Three measurements were obtained under standardized D65 light (18W/D65, Philips, Santiago, Chile) illumination in a color-assessment cabinet (CAC-4, Zhengzhou Hengchen Electric Tech., Henan, China), and the average value was documented for analysis. The spectrophotometer was calibrated according to the manufacturer's instructions prior to the measurement of each specimen; this precaution eliminated measurement uncertainty.

The CIE L^*, a^*, and b^* color coordinates measured against the white background were used to evaluate the color of the specimen and calculate the color change (ΔE_{00}) after ultrasonic scaling using the following CIEDE2000 color-difference formula [55, 56]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)},$$

where $\Delta L'$ is the change in lightness, $\Delta C'$ is the change in chroma, $\Delta H'$ is the change in hue, S is the weighting function, and R_T is the rotation factor. The parametric factors K_L, K_C, and K_H were set as 1 [56].

For the assessment of translucency, TP was calculated for each specimen. Using the ΔE_{00} formula, TP was calculated as the difference between the color value obtained against the white background and that obtained against the black background [57]. TP values were recorded before and after the scaling procedure for all experimental group specimens.

III-3.4. Surface gloss

The surface gloss was measured using a small area glossmeter (WG60; FRU, Beijing, China) designed according to ISO 2813 standards. The glossmeter had a projection angle of 60° and determined the surface gloss in GUs, which ranged from 0 (for a totally nonreflective surface) to 200 (for a totally reflective surface). The specimen was placed in an opaque black container and covered with the glossmeter for elimination of any external light. Measurements were recorded three times at the center of each specimen, and the mean was documented for analysis. The glossmeter was calibrated before each measurement.

III-3.5. Surface roughness

After the ultrasonic scaling procedure in the experimental group, the surface roughness of the experimental and control specimens was measured using a Zeiss LSM 800 MAT confocal laser scanning system coupled with a Zeiss Axio imager Z2m microscope with ZEN software (Zeiss, Jena, Germany). Micrographs were prepared with laser excitation at 405 nm using the C Epiplan-APOCHROMAT 20×/0.7 (Zeiss). Three different sites within the scaled area on each specimen were photographed, and the mean of the three Ra values was documented. The Ra value for surface roughness is the arithmetic mean deviation. All measurements were performed according to ISO 4287 standards.

III-3.6. Surface morphology

One representative specimen each from the experimental and control groups was examined by SEM (model S-4700 SEM; Hitachi High-Technologies Co, Tokyo, Japan) after sputter coating with platinum (Q150T Sputter Coater; Quorum Technologies Ltd., Ashford, Kent, UK). Imaging was performed at an accelerating voltage of 10 kV and magnifications of ×1000 and ×5000.

III-3.7. Statistical analysis

SPSS software (v24.0; IBM Corp., Chicago, IL) was used to perform all statistical analyses. The Shapiro–Wilk test was used to test the normality of the ΔE_{00} values. Differences in ΔE_{00} values among groups were analyzed using one-way ANOVA. Pairwise comparisons between groups were evaluated by post hoc Tukey's honest significant difference tests. Repeated-measures ANOVA was performed with CIE $L^*a^*b^*$, TP, and surface gloss values as dependent variables, and the Bonferroni correction was subsequently applied. Two-way ANOVA was used for the analysis of differences in surface roughness values. The effects of the tested materials and scaling on Ra values were analyzed. The statistical significance value was set as 0.05 for all analyses.

IV. Results

IV-1. Experiment I. Optical and surface properties of monolithic zirconia after simulated toothbrushing

IV-1.1. Color and translucency

Table I-2 summarizes the results of the repeated-measures ANOVA of color change and TP. Of note, analyses were performed separately for color changes and TPs. Because the color changes as the dependent variable did not satisfy a sphericity assumption (p = 0.002) of the repeated-measures ANOVA, the Greenhouse–Geisser assumption (p = 0.857) was used. The repeated-measures ANOVA revealed a significant impact of simulated years and groups on color differences (ΔE_{00}; p < 0.001). Table I-3 summarizes the mean and standard deviation values of color change for each group during the simulated 17 years of toothbrushing. Analyses were performed separately according to the finishing methods—polished and glazed. In the polishing-finished groups, the brushed groups displayed significantly more color changes than PDW. In the glazing-finished groups, GW exhibited greater shade change than GDW (p = 0.014; Figure I-3). Table I-3 and Figure I-3 show that the ΔE_{00} values of most groups, except PW, were within the 50%:50% perceptibility threshold based on previous studies (0.80–1.30 ΔE_{00} units) [62-64]. However, the ΔE_{00} of PW was still within the clinically acceptable color change threshold (1.80–2.25 ΔE_{00} units) [62-65].

In this study, repeated-measures ANOVA was performed for each of the CIE L^*, a*, and b* values. The CIE L^*, a*, and b* color coordinates exhibited significant differences in time and time × group interaction, respectively. A significant tendency in L^* was observed, but in the glazed groups, there was no significant difference in the L^* value with time. However, in the polished groups, a marked decline in the L^* value after brushing was observed, indicating that the specimen was darkened. In the polished groups that were brushed, a higher decline in the L^* value than that in PDW was observed (Figure I-4).

Furthermore, two-way ANOVA revealed marked differences in color changes based on finishing methods and dentifrice used (Tables I-4 and I-5). The polishing-finished groups exhibited significantly higher color change values than the glazing-finished groups ($p < 0.001$).

In this study, TP satisfied a sphericity assumption of the repeated-measures ANOVA; however, no significant change was shown after simulated toothbrushing, irrespective of the period and experimental group ($p > 0.05$; Table I-2). Table I-6 presents the mean values and standard deviations of TP during the experimental interventions. The two-way ANOVA for TP exhibited no marked difference based on the finishing method and dentifrice used (Tables I-4 and I-5).

IV-1.2. Surface gloss

Two-way ANOVA revealed that the finishing methods ($p < 0.001$) and dentifrice used ($p = 0.005$) exerted a marked impact on the surface gloss (Table I-4); however, no significant interaction was found between the finishing method and dentifrice ($p = 0.874$). Table I-5 shows that groups brushed with a whitening dentifrice exhibited a lower surface gloss value than the groups brushed with a conventional dentifrice and stored in DW after 17 years of simulated toothbrushing. Furthermore, the glazing-finished groups exhibited markedly lower GU than the polishing-finished groups after all interventions. Table I-7 presents the means and standard deviations of GU in each group.

IV-1.3. Surface roughness

Table I-4 presents no significant interaction between the specimen finishing method and dentifrice used based on two-way ANOVA ($p = 0.123$). The finishing methods ($p < 0.001$) and dentifrices ($p = 0.048$) each markedly affected the surface roughness of the tested specimens. The glazing-finished groups presented a rougher surface than the polishing-finished groups after all interventions (Table I-5). In addition, GF exhibited significantly higher Ra values than GDW ($p = 0.004$; Table I-7). Figure I-5 displays representative surface images obtained by a confocal laser scanning microscope.

IV-1.4. XRD

In this study, monoclinic peaks were rarely detected in all groups (Figure I-6). The polishing-finished groups (P line groups) exhibited similar crystallographic patterns. Comparatively, specimens covered with glazing material (G line groups) exhibited a weaker signal. Furthermore, compared with GDW, which exhibited no high peaks, GC, GF, and GW, which were G line groups that were brushed, exhibited several high tetragonal peaks.

IV-1.5. SEM

Figure I-7 displays SEM images (magnification, ×5000) of specimens exhibiting differences in surfaces. The surfaces of the brushed groups (PC, PF, PW, GC, GF, and GW) exhibited scratches and striated patterns caused by toothbrushing procedures. In addition, striated patterns, which were created by manually controlled polishing instruments, were observed on the surfaces of PDW specimens. Conversely, the surfaces of the GDW specimens revealed no wear tracks of abrasion.

IV-2. Experiment II. Effects of oral hygiene solutions on the optical and surface properties of high-translucency ceramic restorative materials for digital dentistry

IV-2.1. Color

Table II-2 presents the results of two-way ANOVA assessing the color shift values (ΔE_{00}) after simulated mouth rinsing according to the ceramic materials and oral hygiene solutions. Statistically significant differences in ceramic, solution, and ceramic × solution were found ($p < .001$). Post hoc tests revealed that the use of oral hygiene solution W resulted in more color changes than the use of other solutions in each VE, VM, and EX group (Table II-3). Among the MZ groups, MZ-W and MZ-H showed significantly greater color shifts than MZ-L and MZ-D. LU-W exhibited the most color changes among the LU groups; however, the difference was not statistically significant.

Repeated-measures ANOVA was performed for CIE L^*, a^*, and b^* values obtained on the white background to identify specific changes in color components (Table II-4). The outcomes showed significant differences in time and the time × group interaction for the L^*, a^* and b^* color coordinates ($p < .001$ each). Table II-5 presents the mean values of L^*, a^*, and b^* for each group before and after the simulated mouth rinsing procedure. After rinsing all the ceramic materials with W, the L^* values increased significantly compared to the respective baseline values ($p < .001$). These color changes represented specimens becoming brighter.

IV-2.2. Translucency

First, the TP values of all specimens were analyzed using repeated-measures ANOVA (Tables II- 4 and II-5). All VE groups, VM-L, and VM-W showed significant decreases in TP after simulated mouth rinsing based on the Bonferroni test ($p < .01$). In contrast, MZ-D exhibited an increase in TP ($p < .01$). The remaining groups showed no statistically significant difference before and after mouth rinsing.

Second, two-way ANOVA revealed significant differences in TP according to the ceramics and solutions evaluated (Tables II- 2 and II-6). The TP values of ceramics differed significantly in the following order: LU > VE > EX > VM > MZ ($p < .001$). In addition, solution W resulted in markedly lower TP than solutions D and H.

IV-2.3. Surface gloss

Two-way ANOVA showed that the ceramic, the solution, and the ceramic × solution interaction had a significant impact on the surface gloss of specimens ($p < .001$; Table II-2). Table II-3 shows that the surface gloss of LU-W, VE-W, VM-W, and EX-W exhibited the lowest GU in each ceramic group based on the post hoc Bonferroni test, and the difference was significant. LU-L, VE-L, and VM-L also showed lower GU values than the respective control groups, which were LU-D, VE-D, and VM-D. Among the MZ groups, no significant difference was observed in GU. Table II-6 shows that groups L and W showed lower GU values than group D ($p < .05$).

IV-2.4. Surface roughness

Tables II-2 and II-3 show significant interaction between the ceramic material and the oral rinsing procedure in Ra according to two-way ANOVA ($p < .001$). LU-W, VE-W, VM-W, and EX-W showed the highest Ra values in each ceramic group. However, no statistically significant difference was observed in the LU and MZ groups. Table II-7 shows that the W groups were significantly rougher than the D groups ($p < .05$). Figure II-4 shows representative micrographs of specimen surfaces obtained by CLSM. Figure II-5 also presents three-dimensional (3D) images of four representative groups. In Figure II-5, the VE-W and VM-W images show much rougher surfaces than the corresponding control groups for each ceramic material.

Table II-7 shows the analysis results of the surface roughness by ceramics and solutions used. The VE and VM specimens showed higher mean Ra values than the LU, EX, and MZ specimens. In addition, the groups rinsed with W or H also exhibited higher Ra values than the D groups.

IV-2.5. Surface morphology

Figure II-6 and II-7 show scanning electron micrographs of representative specimens from each group (magnification: ×5000 and ×1000). Particularly, the surfaces of VE-W, VM-W, and EX-W showed marked surface deterioration caused by the oral rinsing simulation compared to the corresponding control surfaces.

IV-3. Experiment III. Effects of ultrasonic scaling on the optical properties and surface characteristics of highly translucent CAD/CAM ceramic restorative materials

IV-3.1. Color

The ΔE_{00} values were normally distributed for all groups (Shapiro–Wilk test, $p > .05$). Table III-2 summarizes the results of one-way ANOVA assessing the color change (ΔE_{00}) after scaling in each group. Statistically significant differences among groups were found ($p < .001$). Post hoc tests revealed that MZ and VM showed more color changes than did VE, LU, or EX, with the order of mean color change values as follows: MZ > VM > VE, LU, EX (Figure III-2). The ΔE_{00} values for LU, VE, and EX were within the 50%:50% perceptibility threshold defined in previous studies (0.80–1.30 ΔE_{00} units) [62-64], while the values for VM and MZ indicated perceptible color changes. While the color change in VM was within the clinically acceptable threshold (1.80–2.25 ΔE_{00} units) [62-65], that in MZ was beyond this threshold. Figure III-3 shows the color changes after the ultrasonic scaling procedure for a representative specimen from each group.

For identification of specific shade changes, repeated-measures ANOVA was performed for CIE L^*, a^*, and b^* color coordinates measured against the white background (Table III-3). The results revealed significant differences in time and the time × group interaction for the L^* and b^* values ($p < .001$, respectively). Table III-4 shows the mean L^*, a^*, and b^* values before and after the scaling procedure for each material. After the VE, VM, and MZ specimens were scaled, the L^* values significant decreased relative to the respective baseline values ($p < .05$, $p < .001$, and $p < .001$, respectively). These changes indicated an increase in the darkness of these specimens. Moreover, MZ showed a significantly increased a^* value and a significantly decreased b^* value after scaling, which indicated an increase in the red and blue components.

IV-3.2. Translucency

Repeated-measures ANOVA was used to evaluate the TP values for all specimens (Tables III-3 and III-5). For all specimens, no significant change in TP was observed after scaling ($p > .05$), although significant differences among materials were observed before scaling ($p < .05$). Specifically, LU was the most translucent material, and VE showed significantly higher translucency than VM or EX. MZ was the opaquest material (Table III-5).

IV-3.3. Surface gloss

Repeated-measures ANOVA revealed that the scaling × group interaction had a significant impact on the surface gloss of specimens ($p < .001$; Table III-3). Table

III-5 shows that the surface gloss of LU, VE, and VM exhibited a significant increase after ultrasonic scaling ($p < .05$, $p < .01$, and $p < .001$, respectively), whereas that of MZ exhibited a significant decrease ($p < .001$).

Marked differences in GUs were observed among the different groups, with MZ exhibiting the highest GU before and after scaling, followed by EX, LU, VM, and VE ($p < .05$).

IV-3.4. Surface roughness

Table III-6 shows no significant interaction between the ceramic material and the ultrasonic scaling procedure according to two-way ANOVA ($p = .697$). Table III-7 shows the mean Ra values for all control and experimental groups. There were no significant differences between the control and experimental groups for any of the materials.

However, two-way ANOVA revealed significant differences in Ra values among groups ($p < .001$; Table III-6). Specifically, the control and experimental VE and VM specimens showed higher Ra values than did the control or experimental EX or MZ specimens (Table III-7).

Figure III-4 presents representative micrographs of specimen surfaces obtained by CLSM. The images of all experimental specimens showed scrapes, which were evidence of the ultrasonic scaling procedure.

IV-3.5. Surface morphology

Figure III-5 shows SEM images of the representative specimen from each control and experimental group, with a magnification of ×5000. In particular, the surface of the experimental specimen of MZ showed marked surface deterioration caused by the ultrasonic scaling procedure (Figure III-5j). Scratches were also observed on the surfaces of the control specimens; these marks were presumably caused by polishing with the lapping machine and 6-μm diamond slurry.

V. Discussion

V-1. Experiment I. Optical and surface properties of monolithic zirconia after simulated toothbrushing

This study evaluated the impact of toothbrushing on the optical properties and surface characteristics of monolithic zirconia materials. The findings rejected the null hypothesis for both optical properties and surface roughness. Statistically significant changes in color parameters were observed as toothbrushing progressed, and a decline in the surface gloss of the groups brushed with fluoride and whitening dentifrices compared with the group stored in DW was identified. In addition, the surface roughness of the glazed group brushed with a fluoride dentifrice appeared markedly rougher than the unbrushed glazed group. After toothbrushing, the glazed groups exhibited markedly higher color stability than the polished groups; however, the glazed groups exhibited less surface gloss and rougher surfaces than the polished groups.

Our findings corroborate a previous study on color change in brushed zirconia specimens. Yuan et al. [66] reported a statistically significant shade change in extrinsically stained and glazed zirconia specimens after 15 years of simulated brushing. While the evaluated ΔE value between the baseline and after 15-year simulated brushing was approximately 1.5, the resulting color change value was within the perceptibility tolerance of 2.6 ΔE [66]. Unlike the previous study that investigated extrinsically characterized zirconia (IPS shade 3), this study assessed the impact of brushing on the color change of intrinsically colored zirconia materials. As extrinsic stains can be easily damaged or removed by external trauma, such as an occlusal reduction procedure, intrinsic coloring is preferred by dentists. However, to date, no study has investigated the impact of brushing on the shade of intrinsically colored zirconia.

In this study, both polished and glazed zirconia specimens exhibited statistically significant color changes; moreover, polished specimens exhibited more color changes than glazed specimens. In addition, polished specimens became considerably darker after toothbrushing, and the color change was at the border of the perceptibility threshold. Furthermore, compared to the polished specimens, the glazed specimens revealed less shade change, which is consistent with Garza et al. [26], who reported that after 12 years of simulated brushing, lithium disilicate specimens glazed after staining were more resistant to color change than specimens that underwent staining and glazing simultaneously. In addition, Alp et al. [67] demonstrated that polished glass ceramics were more susceptible to staining by coffee thermocycling than glazed specimens, suggesting that the glazing layer coated over the colored specimen could play a protective role.

Regarding the surface gloss, Sen et al. [68] reported a marked decline in the gloss of CAD/CAM restorative materials after 1 year of simulated brushing. This study demonstrated that brushing with fluoride or whitening dentifrices markedly reduced the gloss of zirconia specimens. Moreover, the fluoride-free conventional dentifrice decreased the gloss; however, the difference was not statistically significant. It is possible that the fluoride content or higher RDA of the dentifrice could affect the surface characteristics of zirconia specimens. To date, several studies have demonstrated that acidic and alkaline environments could affect the optical or surface properties of ceramic specimens [22-24]. Furthermore, dentin wear is more strongly impacted by the RDA value of dentifrices than by the stiffness of a toothbrush [19].

In this study, the surface roughness of glazed specimens was also marginally affected by use of the fluoride dentifrice. The roughness of zirconia is crucial because it increases the contact area with moisture, which could result in low-temperature degradation [69, 70]. In addition, a whitening dentifrice reduced the surface roughness of the polished zirconia surface, which corroborated the results from Pinelli et al. [21]. The high RDA of a whitening dentifrice was considered to exert a polishing effect on the zirconia surface. The glazed groups revealed a rougher surface than the polished groups. Reportedly, the surface roughness threshold for bacterial colonization was 0.2 μm [45, 46], and the roughness threshold detectable by the tongue was 0.25–0.5 μm [71]. Although the roughness of the brushed, polished zirconia was within these thresholds, glazed zirconia after brushing exhibited higher results. Furthermore, the results of XRD exhibited no apparent evidence of phase transformation. It is possible that the several high peaks observed in the toothbrushed glazed groups imply partial wear of the glazing layer compared with GDW.

The strength of this study is that the two finishing methods of monolithic zirconia—polishing and glazing—were compared after simulated brushing. In addition, a thick glazing layer could result in errors in the intensity of contact or occlusion of the restoration when fabricated with a modeless CAD/CAM technique; thus, glazing should be selected only when needed. Moreover, brushing was simulated for 8.5 and 17 years, and the long-term effects of brushing were investigated. Previous studies have simulated shorter brushing periods of 1 to 15 years [21, 26, 66, 68]. It is also advantageous to evaluate the number of tooth surfaces to be brushed by the scientific method and calculate the appropriate simulation time and appropriate toothbrush replacement cycle. In addition, three toothpaste formulas were compared in this study. The effects of fluoride were compared by selecting the same brand of fluoride-free toothpaste and high fluoride-containing toothpaste. In addition, a whitening toothpaste with extremely high RDA was also compared. Furthermore, substantial data on various optical and surface properties were obtained through the appropriate arrangement of measurements.

This study has some limitations. The first limitation is the in vitro design. Second, the effects of the aging of zirconia on moisture in the mouth and the fatigue of the material could not be considered because of the accumulated mastication in the clinical setting. Third, DW was used to prepare toothpaste slurry; however, the effect of the mixture of the oral saliva and toothpaste was not investigated. Finally, during the roughness measurement process through a confocal scanning laser system, the voids on the surface of the glazing layer generated in the glazing process were disturbed. Thus, additional clinical studies are warranted to overcome these limitations and validate the findings of this study.

V-2. Experiment II. Effects of oral hygiene solutions on the optical and surface properties of high-translucency ceramic restorative materials for digital dentistry

This study investigated the influence of oral rinsing solutions on the optical properties and surface characteristics of high-translucency CAD/CAM dental restorative materials. The findings rejected both the first and second null hypotheses. The results revealed that ceramic material and mouth rinse type significantly affect the color, translucency, surface gloss, and surface roughness. In particular, simulated mouth rinsing with W made both VE and VM brighter, more opaque, less glossy, and rougher.

The ΔE_{00} values for VE-W, VM-W, MZ-W, and MZ-H were beyond the 50%:50% perceptibility threshold defined by Paravina et al. (0.80 ΔE_{00} units) [63]. However, these color changes were within the perceptible threshold reported by Ghinea et al. (1.3 ΔE_{00} units) [62]. In addition, their ΔE_{00} values were much lower than the clinically acceptable threshold reported in both studies (1.80–2.25 ΔE_{00} units) [62-65]. VE-W, VM-W, and MZ-W showed an increase in the L^* value after oral rinsing simulation. This result could be regarded as a positive effect of W, which emphasized the whitening effect. However, because the directions in which the values of a^* and b^* changed differed for each ceramic group, the color changes in the ceramics due to W may not be considered positive: in clinical situations, the color tone of the ceramic restorations changed by W may differ from the shade of the adjacent natural teeth.

Herein, W affected the color, translucency, surface gloss, and surface roughness of the tested ceramics more than other solutions (Table II-6). Soygun et al. [35] reported that Tantum Verde solution, which contained 95 vol % ethanol, influenced the color and surface roughness of Lava Ultimate more than LISTERINE and 0.2% chlorhexidine gluconate solution. They concluded that the results implied that mouth rinsing solutions with lower alcohol content had lesser deteriorating effects on the color and the surface morphology of the tested CAD/CAM ceramics. In this study, however, the alcohol content of W (ethanol 14.58%) was lower than that of L (ethanol 21.6%). Thus, based on the present results, the alcohol content alone does not appear to have a decisive influence on the optical and surface properties of CAD/CAM ceramics. W contained citric acid, sodium chloride, and sodium fluoride, which were not present in L and may have affected the properties of the high-translucency restorative ceramics. Pelino et al. [34] reported that low pH, alcohol, and peroxide-containing whitening mouthwash did not cause color, ultrastructural, or chemical elemental changes in feldspathic porcelain after simulating up to 6 months of daily use. As 15 years of simulation in this study deteriorated the properties of ceramics, these results should be considered when determining the duration of use of these whitening mouth rinses.

Herein, differences in ceramic materials were observed. VE, VM, and EX were influenced by W. The groups rinsed with W showed brightening of shade, decreasing of gloss, and roughening of surfaces compared to those washed with D. Changes in surface morphology were also observed in the CLSM and SEM images of the Figures. There are many reports on the effects of various solutions, such as coffee, tea, and red wine, on the color stability of various ceramic restorations [22, 29, 31, 72-74]. In most cases, the resulting color change values were lower than the clinically acceptable threshold. However, Acar et al. [29] reported that when LU, VE, and EX were subjected to 5,000 thermocycles in coffee, the change in color was less in VE and EX, while a clinically unacceptable shade change occurred only in LU. In this study, the color change due to mouth rinse was negligible in LU; nevertheless, note that the coloring of the LU may change significantly in other solutions such as coffee.

In this study, the surface roughness of VE, VM, and EX was also affected by the use of W. The W groups revealed a rougher surface than the control (D) groups for VE, VM, and EX. The surface roughness threshold for bacterial colonization was reported to be 0.2 μm [45, 46], and the tongue-detectable roughness threshold was 0.25–0.5 μm [71]. Although the Ra value of EX-W was lower than the bacterial colonization threshold, VE-W and VM-W may be perceived as tangible roughness in some patients.

The strength of this study is the evaluation of newly developed CAD/CAM materials with enhanced translucency. Many studies have compared chairside CAD/CAM materials; however, most compared translucency without discrimination or compared ceramics with low translucency [29, 35, 73, 75]. To compare the optical properties of materials, it is more meaningful to evaluate materials with enhanced translucency because many high-translucency materials are used in anterior teeth where aesthetics is a critical factor. Moreover, chairside CAD/CAM materials are often used without additional surface coatings, such as glazing; therefore, it is necessary to evaluate the color stability of the material surface itself.

This study was designed and performed in vitro and has limitations compared to clinical studies. The effectiveness of saliva in actual clinical practice and the aging effect of restorative materials due to environmental factors were not reflected. In practice, only one side of the restorative material is exposed to the mouthwash in the oral cavity, and the opposite side is cemented to the tooth surface. Thus, in an actual patient, only one side will be affected by the oral cleaning solutions; however, in this study, both sides are likely to be affected by the oral cleaning agent, which may increase the color tone change [30, 67].

Furthermore, in contrast to other materials used in this study, a disc-type zirconia was selected for the experiment rather than a small block because the disk type is used more than the small block in clinical practice. The experimental results showed that the MZ group had a larger color difference even in the control group.

Perhaps the manufacturer did not uniformly add coloring additives during the fabrication of the product, or perhaps the effect of the sintering process on each part of the disc varied so that the color was not uniform after sintering. In future studies, it will be necessary to evaluate the color stability of the ceramic bonded to the natural tooth surface or to investigate the color change in zirconia specimens fabricated with small block-type products.

V-3. Experiment III. Effects of ultrasonic scaling on the optical properties and surface characteristics of highly translucent CAD/CAM ceramic restorative materials

The present *in vitro* study investigated the effects of ultrasonic scaling on the optical properties and surface characteristics of highly translucent CAD/CAM ceramic materials. The null hypothesis was rejected, as both optical properties and surface characteristics were altered by scaling, with statistically significant changes in the shades of VM and MZ. In particular, MZ showed the maximum color changes, with increases in its darkness and its red and blue components. After scaling, none of the materials showed marked changes in translucency, although the surface gloss increased in LU, VE, and VM and decreased for MZ. In addition, there was no significant difference in surface roughness values between specimens subjected to scaling and those without scaling in any of the material groups, while there were significant differences in prescaling color, translucency, surface gloss, and surface roughness values among the different materials.

Some clinicians may have encountered scratch-like discoloration after contact between dental porcelain and a stainless-steel scaler tip or curette. However, such discolorations are not publicized because they are considered to be iatrogenic scratches that occur during the clinical process of scaling. Consequently, it is difficult to find academic studies on color changes induced by ultrasonic scaling of ceramic restorations.

The present study experimentally confirmed that the use of ultrasonic scalers on highly translucent dental ceramics can cause discoloration. MZ, which is a high-translucency monolithic Y-TZP zirconia, exhibited extensive discoloration that was beyond the clinically acceptable threshold of 1.80–2.25 ΔE_{00} units [62-65]. The feldspathic porcelain VM also exhibited perceptible but acceptable color changes. However, for a patient with high color sensitivity, such perceptible discoloration can be unacceptable. The LU, VE, and EX groups showed relatively reduced color changes that were imperceptible. Thus, restorative dentists should be aware of differences in color responses to ultrasonic scaling among different materials and select the appropriate material. Moreover, periodontists should consider this color change before undertaking scaling procedures for patients with such restorations. Further research will be needed for the development of monolithic zirconia and feldspathic porcelain materials that exhibit no perceptible color change on ultrasonic scaling.

With regard to translucency, although none of the materials showed marked changes after scaling, there were significant differences in TP values among the different materials, with MZ and LU showing the lowest and highest TP values, respectively, both before and after ultrasonic scaling. Clinically, TP should be considered during the selection of ceramic materials for the restoration of discolored teeth or titanium abutments for implants. A previous study [9] on the translucency of the materials assessed in the present study showed similar results for all materials except VE. This discrepancy could be caused by differences in the TP calculation formula (ΔE and ΔE_{00}), specimen thickness (1.2 and 1.5 mm), and measurement environment.

In the present study, the surface gloss of MZ, which showed a significantly higher GU than did the other materials before scaling, decreased after scaling. However, the surface gloss of LU, VE, and VM increased after ultrasonic scaling. There are few studies on the effects of ultrasonic scaling on the surface gloss of dental ceramics, and further study is needed to determine whether the changes observed in the present study are clinically meaningful. In addition, the five materials in the present study differed significantly in surface gloss. The surface gloss varies according to the degree of polishing [68, 76-78], and the present study found that

MZ exhibited the highest GU, while VE exhibited the lowest GU, after polishing with a 6-μm diamond slurry.

Several studies have evaluated changes in surface roughness after ultrasonic scaling [47, 48, 50, 51]. In the present study, the mean Ra value for all materials except EX was slightly higher for specimens subjected to scaling than for those without scaling. However, no statistically significant difference was noted for any material. This finding differs from those of several previous studies, which reported a significant increase in the surface roughness after scaling [48, 51]. This discrepancy could be attributed to the increased scaling duration in the previous studies. In clinical practice, however, the scaling duration for ceramic restorations should be shorter than that for natural teeth to avoid damage to the restorations. Accordingly, in the present study, ultrasonic scaling was performed for a relatively short duration. The results of the Ra values showed that VE was the roughest material, while MZ and EX were relatively smooth. Although the mean Ra values for the experimental VE and VM specimens were higher than the bacterial adhesion threshold of 0.2 μm [45, 46], they were within the tongue detectable threshold of 0.25–0.5 μm [71].

The strength of this study is that different high-translucency CAD/CAM ceramics were compared after simulated clinical ultrasonic scaling procedures. While LU, VE, EX, and MZ are commercial dental ceramics specifically developed for restorations demanding high translucency, VM is a feldspathic porcelain that is typically more translucent than other conventional dental ceramics. These ceramics are the most frequently chosen for anterior teeth; therefore, their optical properties should be investigated and well managed. Furthermore, an appropriate sequence of measurements provided us with extensive data on various optical and surface properties.

The *in vitro* design is the major limitation of this study. The effects of saliva, accumulated mastication, and aging of the ceramic materials may influence the results in actual clinical conditions. Additional clinical studies are needed to confirm the results of this study. In addition, further studies should assess the method of polishing for the removal of discolorations from ceramic restorations after ultrasonic scaling procedures and the possible side effects of polishing.

VI. Conclusions

The oral hygiene methods markedly affected the optical and surface properties of restorative materials for digital dentistry. Within the limitations of this in vitro study, the following conclusions can be drawn.

VI-1. Experiment I. Optical and surface properties of monolithic zirconia after simulated toothbrushing

The Experiment I reveals that brushing with several dentifrices markedly affects the optical properties and surface characteristics of monolithic zirconia finished with polishing or glazing methods. Within the limitations of this in vitro study, the following conclusions were drawn:

1. Statistically significant differences were found in the color change of the monolithic zirconia material groups after 17 years of simulated brushing; however, the changes were within the previously reported clinically acceptable threshold [62-65]. The translucency parameter showed no significant change.
2. Gloss was significantly lower in the groups that were brushed with fluoride toothpaste and whitening toothpaste than that in the unbrushed group. The surface roughness in the glazed group brushed with the fluoride dentifrice was significantly higher than that in the unbrushed group.

3. Minor differences were observed in XRD among the glazing-finished groups. The glazing layer was slightly worn off with any toothpaste and revealed some ZrO_2 peaks under the silica layer.

The polished groups had significantly lower color stability after brushing; however, the gloss was higher, and the roughness was lower. There was no significant difference noted in translucency.

VI-2. Experiment II. Effects of oral hygiene solutions on the optical and surface properties of high-translucency ceramic restorative materials for digital dentistry

The results of the Experiment II reveal that rinsing with several mouthwashes markedly affects the optical and surface properties of high-translucency CAD/CAM ceramic materials. Within the limitations of this in vitro study, the following conclusions can be drawn:

1. Compared to each corresponding control group, significantly greater color changes were found in VE-W, VM-W, EX-W, MZ-W, and MZ-H after 15 years of simulated oral rinsing; however, the color changes were within the previously reported clinically acceptable threshold [62-65]. The TP was significantly decreased in the VM-L and VM-W groups and all VE groups after simulated oral rinsing.

2. The GU value was significantly lower in LU-W, VE-W, VM-W, and EX-W than in the corresponding control groups. The Ra values of VE-W, VM-W, VM-H, and EX-W were significantly higher than those in the D group of each ceramic type.

3. Several differences were observed in the CLSM and SEM images. The surfaces of VE-W, VM-W, and EX-W showed surface deterioration.

After the simulation of 15 years of oral rinsing with W, the VE and VM became brighter, more opaque, less glossy, and rougher. Dentists should be aware that some mouthwashes may affect the optical properties and surface characteristics of high-translucency CAD/CAM dental restorative materials.

VI-3. Experiment III. Effects of ultrasonic scaling on the optical properties and surface characteristics of highly translucent CAD/CAM ceramic restorative materials

In conclusion, the findings of the Experiment III suggest that ultrasonic scaling, which is a routinely performed procedure in dental clinics, markedly affects the optical properties and surface characteristics of highly translucent CAD/CAM ceramic materials. The findings can aid restorative dentists in selecting appropriate materials and motivate periodontists to give due consideration to restorations when performing scaling procedures in esthetically demanding areas.

VII. Clinical Implications

Oral hygiene procedures are usually performed periodically throughout an individual's lifetime. Critical influence of these oral hygiene practices on the optical and surface properties of newly developed CAD/CAM restorative materials make those materials confined in clinical applications. In this study, the effects of three commonly used oral hygiene techniques were evaluated: toothbrushing, oral rinsing, and ultrasonic scaling.

First, after 17 years of simulated brushing with a whitening dentifrice, monolithic zirconia specimens that had been finished with polishing without glazing showed the maximum change in color; however, the changes were within the previously reported clinically acceptable threshold. Second, after 15 years of simulated oral rinsing with whitening mouthwash, dual network-ceramic specimens and feldspathic ceramic specimens became brighter, rougher, more opaque, and less glossy. Third, after ultrasonic scaling, high-translucency monolithic zirconia exhibited extensive discoloration that was beyond the clinically acceptable threshold of 1.80–2.25 ΔE_{00} units. The feldspathic ceramic specimens also exhibited perceptible but acceptable color changes. Therefore, these procedures were found to partially affect the aesthetic and surface properties of CAD/CAM restorative materials.

Dental clinicians should take these results into consideration when selecting appropriate dental restorative materials for CAD/CAM in dental clinics. Furthermore, it would be beneficial if manufacturers could enhance and develop CAD/CAM dental restorative materials based on the findings of this study.

VIII. Published papers related to this study

J.H. Lee, S.H. Kim, J.S. Han, I.L. Yeo, H.I. Yoon, Optical and Surface Properties of Monolithic Zirconia after Simulated Toothbrushing. Materials 12(7) (2019) 1158. https://doi.org/10.3390/ma12071158

J.H. Lee, S.H. Kim, J.S. Han, I.L. Yeo, H.I. Yoon, J. Lee, Effects of ultrasonic scaling on the optical properties and surface characteristics of highly translucent CAD/CAM ceramic restorative materials: An in vitro study. Ceramics International 45 (2019) 14594-14601. https://doi.org/10.1016/j.ceramint.2019.04.177

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Tables

Experiment I. Optical and surface properties of monolithic zirconia after simulated toothbrushing

Table I-1-1. Materials used in this study.

Classification	Brand	Manufacturer	Composition *
Monolithic zirconia	Rainbow Shade Block, A2	Genoss	ZrO_2, Y_2O_3 4–6%, $HfO_2 \leq 5\%$, $Al_2O_3 \leq 1\%$, Other oxides.
Glaze	Glaze HeraCeram	Heraeus Kulzer	SiO_2 64.0–66.0%, Al_2O_3 10.4–11.4%, K_2O 14.5–15.5%, Na_2O 4.5–5.5%, Other oxides.

* As disclosed by manufacturers.

Table I-1-2. Materials used in this study.

Classification	Brand	Manufacturer	Composition *	Code
Conventional dentifrice (Fluoride-free)	Parodontax Classic Fluoridfrei	GlaxoSmith Kline	Sodium Bicarbonate, Aqua, Glycerin, Alcohol, Cocamidopropyl Betaine, *Mentha arvensis* Oil, *Mentha piperita* Oil, Xanthan Gum, *Echinacea purpurea* Flower/Leaf/Stem Juice, *Krameria triandra* Extract, Chamomilla Recutita Extract, *Salvia officinalis* Oil, *Commiphora myrrha* Extract, Limonene, Sodium Saccharin, Linalool, CI 77491.	C
Fluoride dentifrice	Parodontax Fluorid	GlaxoSmith Kline	Sodium Bicarbonate, Aqua, Glycerin, Alcohol, Cocamidopropyl Betaine, *Mentha arvensis* Oil, *Mentha piperita* Oil, Xanthan Gum, *Echinacea purpurea* Flower/Leaf/Stem Juice, *Krameria triandra* Extract, Sodium Fluoride, Chamomilla Recutita Extract, *Salvia officinalis* Oil, *Commiphora myrrha* Extract, Limonene, Sodium Saccharin, Linalool, CI 77491, Enthalt Natriumfluorid (1400 ppm fluoride).	F
Whitening dentifrice	Crest 3d White Vivid	Procter & Gamble	Water, Sorbitol, Hydrated Silica, Disodium Pyrophosphate, Sodium lauryl sulfate, Flavor, Cellulose Gum, Sodium Hydroxide, Sodium Saccharin, Carbomer, Mica, Titanium Dioxide, Blue 1, Sodium Fluoride 0.243% (1500 ppm fluoride ion).	W

* As disclosed by manufacturers.

Table I-2. Results of the repeated-measures ANOVA with color change (ΔE_{00}) and translucency parameter as the dependent variable.

Source	Type III Sum of Squares	*df*	Mean Squares	*F*	*p*
Dependent variable: Color change (ΔE_{00})					
Time	9.934	1.715	5.794	336.669 ***	<.001
Time × Group	2.142	12.002	0.178	10.371 ***	<.001
Error	2.125	123.448	0.017		
Dependent variable: Translucency parameter					
Time	0.025	2.000	0.012	0.908	0.406
Time × Group	0.047	14.000	0.003	0.243	0.998
Error	1.979	144.000	0.014		

***$p < .001$.

Table I-3. The mean and standard deviation of color change (ΔE_{00}) values.

Group	Simulated Brushing Time			
	Between Baseline and after 8.5 Years		Between Baseline and after 17 Years	
	Mean	Standard Deviation	Mean	Standard Deviation
PDW	0.2458 ^{a}	0.1083	0.3158 ^{a}	0.1184
PC	0.4035 ^{a,b}	0.1574	0.7164 ^{b}	0.1670
PF	0.509 ^{b}	0.1817	0.7498 ^{b}	0.2881
PW	0.5857 ^{b}	0.1716	0.8106 ^{b}	0.1946
GDW	0.1988 ^{A}	0.0365	0.1953 ^{A}	0.0690
GC	0.253 ^{A}	0.0727	0.301 ^{A,B}	0.1687
GF	0.2643 ^{A}	0.1399	0.3051 ^{A,B}	0.1735
GW	0.2785 ^{A}	0.1443	0.4846 ^{B}	0.1600

PDW, polished surface and storage in distilled water; PC, polished surface and brushed with a conventional dentifrice; PF, polished surface and brushed with a fluoride dentifrice; PW, polished surface and brushed with a whitening dentifrice; GDW, glazed surface and storage in distilled water; GC, glazed surface and brushed with a conventional dentifrice; GF, glazed surface and brushed with a fluoride dentifrice; GW, glazed surface and brushed with a whitening dentifrice. Bonferroni: a < b; A < B. Means with the same superscript in each column are not significantly different from each other based on the Bonferroni test ($p > .05$).

Table I-4-1. Results of two-way ANOVA with color change, translucency parameter, surface gloss, and surface roughness as the dependent variable.

Source	Type III Sum of Squares	*df*	Mean Squares	*F*	*p*
Dependent variable: Color change (ΔE_{00})					
Finishing	2.134	1	2.134	67.84 ***	<.001
Dentifrice	1.629	3	0.543	17.262 ***	<.001
Finishing × Dentifrice	0.322	3	0.107	3.407 *	0.022
Error	2.265	72	0.031		
Dependent variable: Translucency parameter					
Finishing	0.060	1	0.060	0.634	0.428
Dentifrice	0.213	3	0.071	0.754	0.524
Finishing × Dentifrice	0.065	3	0.022	0.231	0.874
Error	6.773	72	0.094		

***p < .001; **p < .01; *p < .05.

Table I-4-2. Results of two-way ANOVA with color change, translucency parameter, surface gloss, and surface roughness as the dependent variable.

Source	Type III Sum of Squares	*df*	Mean Squares	*F*	*p*
Dependent variable: Gloss (GU)					
Finishing	4124.192	1	4124.192	22.886 ***	<.001
Dentifrice	2477.803	3	825.934	4.583 **	0.005
Finishing × Dentifrice	125.081	3	41.694	0.231	0.874
Error	12974.882	72	180.2067		
Dependent variable: Roughness (Ra)					
Finishing	4.266	1	4.266	97.718 ***	<.001
Dentifrice	0.363	3	0.121	2.769 *	0.048
Finishing × Dentifrice	0.261	3	0.087	1.990	0.123
Error	3.143	72	0.044		

***$p < .001$; **$p < .01$; *$p < .05$.

Table I-5-1. The mean and standard error of each dependent variable according to the finishing methods and dentifrice used.

		Color Change (ΔE_{00}) *		Translucency Parameter	
Group	n	Mean	Standard Error	Mean	Standard Error
Finishing					
P	40	0.6481 ^{b}	0.028	4.7545 ^{a}	0.049
G	40	0.3215 ^{a}	0.028	4.6999 ^{a}	0.049
Dentifrice					
DW	20	0.2555 ^{A}	0.04	4.7742 ^{A}	0.069
C	20	0.5087 ^{B}	0.04	4.7819 ^{A}	0.069
F	20	0.5275 ^{B}	0.04	4.6881 ^{A}	0.069
W	20	0.6476 ^{B}	0.04	4.6647 ^{A}	0.069

P, polished; G, glazed; DW, storage in distilled water; C, brushed with a conventional dentifrice; F, brushed with a fluoride dentifrice; W, brushed with a whitening dentifrice. Bonferroni: a < b; A < B. Means with the same superscript in each column are not significantly different from each other based on the Bonferroni test ($p > .05$). * Color change (ΔE_{00}) between the baseline and 17 years of simulated brushing.

Table I-5-2. The mean and standard error of each dependent variable according to the finishing methods and dentifrice used.

		Gloss (GU)		Roughness (Ra: μm)	
Group	***n***	**Mean**	**Standard Error**	**Mean**	**Standard Error**
		Finishing			
P	40	96.075 [b]	2.123	0.132 [a]	0.033
G	40	81.715 [a]	2.123	0.594 [b]	0.033
		Dentifrice			
DW	20	93.8 [B]	3.002	0.298 [A]	0.047
C	20	93.275 [B]	3.002	0.321 [A]	0.047
F	20	88.585 [A,B]	3.002	0.473 [A]	0.047
W	20	79.92 [A]	3.002	0.36 [A]	0.047

P, polished; G, glazed; DW, storage in distilled water; C, brushed with a conventional dentifrice; F, brushed with a fluoride dentifrice; W, brushed with a whitening dentifrice. Bonferroni: a < b; A < B. Means with the same superscript in each column are not significantly different from each other based on the Bonferroni test ($p > .05$). * Color change (ΔE_{00}) between the baseline and 17 years of simulated brushing.

Table I-6. The mean and standard deviation of translucency parameter values.

Group	Simulated Brushing Time					
	Baseline		8.5 Years		17 Years	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
PDW	4.7715	0.1008	4.7717	0.2972	4.7731	0.3186
PC	4.7829	0.2804	4.7802	0.2432	4.7807	0.2615
PF	4.7681	0.3191	4.7535	0.2811	4.7464	0.3464
PW	4.7585	0.4046	4.7484	0.4712	4.7179	0.4237
GDW	4.7675	0.3011	4.7696	0.2563	4.7753	0.2633
GC	4.7851	0.3517	4.7830	0.3311	4.7831	0.2908
GF	4.7297	0.2942	4.6916	0.2870	4.6297	0.2552
GW	4.6526	0.2499	4.6406	0.2856	4.6115	0.2533

PDW, polished surface and storage in distilled water; PC, polished surface and brushed with a conventional dentifrice; PF, polished surface and brushed with a fluoride dentifrice; PW, polished surface and brushed with a whitening dentifrice; GDW, glazed surface and storage in distilled water; GC, glazed surface and brushed with a conventional dentifrice; GF, glazed surface and brushed with a fluoride dentifrice; GW, glazed surface and brushed with a whitening dentifrice. No significant difference was shown ($p > .05$).

Table I-7. The mean and standard deviation of surface gloss (GU) and surface roughness (Ra) values.

Group	n	Gloss (GU)		Roughness (Ra: μm)	
		Mean	Standard Deviation	Mean	Standard Deviation
PDW	10	102.4 ^{a}	19.98	0.1549 ^{a}	0.0911
PC	10	101.33 ^{a}	14.68	0.0976 ^{a}	0.0735
PF	10	93.97 ^{a}	19.32	0.1759 ^{a}	0.1097
PW	10	86.6 ^{a}	20.14	0.1004 ^{a}	0.0507
GDW	10	85.2 ^{A}	1.55	0.441 ^{A}	0.1614
GC	10	85.22 ^{A}	1.13	0.5443 ^{A,B}	0.2540
GF	10	83.2 ^{A}	2.99	0.7704 ^{B}	0.2819
GW	10	73.24 ^{A}	5.98	0.6205 ^{A,B}	0.3885

PDW, polished surface and storage in distilled water; PC, polished surface and brushed with a conventional dentifrice; PF, polished surface and brushed with a fluoride dentifrice; PW, polished surface and brushed with a whitening dentifrice; GDW, glazed surface and storage in distilled water; GC, glazed surface and brushed with a conventional dentifrice; GF, glazed surface and brushed with a fluoride dentifrice; GW, glazed surface and brushed with a whitening dentifrice. Bonferroni: A < B. Means with the same superscript in each column are not significantly different from each other based on the Bonferroni test ($p > .05$).

Experiment II. Effects of oral hygiene solutions on the optical and surface properties of high-translucency ceramic restorative materials for digital dentistry

Table II-1-1. Study materials.

Classification	Brand	Manufacturer	Lot	Color	Size	Code
Resin nano ceramic	LAVA Ultimate	3M ESPE	N941201	A2-HT	14L	LU
Dual-network ceramic	VITA Enamic	VITA Zahnfabrik	80600	2M2-HT	EM-14	VE
Feldspathic ceramic	VITA Mark II	VITA Zahnfabrik	59451	2M2C	I14	VM
Lithium disilicate glass ceramic	IPS e.max CAD	Ivoclar Vivadent	X42738	HT A2	C14	EX
High-translucency monolithic zirconia	Rainbow Shine-T	Genoss	18K20-02	A2	Ø98-12T	MZ
Mouthwash	LISTERINE Cool Mint	Johnson & Johnson	G085A			L
Tooth whitening mouthwash	LISTERINE Healthy White Natural Lemon & Salt	Johnson & Johnson	261018C 300A			W
Chlorohexidine	Hexamedine	Bukwang Pharmaceutical	18113			H

Table II-1-2. Study materials.

Classification	Brand	Composition*
Resin nano ceramic	LAVA Ultimate	80% nano ceramic particles (69% SiO_2, 31% ZrO_2) 20% highly crosslinked (methacrylate-based) polymer matrix (Bis-GMA, UDMA, Bis-EMA, TEGDMA)
Dual-network ceramic	VITA Enamic	86% feldspathic-based ceramic network (58-63% SiO_2, 20-23% Al_2O_3, 9-11% Na_2O, 4-6% K_2O, 0-1% ZrO_2) 14% acrylate polymer network (UDMA and TEGDMA)
Feldspathic ceramic	VITA Mark II	56-64% SiO_2, 20-23% Al_2O_3, 6-9%Na_2O, 6-8% K_2O
Lithium disilicate glass ceramic	IPS e.max CAD	58-80% SiO_2, 11-19% Li_2O, 0-13% K_2O, 0-8% ZrO_2, 0-5% Al_2O_3
High-translucency monolithic zirconia	Rainbow Shine-T	81-94% ZrO_2, 6-9% Y_2O_3, 5%≥HfO_2, 1%≥Al_2O_3, other oxides

Bis-EMA, ethoxylated bisphenol-A dimethacrylate; Bis-GMA, bisphenol-A glycidyl dimethacrylate; TEGDMA, triethyleneglycol dimethacrylate; UDMA, urethane dimethacrylate. *As disclosed by manufacturers.

Table II-1-3. Study materials.

Classification	Brand	Composition*
Mouthwash	LISTERINE Cool Mint	Active ingredients: thymol, eucalyptol, methyl salicylate, and menthol. Inactive ingredients: water, ethanol (21.6%), poloxamer 407, sorbitol solution (70%), flavor, sodium saccharin, benzoic acid, zinc chloride, sodium benzoate and green 3
Tooth whitening mouthwash	LISTERINE Healthy White Natural Lemon & Salt	Active ingredients: Thymol, eucalyptol, menthol, and sodium fluoride 0.02% (0.01% w/v Fluoride Ion). Inactive ingredients: water, ethanol (14.58%), poloxamer 407, sorbitol solution (70%), sucralose, sodium saccharin, tetrapotassium pyrophosphate, pentasodium triphosphate, sodium chloride, citric acid, flavor, sodium benzoate
Chlorohexidine	Hexamedine	Chlorohexidine gluconate 0.005 mL/g

*As disclosed by manufacturers.

Table II-2. Results of two-way ANOVA with dependent variable color change, translucency parameter, surface gloss, and surface roughness.

Source	Type III Sum of Squares	*df*	Mean Squares	*F*	*p*
Dependent variable: Color change (ΔE_{00})					
Ceramic	8.780	4	2.195	32.142***	<.001
Solution	9.268	3	3.089	45.235***	<.001
Ceramic × Solution	3.391	12	0.283	4.138***	<.001
Error	12.293	180	0.068		
Dependent variable: Translucency parameter					
Ceramic	1052.427	4	263.107	1046.087***	<.001
Solution	3.979	3	1.326	5.273**	<.01
Ceramic × Solution	4.698	12	0.391	1.556	0.108
Error	45.273	180	0.252		
Dependent variable: Surface gloss (GU)					
Ceramic	414215.006	4	103553.752	9717.305***	<.001
Solution	9395.500	3	3131.833	293.886***	<.001
Ceramic × Solution	4484.600	12	373.717	35.069***	<.001
Error	1918.194	180	10.657		
Dependent variable: Surface roughness (Ra)					
Ceramic	1.309	4	0.327	197.980***	<.001
Solution	0.400	3	0.133	80.628***	<.001
Ceramic × Solution	0.453	12	0.038	22.858***	<.001
Error	0.364	220	0.002		

***$p < .001$, **$p < .01$

Table II-3. Mean and standard deviation (SD) of color change, surface gloss, and surface roughness.

Group		Dependent variable					
		Color change (ΔE_{00})*		Gloss (GU)		Roughness (Ra: μm)	
		Mean	SD	Mean	SD	Mean	SD
LU							
	L	0.551^{a}	0.15	51.91^{b}	2.47	0.079^{a}	0.01
	W	0.59^{a}	0.21	40.58^{a}	3.97	0.089^{a}	0.01
	H	0.397^{a}	0.16	53.32^{b}	3.07	0.078^{a}	0.02
	D	0.318^{a}	0.13	58.2^{c}	3.26	0.066^{a}	0.01
VE							
	L	0.607^{a}	0.10	12.93^{b}	3.58	0.193^{a}	0.02
	W	0.993^{b}	0.22	2.23^{a}	1.12	0.312^{b}	0.06
	H	0.382^{a}	0.14	14.23^{b}	3.94	0.19^{a}	0.04
	D	0.432^{a}	0.13	18.67^{c}	5.99	0.161^{a}	0.02
VM							
	L	0.421^{a}	0.08	26.1^{b}	2.88	0.153^{ab}	0.04
	W	1.107^{b}	0.24	6.18^{a}	1.31	0.419^{c}	0.12
	H	0.159^{a}	0.05	31.16^{c}	3.30	0.187^{b}	0.09
	D	0.209^{a}	0.07	30.43^{c}	6.43	0.122^{a}	0.02
EX							
	L	0.189^{a}	0.08	61.88^{b}	1.91	0.07^{ab}	0.02
	W	0.747^{b}	0.16	34.56^{a}	3.56	0.107^{b}	0.01
	H	0.117^{a}	0.07	66.35^{c}	1.47	0.046^{a}	0.00
	D	0.163^{a}	0.09	63.34^{bc}	1.56	0.046^{a}	0.01
MZ							
	L	0.718^{a}	0.51	142.35^{a}	2.38	0.056^{a}	0.03
	W	1.163^{b}	0.41	142.59^{a}	1.61	0.055^{a}	0.01
	H	1.073^{b}	0.67	142.56^{a}	1.91	0.053^{a}	0.01
	D	0.759^{a}	0.40	139.23^{a}	3.28	0.059^{a}	0.02

Bonferroni: a < b < c. Means with the same superscript in each column and each ceramic are not significantly different from each other based on the Bonferroni test ($p > .05$) *Color change (ΔE_{00}) between baseline and simulated oral rinsing. LU, resin nano ceramic. VE, dual-network ceramic. VM, feldspathic ceramic. EX, lithium disilicate ceramic. MZ, high-translucency monolithic zirconia. L, conventional mouthwash. W, whitening-enhanced mouthwash. H, chlorhexidine gluconate. D, distilled water.

Table II-4. Results of repeated-measures ANOVA with dependent variables CIE *L**, *a**, *b** and translucency parameter.

Source	Type III Sum of Squares	*df*	Mean Squares	*F*	*p*
Dependent variable: *L**					
Time	28.569	1	28.569	342.657***	<.001
Time × Group	36.948	19	1.945	23.324***	<.001
Error	15.008	180	0.083		
Dependent variable: *a**					
Time	0.081	1	0.081	43.709***	<.001
Time × Group	1.269	19	0.067	35.948***	<.001
Error	0.334	180	0.002		
Dependent variable: *b**					
Time	3.591	1	3.591	58.915***	<.001
Time × Group	23.272	19	1.225	20.095***	<.001
Error	10.972	180	0.061		
Dependent variable: Translucency parameter					
Time	0.830	1	0.830	22.850***	<.001
Time × Group	4.610	19	0.243	6.680***	<.001
Error	6.538	180	0.036		

***$p < .001$

Table II-5-1. Mean and standard deviation (SD) of CIE *L**, *a**, *b** and translucency parameter values.

Group	n	Dependent variable *L** Before Mean	Before SD	After Mean	After SD	*p*
LU						
L	10	92.87[a]	0.53	92.8[a]	0.4	0.588
W	10	92.81[a]	0.7	93.32[a]	0.67	<.001
H	10	92.47[a]	0.65	92.1[a]	0.63	<.01
D	10	92.69[a]	0.79	92.44[a]	0.77	0.054
VE						
L	10	91.8[a]	0.22	92.72[a]	0.13	<.001
W	10	92.38[a]	0.32	93.94[a]	0.3	<.001
H	10	92.5[a]	0.29	93.01[a]	0.33	<.001
D	10	92.42[a]	0.15	93[a]	0.21	<.001
VM						
L	10	94.8[a]	0.43	94.8[a]	0.34	1
W	10	94.76[a]	0.42	96.43[a]	0.25	<.001
H	10	94.74[a]	0.39	94.68[a]	0.41	0.643
	10	95.25[a]	0.9	95.42[a]	0.79	0.19
EX						
L	10	92.8[a]	0.13	93.03[a]	0.12	0.077
W	10	92.83[a]	0.13	94.06[a]	0.32	<.001
H	10	92.57[a]	0.28	92.65[a]	0.26	0.537
D	10	92.85[a]	0.15	93.04[a]	0.22	0.143
MZ						
L	10	79.72[b]	6.35	80[b]	5.6	<.05
W	10	72.13[a]	4.11	73.53[a]	4.17	<.001
H	10	75.14[a]	5.31	76.38[ab]	4.76	<.001
D	10	74.66[a]	7.22	75.53[a]	6.85	<.001

Bonferroni: a < b. Means with the same superscript in each column and each ceramic are not significantly different from each other based on the Bonferroni test ($p > .05$). LU, resin nano ceramic. VE, dual-network ceramic. VM, feldspathic ceramic. EX, lithium disilicate ceramic. MZ, high-translucency monolithic zirconia. L, conventional mouthwash. W, whitening-enhanced mouthwash. H, chlorhexidine gluconate. D, distilled water.

Table II-5-2. Mean and standard deviation (SD) of CIE *L**, *a**, *b** and translucency parameter values.

Group	n	Dependent variable				
		a^*				
		Before		After		p
		Mean	SD	Mean	SD	
LU						
L	10	-2.34[a]	0.05	-2.51[a]	0.06	<.001
W	10	-2.36[a]	0.11	-2.42[a]	0.09	<.01
H	10	-2.4[a]	0.09	-2.37[a]	0.11	0.121
D	10	-2.34[a]	0.11	-2.45[a]	0.12	<.001
VE						
L	10	2.4[a]	0	2.21[a]	0.06	<.001
W	10	2.34[a]	0.05	2.44[b]	0.07	<.001
H	10	2.37[a]	0.05	2.39[b]	0.03	0.301
D	10	2.4[a]	0	2.28[ab]	0.04	<.001
VM						
L	10	-0.26[b]	0.08	-0.58[a]	0.13	<.001
W	10	-0.36[b]	0.05	-0.15[b]	0.07	<.001
H	10	-0.35[b]	0.08	-0.26[b]	0.07	<.001
D	10	-0.08[a]	0.27	-0.14[b]	0.24	<.01
EX						
L	10	-1.38[a]	0.04	-1.38[a]	0.04	1
W	10	-1.41[a]	0.07	-1.42[a]	0.06	0.605
H	10	-1.35[a]	0.05	-1.31[a]	0.06	<.05
D	10	-1.43[a]	0.05	-1.41[a]	0.06	0.301
MZ						
L	10	2.37[a]	0.11	2.35[a]	0.07	0.301
W	10	2.52[ab]	0.18	2.54[b]	0.13	0.301
H	10	2.52[ab]	0.13	2.53[b]	0.11	0.605
D	10	2.57[b]	0.13	2.52[b]	0.11	<.05

Bonferroni: a < b. Means with the same superscript in each column and each ceramic are not significantly different from each other based on the Bonferroni test (p > .05). LU, resin nano ceramic. VE, dual-network ceramic. VM, feldspathic ceramic. EX, lithium disilicate ceramic. MZ, high-translucency monolithic zirconia. L, conventional mouthwash. W, whitening-enhanced mouthwash. H, chlorhexidine gluconate. D, distilled water.

Table II-5-3. Mean and standard deviation (SD) of CIE L^*, a^*, b^* and translucency parameter values.

Group	n	Dependent variable b^*				
		Before		After		
		Mean	SD	Mean	SD	p
LU						
L	10	15.36[a]	0.53	14.59[a]	0.45	<.001
W	10	15.26[a]	0.79	14.48[a]	0.71	<.001
H	10	14.79[a]	0.54	14.31[a]	0.48	<.001
D	10	14.99[a]	0.64	14.68[a]	0.74	<.01
VE						
L	10	22.39[a]	0.15	22.25[a]	0.23	0.206
W	10	22.25[a]	0.2	22.79[a]	0.1	<.001
H	10	22.41[a]	0.24	22.46[a]	0.32	0.651
D	10	22.2[a]	0.18	22.56[a]	0.19	<.01
VM						
L	10	17.93[a]	0.41	17.91[a]	0.44	0.856
W	10	17.62[a]	0.27	18.35[a]	0.29	<.001
H	10	17.95[a]	0.31	17.89[a]	0.26	0.588
D	10	18.58[a]	0.82	18.53[a]	0.83	0.651
EX						
L	10	16.16[a]	0.17	16.33[a]	0.22	0.125
W	10	16.16[a]	0.18	16.15[a]	0.2	0.928
H	10	16.25[a]	0.26	16.32[a]	0.24	0.527
D	10	16.08[a]	0.21	16.09[a]	0.23	0.928
MZ						
L	10	30.44[b]	1.81	29.38[b]	2.17	<.001
W	10	27.96[a]	2.35	27.05[a]	1.9	<.001
H	10	29.13[ab]	2	28.22[ab]	2.23	<.001
D	10	29.59[ab]	2.47	29.37[b]	2.63	<.05

Bonferroni: a < b. Means with the same superscript in each column and each ceramic are not significantly different from each other based on the Bonferroni test ($p > .05$). LU, resin nano ceramic. VE, dual-network ceramic. VM, feldspathic ceramic. EX, lithium disilicate ceramic. MZ, high-translucency monolithic zirconia. L, conventional mouthwash. W, whitening-enhanced mouthwash. H, chlorhexidine gluconate. D, distilled water.

Table II-5-4. Mean and standard deviation (SD) of CIE *L**, *a**, *b** and translucency parameter values.

Group	n	Dependent variable Translucency parameter				*p*
		Before		After		
		Mean	SD	Mean	SD	
LU						
L	10	13.12[a]	0.22	13.16[a]	0.27	0.636
W	10	13.24[a]	0.42	13.38[a]	0.41	0.085
H	10	13.64[a]	0.37	13.52[a]	0.46	0.181
D	10	13.30[a]	0.46	13.37[a]	0.44	0.407
VE						
L	10	12.99[a]	0.13	12.70[a]	0.14	<.01
W	10	12.95[a]	0.08	12.41[a]	0.17	<.001
H	10	13.11[a]	0.1	12.83[a]	0.13	<.01
D	10	13.03[a]	0.1	12.72[a]	0.13	<.001
VM						
L	10	11.71[a]	0.23	11.47[a]	0.17	<.01
W	10	11.78[a]	0.17	11.23[a]	0.21	<.001
H	10	11.67[a]	0.23	11.61[a]	0.3	0.47
D	10	12.09[a]	0.16	11.98[a]	0.18	0.172
EX						
L	10	11.74[a]	0.11	11.75[a]	0.11	0.935
W	10	11.79[a]	0.06	11.67[a]	0.13	0.154
H	10	11.73[a]	0.1	11.85[a]	0.11	0.147
D	10	11.76[a]	0.12	11.75[a]	0.12	0.859
MZ						
L	10	7.02[a]	1.18	7.16[a]	0.9	0.114
W	10	6.32[a]	0.76	6.33[a]	1.01	0.932
H	10	6.80[a]	0.83	6.83[a]	1.17	0.742
D	10	6.76[a]	1.02	7.02[a]	0.93	<.01

Bonferroni: a < b. Means with the same superscript in each column and each ceramic are not significantly different from each other based on the Bonferroni test (p > .05). LU, resin nano ceramic. VE, dual-network ceramic. VM, feldspathic ceramic. EX, lithium disilicate ceramic. MZ, high-translucency monolithic zirconia. L, conventional mouthwash. W, whitening-enhanced mouthwash. H, chlorhexidine gluconate. D, distilled water.

Table II-6-1. Mean and standard error of each dependent variable according to ceramics and solutions used.

	Color change (ΔE_{00})*		Translucency (TP)	
Group	Mean	Standard error	Mean	Standard error
Ceramic				
LU	0.464^{ab}	0.041	13.36^{e}	0.079
VE	0.603^{b}	0.041	12.664^{d}	0.079
VM	0.474^{b}	0.041	11.572^{b}	0.079
EX	0.304^{a}	0.041	11.756^{c}	0.079
MZ	0.928^{c}	0.041	6.834^{a}	0.079
Solution				
L	0.497^{a}	0.037	11.247^{ab}	0.071
W	0.92^{b}	0.037	11.005^{a}	0.071
H	0.425^{a}	0.037	11.329^{b}	0.071
D	0.376^{a}	0.037	11.368^{b}	0.071

Bonferroni: a < b < c < d < e. Means with the same superscript in each column and each section are not significantly different from each other based on the Bonferroni test ($p > .05$) *Color change (ΔE_{00}) between baseline and simulated oral rinsing. LU, resin nano ceramic. VE, dual-network ceramic. VM, feldspathic ceramic. EX, lithium disilicate ceramic. MZ, high-translucency monolithic zirconia. L, conventional mouthwash. W, whitening-enhanced mouthwash. H, chlorhexidine gluconate. D, distilled water.

Table II-6-2. Mean and standard error of each dependent variable according to ceramics and solutions used.

	Gloss (GU)		Roughness (Ra: μm)	
Group	**Mean**	**Standard error**	**Mean**	**Standard error**
Ceramic				
LU	51.003[c]	0.516	0.078[a]	0.006
VE	12.015[a]	0.516	0.214[b]	0.006
VM	23.468[b]	0.516	0.22[b]	0.006
EX	56.533[d]	0.516	0.067[a]	0.006
MZ	141.683[e]	0.516	0.056[a]	0.006
Solution				
L	59.034[b]	0.462	0.110[ab]	0.005
W	45.228[a]	0.462	0.196[c]	0.005
H	61.524[c]	0.462	0.111[b]	0.005
D	61.974[c]	0.462	0.091[a]	0.005

Bonferroni: a < b < c < d < e. Means with the same superscript in each column and each section are not significantly different from each other based on the Bonferroni test (p > .05) *Color change (ΔE_{00}) between baseline and simulated oral rinsing. LU, resin nano ceramic. VE, dual-network ceramic. VM, feldspathic ceramic. EX, lithium disilicate ceramic. MZ, high-translucency monolithic zirconia. L, conventional mouthwash. W, whitening-enhanced mouthwash. H, chlorhexidine gluconate. D, distilled water.

Experiment III. Effects of ultrasonic scaling on the optical properties and surface characteristics of highly translucent CAD/CAM ceramic restorative materials

Table III-1-1. Description of five highly translucent CAD/CAM ceramics evaluated in the present study.

Classification	Brand	Manufacturer	Lot	Color	Size	Code
Resin nano ceramic	LAVA Ultimate	3M ESPE	N941201	A2-HT	14L	LU
Dual-network ceramic	VITA Enamic	VITA Zahnfabrik	80600	2M2-HT	EM-14	VE
Feldspathic ceramic	VITA Mark II	VITA Zahnfabrik	59451	2M2C	I14	VM
Lithium disilicate glass ceramic	IPS e.max CAD	Ivoclar Vivadent	X42738	HT A2	C14	EX
High-translucency monolithic zirconia	Rainbow Shine-T	Genoss	18K20-02	A2	Ø98-12T	MZ

Table III-1-2. Description of five highly translucent CAD/CAM ceramics evaluated in the present study.

Classification	Brand	Composition*
Resin nano ceramic	LAVA Ultimate	80% nano ceramic particles (69% SiO_2, 31% ZrO_2) 20% highly crosslinked (methacrylate-based) polymer matrix (Bis-GMA, UDMA, Bis-EMA, TEGDMA)
Dual-network ceramic	VITA Enamic	86% feldspathic-based ceramic network (58-63% SiO_2, 20-23% Al_2O_3, 9-11% Na_2O, 4-6% K_2O, 0-1% ZrO_2) 14% acrylate polymer network (UDMA and TEGDMA)
Feldspathic ceramic	VITA Mark II	56-64% SiO_2, 20-23% Al_2O_3, 6-9%Na_2O, 6-8% K_2O
Lithium disilicate glass ceramic	IPS e.max CAD	58-80% SiO_2, 11-19% Li_2O, 0-13% K_2O, 0-8% ZrO_2, 0-5% Al_2O_3
High-translucency monolithic zirconia	Rainbow Shine-T	81-94% ZrO_2, 6-9% Y_2O_3, 5%≥HfO_2, 1%≥Al_2O_3, other oxides

Bis-EMA, ethoxylated bisphenol-A dimethacrylate; Bis-GMA, bisphenol-A glycidyl dimethacrylate; TEGDMA, triethyleneglycol dimethacrylate; UDMA, urethane dimethacrylate. *As disclosed by manufacturers.

Table III-2. Results of one-way analysis of variance with the color change after ultrasonic scaling as the dependent variable (ΔE_{00}).

Group	n	Mean	Standard deviation	*F*	*p*
LU	10	0.243[a]	0.112		
VE	10	0.480[a]	0.328		
VM	10	1.591[b]	0.561	79.243***	<.001
EX	10	0.143[a]	0.058		
MZ	10	4.466[c]	1.282		

LU: Lava Ultimate, shade A2-HT (resin nano ceramic), VE: Vita Enamic, shade 2M2-HT (dual-network ceramic), VM: Vitablocs Mark II, shade 2M2c (feldspathic ceramic), EX: IPS e.max CAD, shade A2-HT (lithium disilicate ceramic), MZ: Rainbow Shine-T, shade A2 (high-translucency monolithic yttria-stabilized tetragonal zirconia polycrystal), ***p < .001, Post hoc analysis: a < b < c

Table III-3. Results of repeated-measures analysis of variance with the CIE L^* a^* b^*, translucency parameter, and surface gloss values as dependent variables.

Source	Type III sum of squares	*df*	Mean squares	*F*	*p*
Dependent variable: L^*					
Time	81.722	1	81.722	196.593***	<.001
Time × group	99.282	4	24.821	59.71***	<.001
Error	18.706	45	0.416		
Dependent variable: a^*					
Time	0.384	1	0.384	3.154	0.083
Time × group	0.721	4	0.180	1.478	0.225
Error	5.485	45	0.122		
Dependent variable: b^*					
Time	13.177	1	13.177	40.317***	<.001
Time × group	37.391	4	9.348	28.601***	<.001
Error	14.708	45	0.327		
Dependent variable: translucency parameter					
Time	0.001	1	0.001	0.007	0.935
Time × group	0.155	4	0.039	0.210	0.931
Error	8.274	45	0.184		
Dependent variable: surface gloss (GU)					
Time	25.502	1	25.502	2.180	0.147
Time × group	793.821	4	198.455	16.967***	<.001
Error	526.332	45	11.696		

Five highly translucent CAD/CAM ceramic restorative materials were subjected to ultrasonic scaling. CIE: Commission Internationale de l'Éclairage, GU: gloss unit, ***$p < .001$

Table III-4-1. Mean CIE L^*, a^*, and b^* values for five highly translucent CAD/CAM ceramic restorative materials subjected to ultrasonic scaling.

Group	n	Dependent variable (mean ± standard deviation) L^*		
		Before scaling	After scaling	p
LU	10	92.50 ± 0.91^{bcd}	92.22 ± 0.83^{b}	0.337
VE	10	92.23 ± 0.25^{bc}	91.51 ± 0.59^{b}	<.05
VM	10	96.05 ± 0.34^{cd}	93.65 ± 0.87^{b}	<.001
EX	10	92.51 ± 0.17^{bcd}	92.33 ± 0.22^{b}	0.536
MZ	10	76.05 ± 5.99^{a}	70.59 ± 5.46^{a}	<.001

CIE: Commission Internationale de l'Éclairage
LU: Lava Ultimate, shade A2-HT (resin nano ceramic), VE: Vita Enamic, shade 2M2-HT (dual-network ceramic), VM: Vitablocs Mark II, shade 2M2c (feldspathic ceramic), EX: IPS e.max CAD, shade A2-HT (lithium disilicate ceramic), MZ: Rainbow Shine-T, shade A2 (high-translucency monolithic yttria-stabilized tetragonal zirconia polycrystal)
Bonferroni: a < b < c < d
Values with the same superscript letters in each column are not significantly different from each other (Bonferroni test; $p > .05$).

Table III-4-2. Mean CIE *L**, *a**, and *b** values for five highly translucent CAD/CAM ceramic restorative materials subjected to ultrasonic scaling.

Group	n	Dependent variable (mean ± standard deviation) *a**		
		Before scaling	**After scaling**	***p***
LU	10	-2.31 ± 0.11^{a}	-2.31 ± 0.07^{a}	1
VE	10	2.25 ± 0.05^{d}	2.29 ± 0.03^{d}	0.799
VM	10	0.29 ± 0.34^{c}	0.42 ± 0.44^{c}	0.409
EX	10	-1.33 ± 0.05^{b}	-1.33 ± 0.05^{b}	1
MZ	10	2.44 ± 0.13^{d}	2.89 ± 1.09^{d}	<.01

CIE: Commission Internationale de l'Éclairage
LU: Lava Ultimate, shade A2-HT (resin nano ceramic), VE: Vita Enamic, shade 2M2-HT (dual-network ceramic), VM: Vitablocs Mark II, shade 2M2c (feldspathic ceramic), EX: IPS e.max CAD, shade A2-HT (lithium disilicate ceramic), MZ: Rainbow Shine-T, shade A2 (high-translucency monolithic yttria-stabilized tetragonal zirconia polycrystal)
Bonferroni: a < b < c < d
Values with the same superscript letters in each column are not significantly different from each other (Bonferroni test; $p > .05$).

Table III-4-3. Mean CIE L^*, a^*, and b^* values for five highly translucent CAD/CAM ceramic restorative materials subjected to ultrasonic scaling.

Group	n	Dependent variable (mean ± standard deviation) b^*		
		Before scaling	**After scaling**	***p***
LU	10	15.26 ± 0.70[a]	15.07 ± 0.64[a]	0.461
VE	10	22.49 ± 0.15[c]	22.45 ± 0.28[c]	0.876
VM	10	19.63 ± 0.61[b]	19.50 ± 0.85[b]	0.614
EX	10	16.28 ± 0.23[a]	16.18 ± 0.28[a]	0.698
MZ	10	30.03 ± 2.18[d]	26.86 ± 2.59[d]	<.001

CIE: Commission Internationale de l'Éclairage
LU: Lava Ultimate, shade A2-HT (resin nano ceramic), VE: Vita Enamic, shade 2M2-HT (dual-network ceramic), VM: Vitablocs Mark II, shade 2M2c (feldspathic ceramic), EX: IPS e.max CAD, shade A2-HT (lithium disilicate ceramic), MZ: Rainbow Shine-T, shade A2 (high-translucency monolithic yttria-stabilized tetragonal zirconia polycrystal)
Bonferroni: a < b < c < d
Values with the same superscript letters in each column are not significantly different from each other (Bonferroni test; $p > .05$).

Table III-5-1. Mean translucency parameter and surface gloss values for five highly translucent CAD/CAM ceramic restorative materials subjected to ultrasonic scaling.

Group	n	Dependent variable (mean ± standard deviation) Translucency parameter		
		Before scaling	After scaling	p
LU	10	13.60 ± 0.46[d]	13.57 ± 0.49[c]	0.869
VE	10	12.87 ± 0.12[c]	12.95 ± 0.17[c]	0.68
VM	10	11.96 ± 0.21[b]	11.98 ± 0.28[b]	0.908
EX	10	11.76 ± 0.11[b]	11.85 ± 0.15[b]	0.644
MZ	10	6.82 ± 0.81[a]	6.70 ± 0.95[a]	0.521

LU: Lava Ultimate, shade A2-HT (resin nano ceramic), VE: Vita Enamic, shade 2M2-HT (dual-network ceramic), VM: Vitablocs Mark II, shade 2M2c (feldspathic ceramic), EX: IPS e.max CAD, shade A2-HT (lithium disilicate ceramic), MZ: Rainbow Shine-T, shade A2 (high-translucency monolithic yttria-stabilized tetragonal zirconia polycrystal), GU: gloss unit

Bonferroni: a < b < c < d < e

Values with the same superscript letters in each column are not significantly different from each other (Bonferroni test; $p > .05$).

Table III-5-2. Mean translucency parameter and surface gloss values for five highly translucent CAD/CAM ceramic restorative materials subjected to ultrasonic scaling.

Group	n	Dependent variable (mean ± standard deviation) Surface gloss (GU)		
		Before scaling	After scaling	p
LU	10	53.47 ± 3.95^{c}	56.61 ± 4.36^{c}	<.05
VE	10	17.08 ± 4.59^{a}	21.27 ± 4.14^{a}	<.01
VM	10	26.01 ± 2.64^{b}	31.66 ± 2.41^{b}	<.001
EX	10	68.43 ± 1.26^{d}	70.51 ± 1.41^{d}	0.181
MZ	10	129.25 ± 6.27^{e}	119.24 ± 8.48^{e}	<.001

LU: Lava Ultimate, shade A2-HT (resin nano ceramic), VE: Vita Enamic, shade 2M2-HT (dual-network ceramic), VM: Vitablocs Mark II, shade 2M2c (feldspathic ceramic), EX: IPS e.max CAD, shade A2-HT (lithium disilicate ceramic), MZ: Rainbow Shine-T, shade A2 (high-translucency monolithic yttria-stabilized tetragonal zirconia polycrystal), GU: gloss unit

Bonferroni: a < b < c < d < e

Values with the same superscript letters in each column are not significantly different from each other (Bonferroni test; $p > .05$).

Table III-6. Results of two-way analysis of variance with the surface roughness (Ra) value as the dependent variable.

Source	**Type III sum of squares**	***df***	**Mean squares**	***F***	***p***
Dependent variable: surface roughness (Ra)					
Material	0.442	4	0.110	30.391***	<.001
Scaling	0.010	1	0.010	2.794	0.098
Material × scaling	0.008	4	0.002	0.553	0.697
Error	0.327	90	0.004		

Five highly translucent CAD/CAM ceramic restorative materials were subjected to ultrasonic scaling. ***$p < .001$

Table III-7. Mean surface roughness (Ra) values for five highly translucent CAD/CAM ceramic restorative materials subjected to ultrasonic scaling.

Material	n	Dependent variable (mean ± standard deviation) Surface roughness (Ra: μm)		
		Before scaling	**After scaling**	***p***
LU	10	0.091 ± 0.012[ab]	0.106 ± 0.035[a]	0.58
VE	10	0.2 ± 0.025[c]	0.23 ± 0.131[b]	0.272
VM	10	0.16 ± 0.03[bc]	0.208 ± 0.123[b]	0.075
EX	10	0.054 ± 0.011[a]	0.049 ±0.023[a]	0.869
MZ	10	0.052 ± 0.007[a]	0.064 ±0.023[a]	0.663

LU: Lava Ultimate, shade A2-HT (resin nano ceramic), VE: Vita Enamic, shade 2M2-HT (dual-network ceramic), VM: Vitablocs Mark II, shade 2M2c (feldspathic ceramic), EX: IPS e.max CAD, shade A2-HT (lithium disilicate ceramic), MZ: Rainbow Shine-T, shade A2 (high-translucency monolithic yttria-stabilized tetragonal zirconia polycrystal)

Bonferroni: a < b < c

Values with the same superscript letters in each column are not significantly different from each other (Bonferroni test; $p > .05$).

Figures

Experiment I. Optical and surface properties of monolithic zirconia after simulated toothbrushing

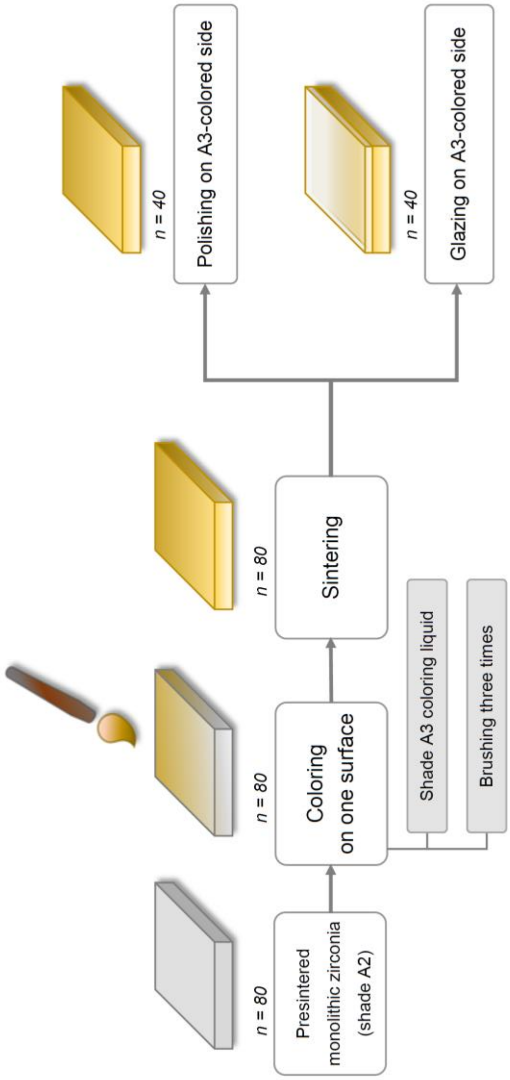

Figure I-1. Specimen preparation.

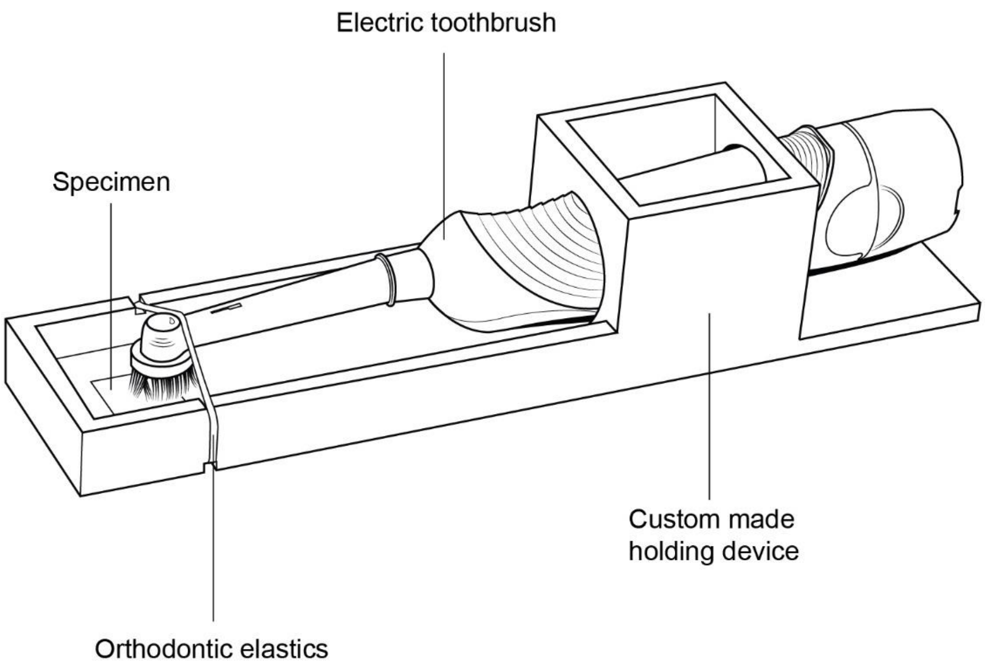

Figure I-2. Schematic drawing of the customized fixture, zirconia specimen, orthodontic elastics, and electric toothbrush.

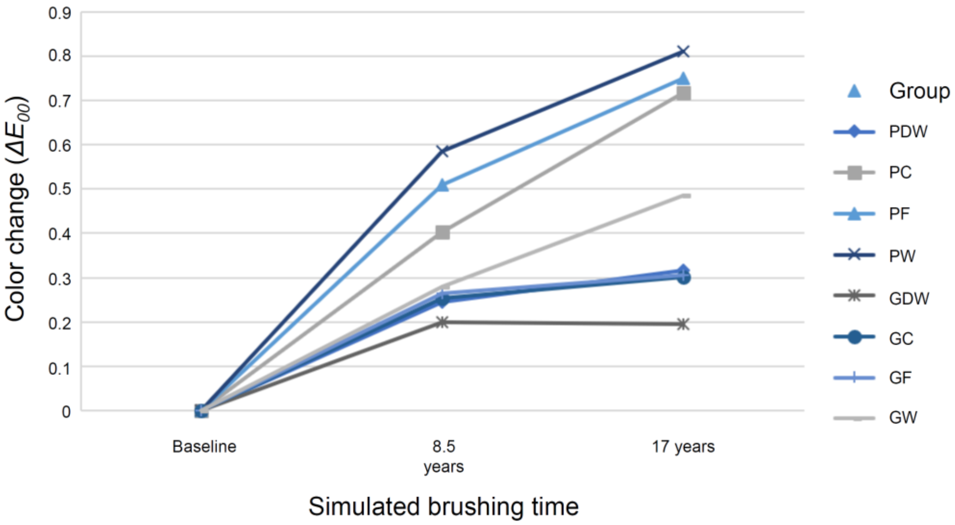

Figure I-3. Color changes (ΔE_{00}) of polished or glazed monolithic zirconia specimens between the baseline and simulated brushing time.

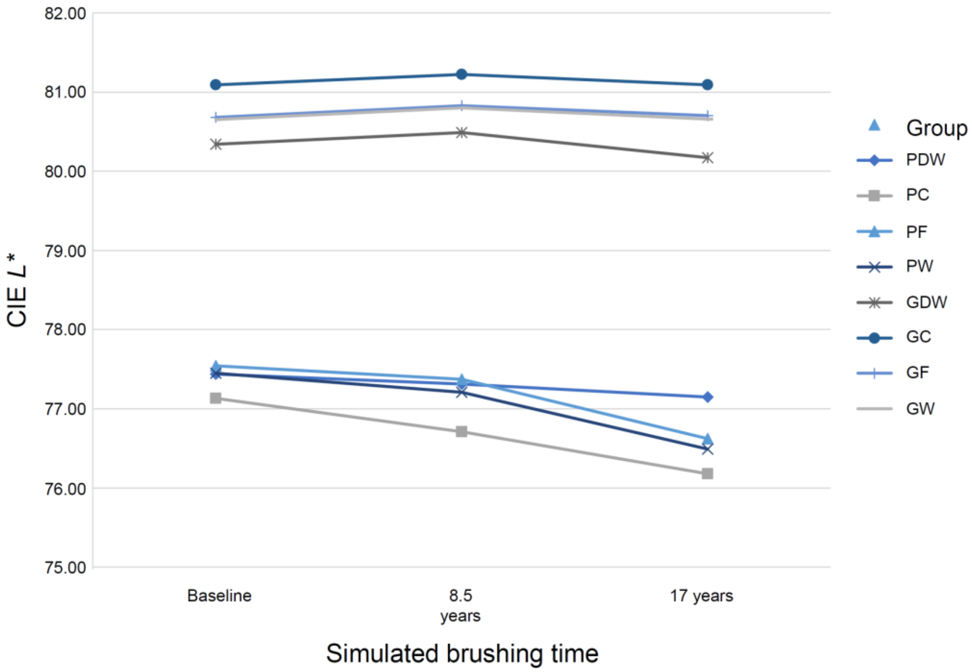

Figure I-4. CIE *L** of polished or glazed monolithic zirconia specimens according to simulated brushing time.

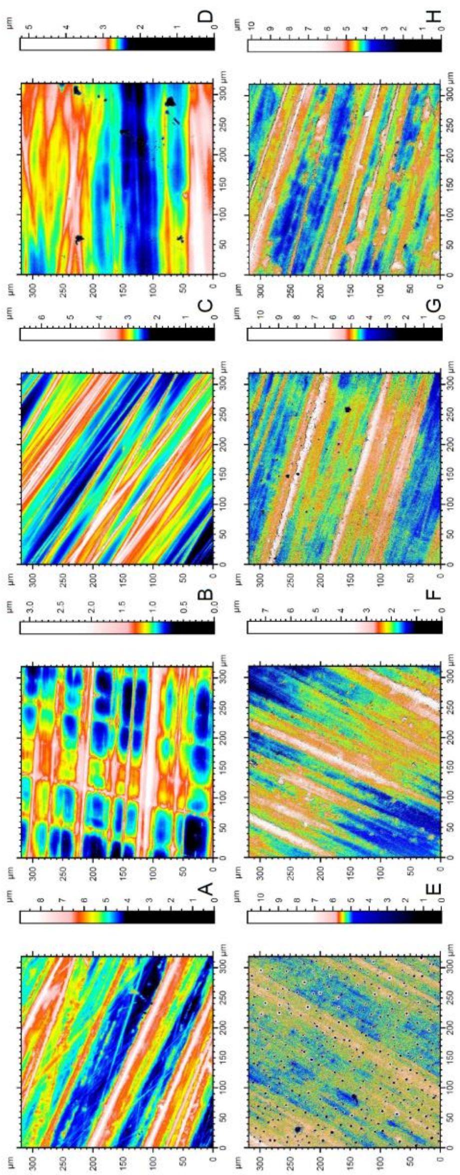

Figure I-5. Confocal laser scanning microscope images of groups (fields of view: 320 µm × 320 µm). (**A**), polished surface and storage in distilled water (PDW). (**B**), polished surface and brushed with a conventional dentifrice (PC). (**C**), polished surface and brushed with a fluoride dentifrice (PF). (**D**), polished surface and brushed with a whitening dentifrice (PW). (**E**), glazed surface and storage in distilled water (GDW). (**F**), glazed surface and brushed with a conventional dentifrice (GC). (**G**), glazed surface and brushed with a fluoride dentifrice (GF). (**H**), glazed surface and brushed with a whitening dentifrice (GW).

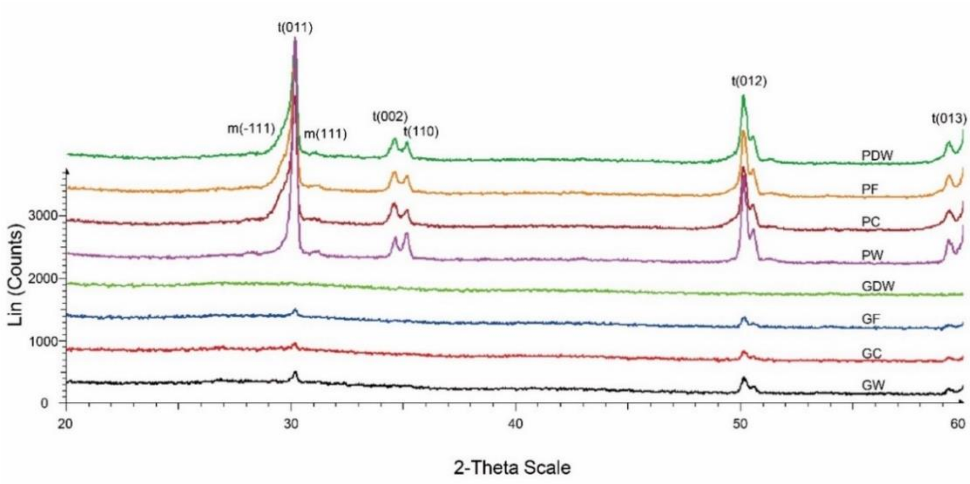

Figure I-6. X-ray diffraction patterns of experimental groups in the 2-theta range from 20 to 60. t, Tetragonal zirconia phase; m, monoclinic zirconia phase; PDW, polished surface and storage in distilled water; PC, polished surface and brushed with a conventional dentifrice; PF, polished surface and brushed with a fluoride dentifrice; PW, polished surface and brushed with a whitening dentifrice; GDW, glazed surface and storage in distilled water; GC, glazed surface and brushed with a conventional dentifrice; GF, glazed surface and brushed with a fluoride dentifrice; GW, glazed surface and brushed with a whitening dentifrice.

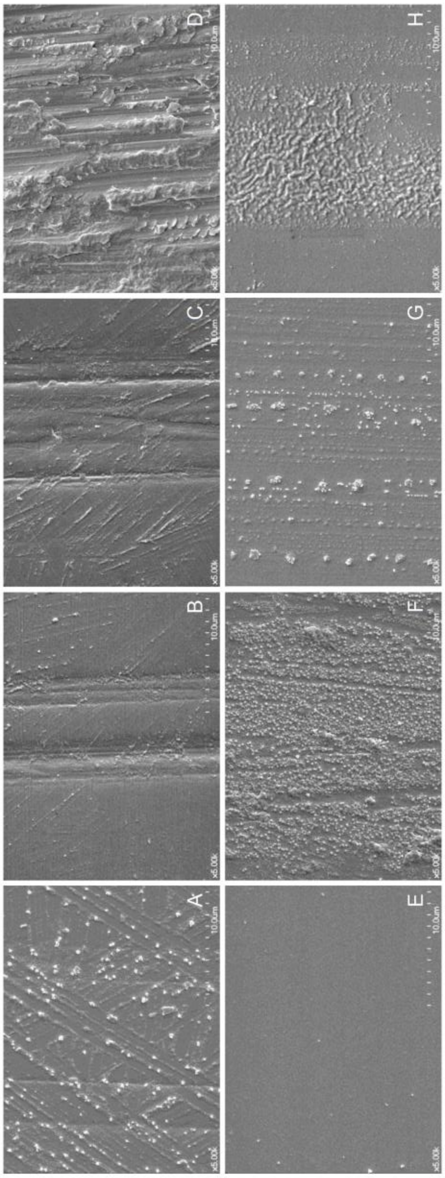

Figure I-7. SEM images of groups (original magnification, ×5000). (**A**), polished surface and storage in distilled water (PDW). (**B**), polished surface and brushed with a conventional dentifrice (PC). (**C**), polished surface and brushed with a fluoride dentifrice (PF). (**D**), polished surface and brushed with a whitening dentifrice (PW). (**E**), glazed surface and storage in distilled water (GDW). (**F**), glazed surface and brushed with a conventional dentifrice (GC). (**G**), glazed surface and brushed with a fluoride dentifrice (GF). (**H**), glazed surface and brushed with a whitening dentifrice (GW).

Experiment II. Effects of oral hygiene solutions on the optical and surface properties of high-translucency ceramic restorative materials for digital dentistry

Group		Ceramic				
		LU	VE	VM	EX	MZ
Solution	L	LU-L	VE-L	VM-L	EX-L	MZ-L
	W	LU-W	VE-W	VM-W	EX-W	MZ-W
	H	LU-H	VE-H	VM-H	EX-H	MZ-H
	D	LU-D	VE-D	VM-D	EX-D	MZ-D

Figure II-1. Distribution of study groups.
LU, resin nano ceramic (Lava Ultimate). VE, dual-network ceramic (Vita Enamic). VM, feldspathic ceramic (Vitablocs Mark II). EX, lithium disilicate ceramic (IPS e.max CAD). MZ, high-translucency monolithic zirconia (Rainbow Shine-T). L, conventional mouthwash (LISTERINE Cool Mint). W, whitening-enhanced mouthwash (LISTERINE Healthy White). H, chlorhexidine gluconate (Hexamedine). D, distilled water.

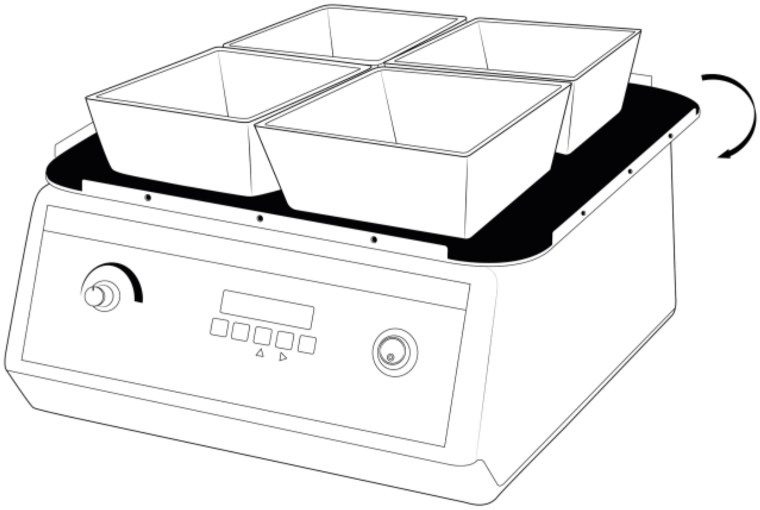

Figure II-2.
Schematic drawing showing the oral rinsing simulation of a high-translucency CAD/CAM ceramic specimen.

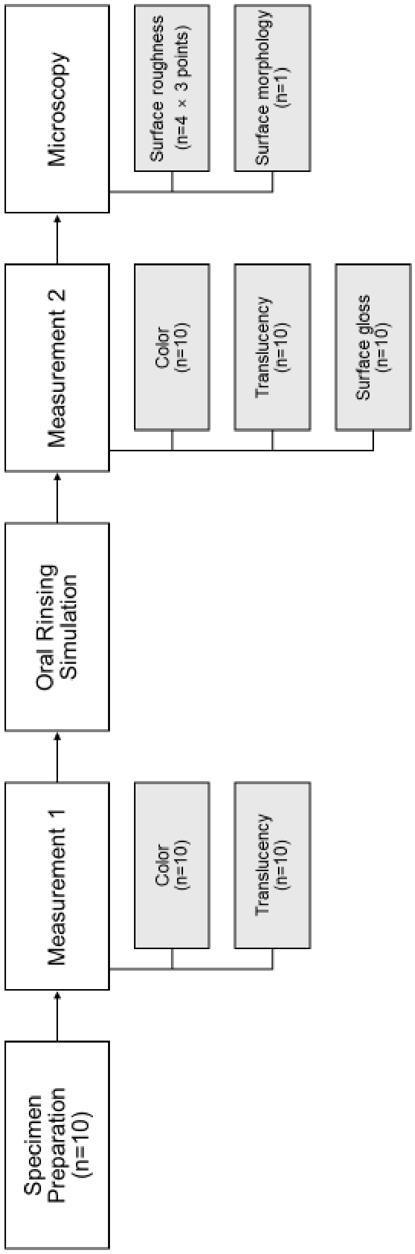

Figure II-3. Design of this study.

Flowchart showing the methods and measurements used in this study.

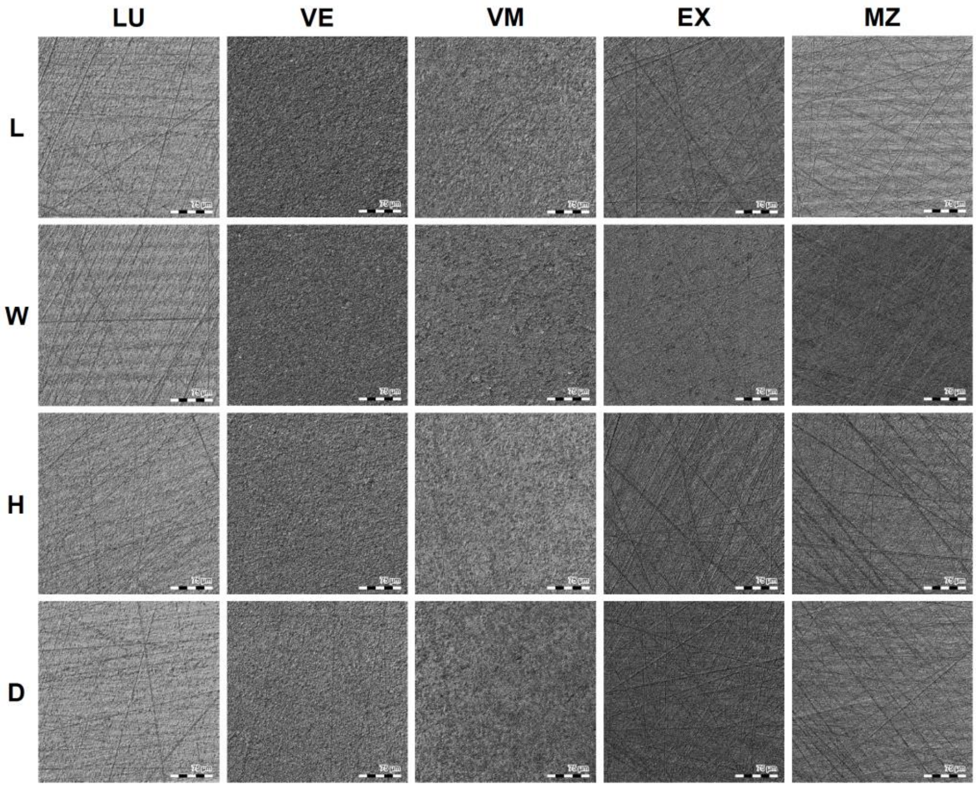

Figure II-4.

Confocal laser scanning microscopy images (original magnification, × 20) for representative specimens of high-translucency CAD/CAM ceramics subjected to oral rinsing simulation.

LU, resin nano ceramic (Lava Ultimate). VE, dual-network ceramic (Vita Enamic). VM, feldspathic ceramic (Vitablocs Mark II). EX, lithium disilicate ceramic (IPS e.max CAD). MZ, high-translucency monolithic zirconia (Rainbow Shine-T). L, conventional mouthwash (LISTERINE Cool Mint). W, whitening-enhanced mouthwash (LISTERINE Healthy White). H, chlorhexidine gluconate (Hexamedine). D, distilled water.

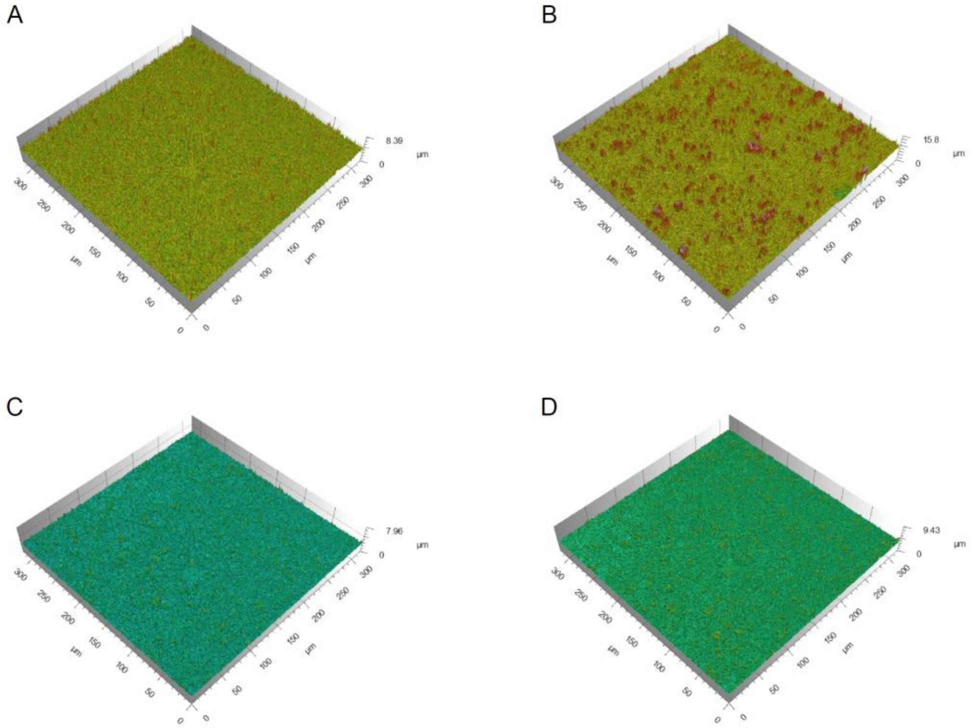

Figure II-5. Three-dimensional confocal laser scanning microscopy (original magnification, ×20) images of representative specimens of high-translucency CAD/CAM ceramics subjected to oral rinsing simulation.

VE-W and VM-W show rougher surfaces than the corresponding control groups (VE-D and VM-D).

A. VE-W: dual-network ceramic in whitening-enhanced mouthwash; B. VM-W: feldspathic ceramic in whitening-enhanced mouthwash; C. VE-D: dual-network ceramic in distilled water; D. VM-D: feldspathic ceramic in distilled water.

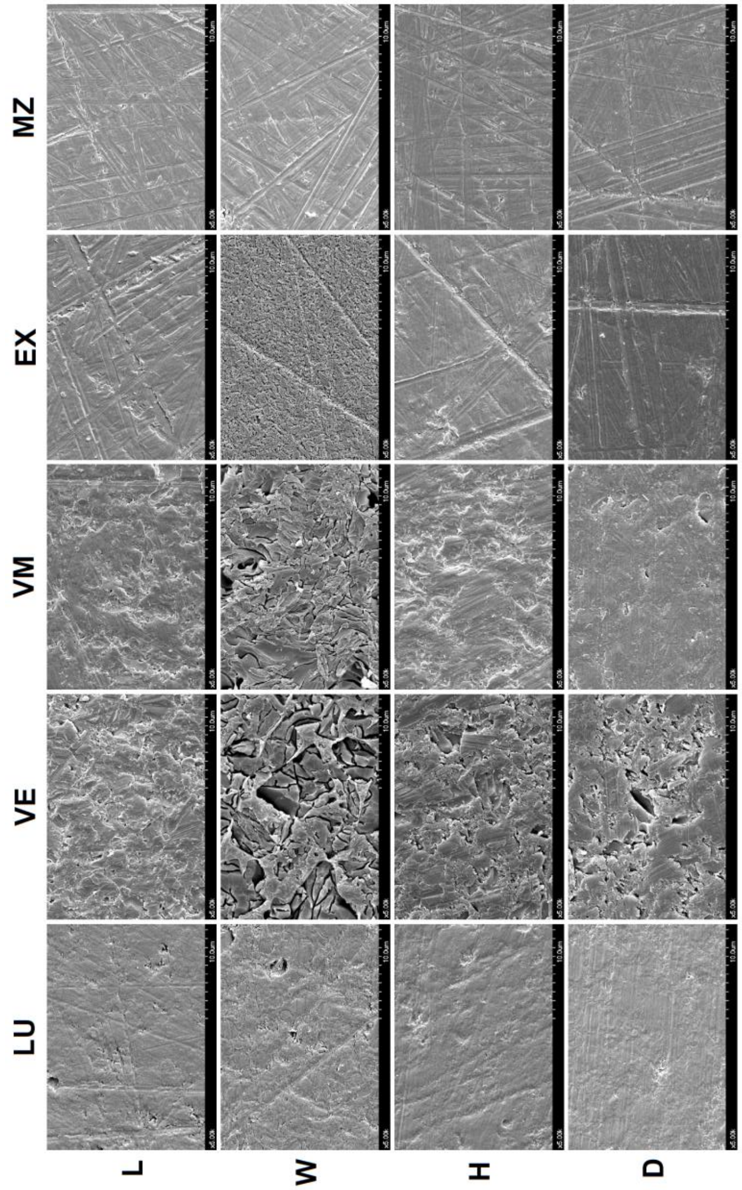

Figure II-6. Scanning electron microscopy images (original magnification, × 5000) of representative specimens of high-translucency CAD/CAM ceramics subjected to oral rinsing simulation. The surfaces of VE-W, VM-W, and EX-W show marked deterioration caused by the oral rinsing simulation.

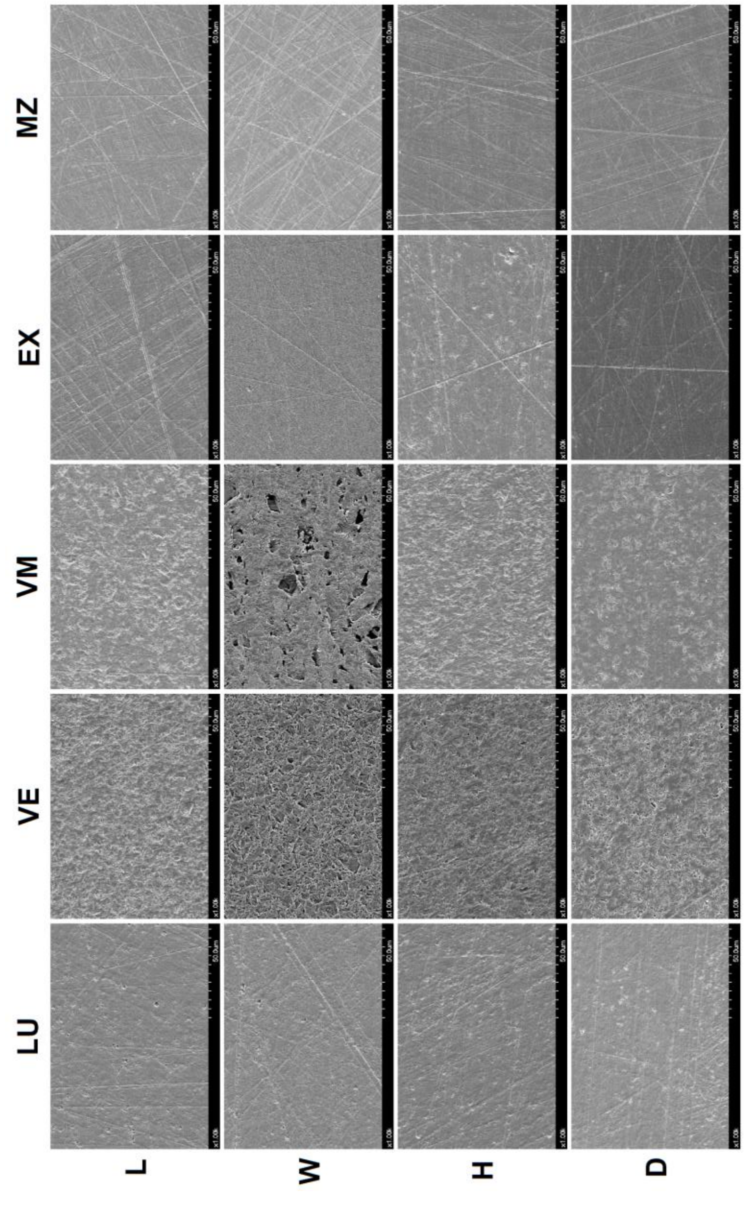

Figure II-7. Scanning electron microscopy images (original magnification, × 1000) of representative specimens of high-translucency CAD/CAM ceramics subjected to oral rinsing simulation. The surfaces of VE-W, VM-W, and EX-W show marked deterioration caused by the oral rinsing simulation.

Experiment III. Effects of ultrasonic scaling on the optical properties and surface characteristics of highly translucent CAD/CAM ceramic restorative materials

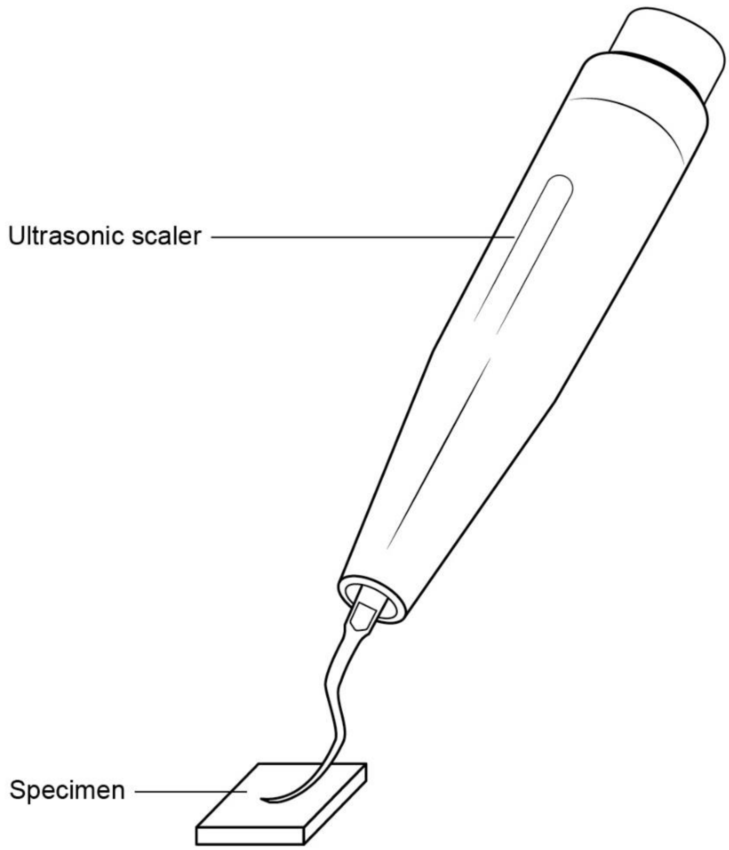

Figure III-1. Schematic drawing showing the ultrasonic scaling of a highly translucent CAD/CAM ceramic specimen.

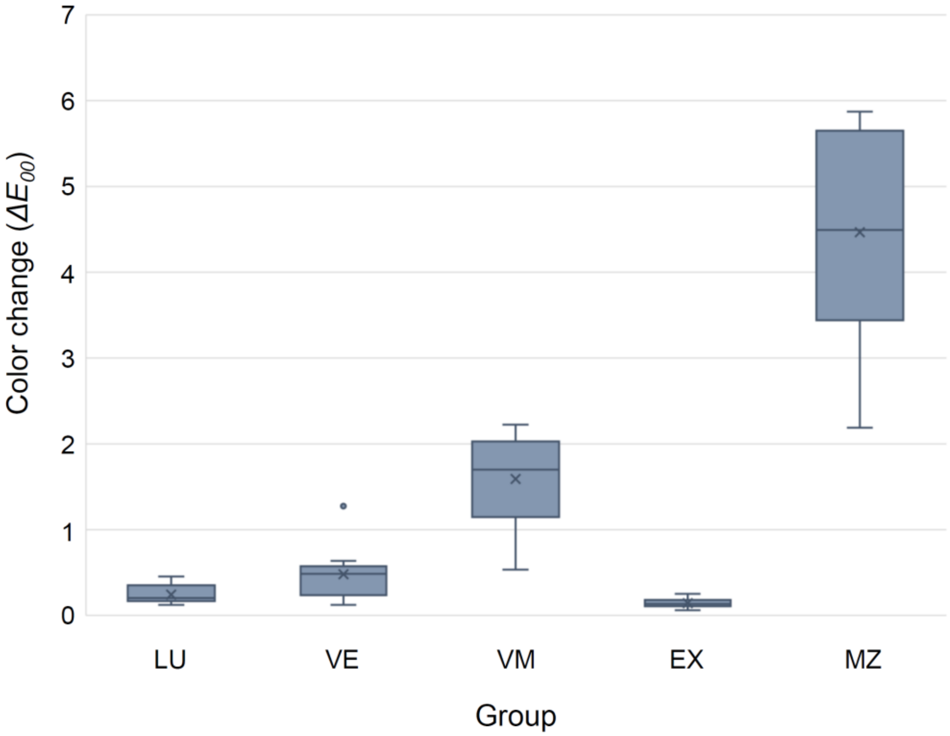

Figure III-2. Color changes (ΔE00) after ultrasonic scaling of different highly translucent CAD/CAM ceramic restorative materials.
LU: Lava Ultimate, shade A2-HT (resin nano ceramic)
VE: Vita Enamic, shade 2M2-HT (dual-network ceramic)
VM: Vitablocs Mark II, shade 2M2c (feldspathic ceramic)
EX: IPS e.max CAD, shade A2-HT (lithium disilicate ceramic)
MZ: Rainbow Shine-T, shade A2 (high-translucency monolithic yttria-stabilized tetragonal zirconia polycrystal)

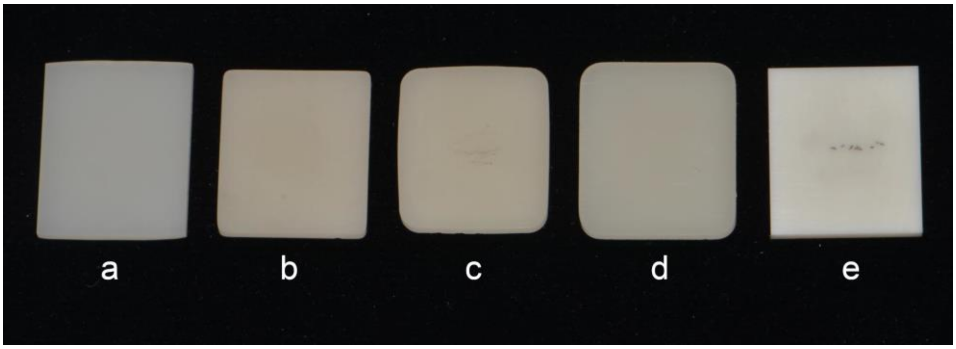

Figure III-3. Color changes in representative specimens of highly translucent CAD/CAM ceramics subjected to ultrasonic scaling. The feldspathic ceramic (c) and monolithic zirconia (e) specimens show perceptible color changes at the center.

(a) Resin nano ceramic (Lava Ultimate, shade A2-HT)

(b) Dual-network ceramic (Vita Enamic, shade 2M2-HT)

(c) Feldspathic ceramic (Vitablocs Mark II, shade 2M2c)

(d) Lithium disilicate ceramic (IPS e.max CAD, shade A2-HT)

(e) High-translucency monolithic yttria-stabilized tetragonal zirconia polycrystal (Rainbow Shine-T, shade A2)

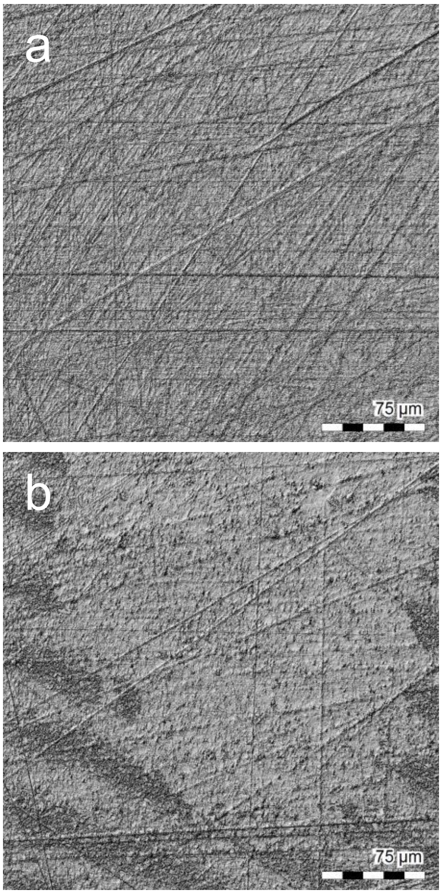

Figure III-4-1. Confocal laser scanning microscopy images (original magnification, ×20) for representative specimens of highly translucent CAD/CAM ceramics subjected to ultrasonic scaling. The images of all experimental specimens are showing scrapes as evidence of the ultrasonic scaling procedure.

(a and b) Control (a) and experimental (b) resin nano ceramic specimens (Lava Ultimate, shade A2-HT)

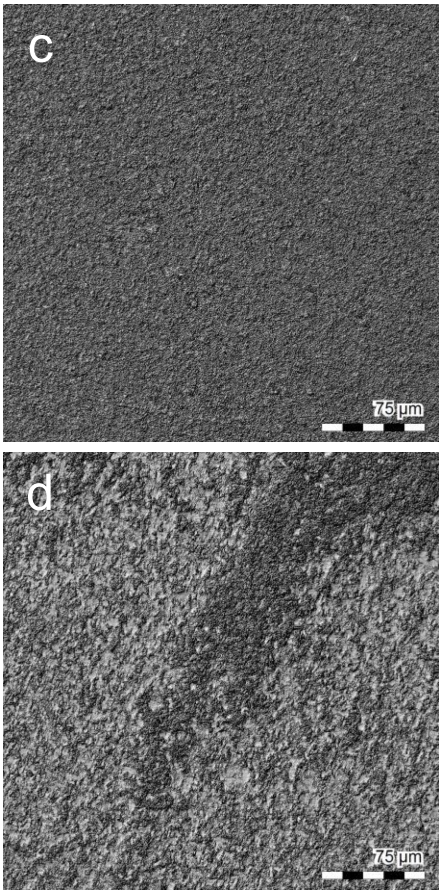

Figure III-4-2. Confocal laser scanning microscopy images (original magnification, ×20) for representative specimens of highly translucent CAD/CAM ceramics subjected to ultrasonic scaling. The images of all experimental specimens are showing scrapes as evidence of the ultrasonic scaling procedure.

(c and d) Control (c) and experimental (d) dual-network ceramic specimens (Vita Enamic, shade 2M2-HT)

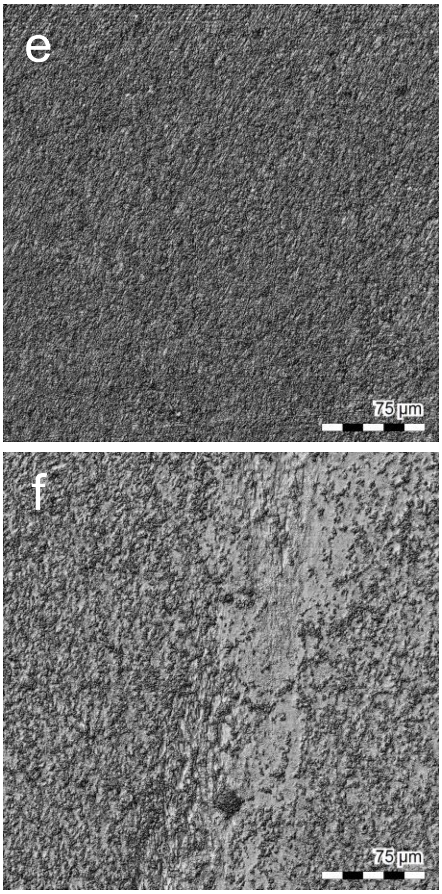

Figure III-4-3. Confocal laser scanning microscopy images (original magnification, ×20) for representative specimens of highly translucent CAD/CAM ceramics subjected to ultrasonic scaling. The images of all experimental specimens are showing scrapes as evidence of the ultrasonic scaling procedure.

(e and f) Control (e) and experimental (f) feldspathic ceramic specimens (Vitablocs Mark II, shade 2M2c)

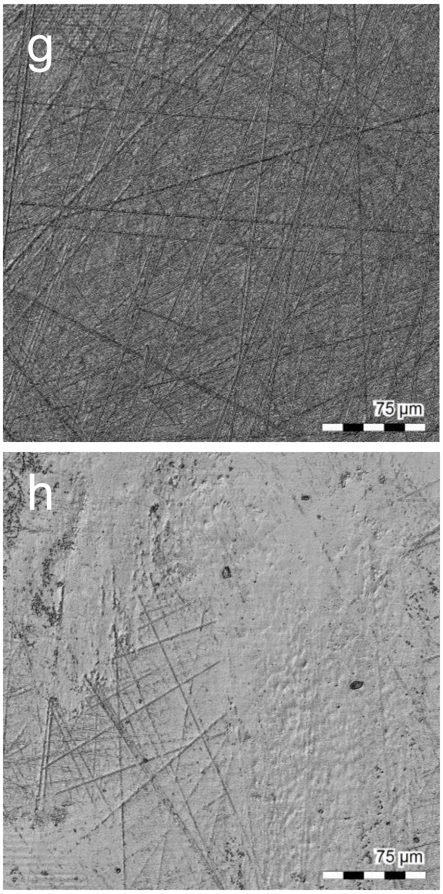

Figure III-4-4. Confocal laser scanning microscopy images (original magnification, ×20) for representative specimens of highly translucent CAD/CAM ceramics subjected to ultrasonic scaling. The images of all experimental specimens are showing scrapes as evidence of the ultrasonic scaling procedure.

(g and h) Control (g) and experimental (h) lithium disilicate glass ceramic specimens (IPS e.max CAD, shade A2-HT)

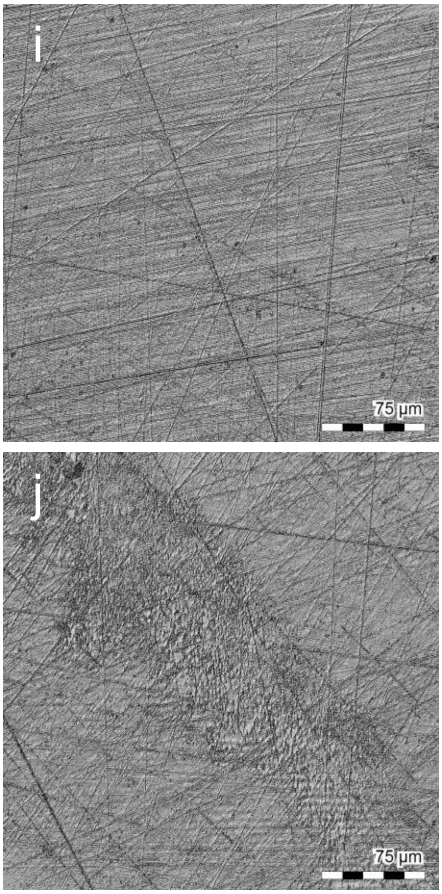

Figure III-4-5. Confocal laser scanning microscopy images (original magnification, ×20) for representative specimens of highly translucent CAD/CAM ceramics subjected to ultrasonic scaling. The images of all experimental specimens are showing scrapes as evidence of the ultrasonic scaling procedure.

(i and j) Control (i) and experimental (j) high-translucency monolithic yttria-stabilized tetragonal zirconia polycrystal specimens (Rainbow Shine-T, shade A2)

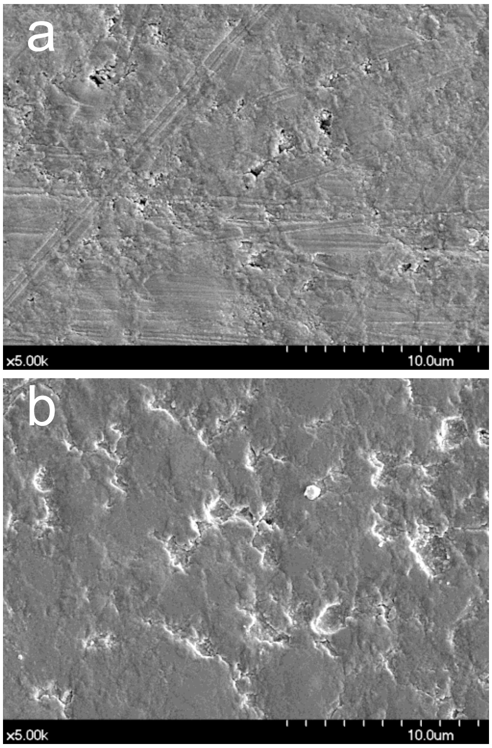

Figure III-5-1. Scanning electron microscopy images (original magnification, ×5000) of representative specimens of highly translucent CAD/CAM ceramics subjected to ultrasonic scaling. The surface of the experimental MZ specimen (j) shows marked deterioration caused by the ultrasonic scaling procedure.

(a and b) Control (a) and experimental (b) resin nano ceramic specimens (Lava Ultimate, shade A2-HT)

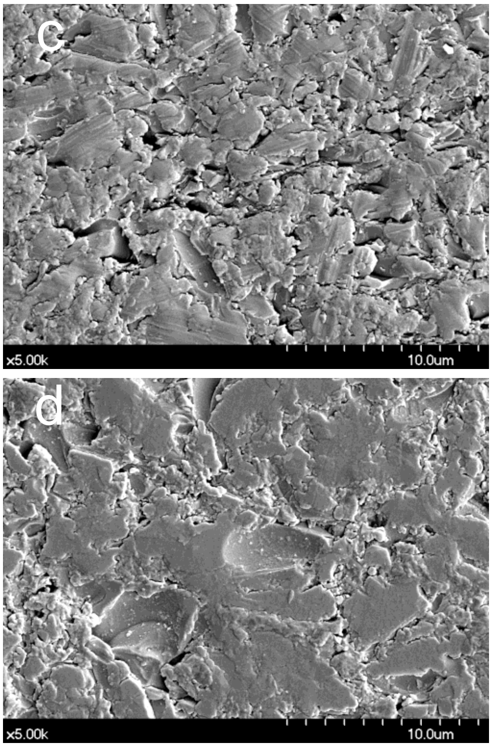

Figure III-5-2. Scanning electron microscopy images (original magnification, ×5000) of representative specimens of highly translucent CAD/CAM ceramics subjected to ultrasonic scaling. The surface of the experimental MZ specimen (j) shows marked deterioration caused by the ultrasonic scaling procedure.

(c and d) Control (c) and experimental (d) dual-network ceramic specimens (Vita Enamic, shade 2M2-HT)

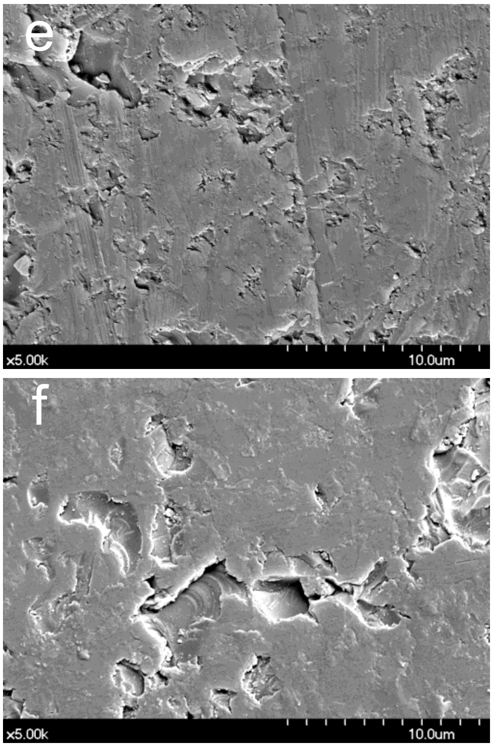

Figure III-5-3. Scanning electron microscopy images (original magnification, ×5000) of representative specimens of highly translucent CAD/CAM ceramics subjected to ultrasonic scaling. The surface of the experimental MZ specimen (j) shows marked deterioration caused by the ultrasonic scaling procedure.

(e and f) Control (e) and experimental (f) feldspathic ceramic specimens (Vitablocs Mark II, shade 2M2c)

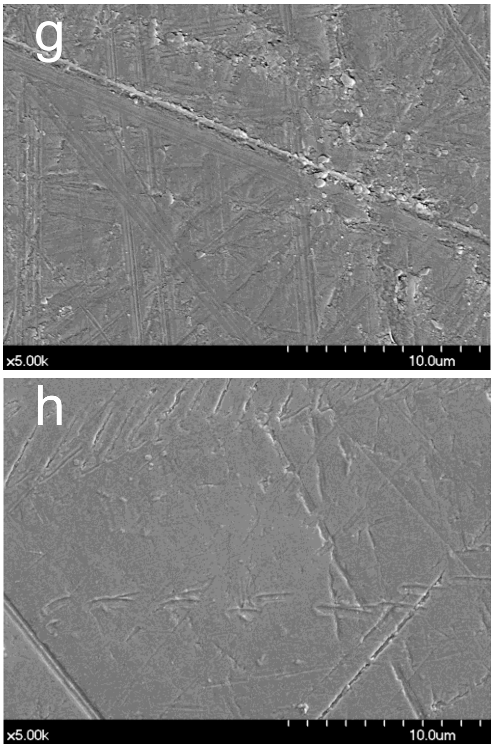

Figure III-5-4. Scanning electron microscopy images (original magnification, ×5000) of representative specimens of highly translucent CAD/CAM ceramics subjected to ultrasonic scaling. The surface of the experimental MZ specimen (j) shows marked deterioration caused by the ultrasonic scaling procedure.

(g and h) Control (g) and experimental (h) lithium disilicate glass ceramic specimens (IPS e.max CAD, shade A2-HT)

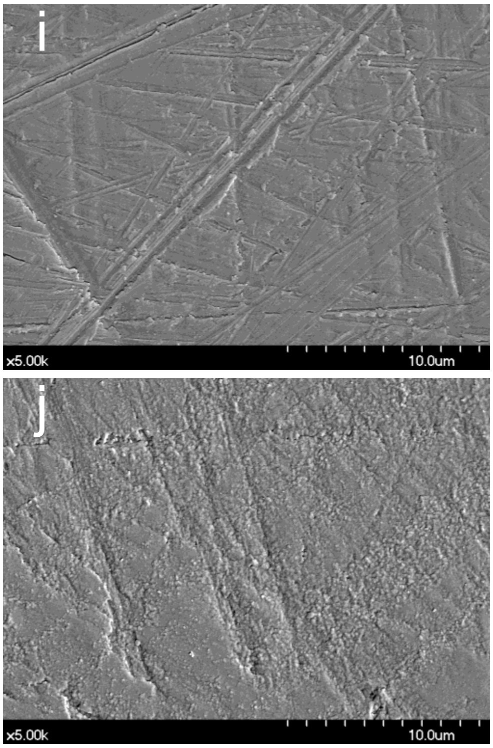

Figure III-5-5. Scanning electron microscopy images (original magnification, ×5000) of representative specimens of highly translucent CAD/CAM ceramics subjected to ultrasonic scaling. The surface of the experimental MZ specimen (j) shows marked deterioration caused by the ultrasonic scaling procedure.

(i and j) Control (i) and experimental (j) high-translucency monolithic yttria-stabilized tetragonal zirconia polycrystal specimens (Rainbow Shine-T, shade A2)

국문 초록

구강 위생 술식이 치과용 CAD/CAM 수복 재료의 심미성과 표면 특성에 미치는 효과

이 재 현

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(지도교수 한 중 석)

연구목적: 투명도가 향상된 디지털 치과용 수복재료들이 개발되어 심미적 요구도가 높은 부위의 수복에도 선택되고 있다. 본 연구의 목적은 다양한 구강 위생 술식들이 디지털 치과용 수복 재료의 광학적 특성과 표면 성상에 미치는 영향을 평가하는 것이었다. 첫번째 실험은 칫솔질이 단일구조 수복용 지르코니아에 미치는 영향을 평가하였으며, 두번째와 세번째 실험은 각각 구강 세정 용액과 초음파 스케일링이 다양한 캐드캠 (computer-aided design and computer-aided manufacturing; CAD/CAM) 세라믹 수복 재료의 광학적 특성과 표면 특성에 미치는 영향을 평가하였다.

연구방법: 실험 1을 위하여 80개의 사각형 단일구조 수복용 지르코니아 시편을 준비하였고, 연마 (P)와 유약처리(G)의 두가지 방법으로 나누어 마무리하였다. 이 시편들은 각각 다음의 4가지 방법으로 처리되었다: 증류수에 보관 (DW, 대조군); 불소 미포함 치약으로 칫솔질 (C); 고농도 불소 치약으로 칫솔질 (F); 미백 기능 강화 치약으로 칫솔질 (W). 이렇게 총 8개의 그룹이 형성되었다: PDW, PC, PF, PW, GDW, GC, GF, GW (n = 10). 전동칫솔로 시편마다 각각 520분의 칫솔질을 시행하였다. 실험 2를 위하여 투명도가 강화된 다음의 다섯가지 캐드캠용 세라믹 재료를 사용하여 총 200개의 시편을 제작하였다: resin nano ceramic (Lava Ultimate); dual-network ceramic (Vita Enamic); feldspathic ceramic (Vita Mark II); lithium disilicate (e.max CAD); high-translucency monolithic zirconia (Rainbow Shine-T). 각각의 세라믹은 다시 다음의 4가지 방법으로 나누어 총 20개의 그룹이 형성되었다 (n=10): 종래형 구강세정액; 미백 기능 강화 구강세정액; 클로르헥시딘 글루콘산염 액; 증류수 (대조군). 각각의 용액에 담가 100 rpm으로 총 180시간동안의 구강세정을 시뮬레이션하였다. 실험 3을 위하여 resin nano ceramic (LU), dual-network ceramic (VE), feldspathic ceramic (VM), lithium disilicate ceramic (EX), high-translucency monolithic zirconia (MZ)로 총 100개의 시편을 제작하였다. 시편의 절반은 중앙부에 초음파 스케일링을 시행하였다 (n=10). 실

험 1, 2, 3에서의 시편들의 색조, 투명도, 광택도, 표면 거칠기, 결정상, 표면 형태를 평가하였다. 일원배치 분산분석, 반복측정 분산분석, 이원배치 분산분석이 통계분석에 사용되었다 (α = 0.05).

연구결과: 실험 1의 결과, 칫솔질 전과 후의 색조 변화 (ΔE_{00})는 각각의 그룹에서 0.3158 (PDW), 0.7164 (PC), 0.7498 (PF), 0.8106 (PW), 0.1953 (GDW), 0.301 (GC), 0.3051 (GF), 0.4846 (GW)이었다. 색조 변화와, 광택도, 표면 거칠기에서 그룹 간에 통계적으로 유의한 차이가 관찰되었다. 실험 2의 결과, 세라믹과 용액의 종류는 구강 세정 전후의 색조 변화와 광택도, 표면 거칠기에 통계적으로 유의한 영향을 미쳤다. Dual-network ceramic과 feldspathic ceramic은 미백기능이 강화된 구강세정액으로 세정된 후에 더 밝고, 불투명하고, 광택도가 낮고, 거칠었다. 실험 3의 결과, 각각의 세라믹에서의 스케일링 전후의 색조 변화 (ΔE_{00})는 0.243 (LU), 0.48 (VE), 1.591 (VM), 0.143 (EX), 4.466 (MZ)이었으며 그룹 간 통계적 차이가 관찰되었다. 초음파 스케일링은 LU, VE, VM, MZ의 광택도도 변화시켰다. 현미경 사진들에서 스케일링 후의 표면 변화를 관찰할 수 있었다.

결론: 구강 위생 술식인 칫솔질, 구강 세정, 초음파 스케일링은 투명도가 높

은 디지털 치과용 수복 재료들의 광학적 특성과 표면 성상에 일부 영향을 미쳤다.

………………………………………………………………………………………

주요어: 광학적 특성, 구강 세정, 디지털 치의학, 색조, 세라믹, 칫솔질, 초음파 치석제거술, 표면

학번: 2015-31250