Eur. J. Prosthodont. Rest. Dent., Vol.18, No. 4, pp 177-184
Printed in Great Britain

doi:10.1922/EJPRD_920Kukiattrakoon08

Surface Characteristic Changes of Dental Ceramics after Cyclic Immersion in Acidic Agents and Titratable Acidity

Peerapong Junpoom*, Boonlert Kukiattrakoon* and Chanothai Hengtrakool†

Abstract - *The potential erosive effect of acidic food, sour fruits and drinks on all-ceramic restorations used in dentistry has not been clearly documented. Surface characteristic changes have been evaluated and compared for disc-shaped specimens (diameter 12.0 mm and thickness 2.0 mm) of fluorapatite-leucite and fluorapatite ceramics using various storage agents (deionized water, citrate buffer solution, pineapple juice, green mango juice, cola soft drink and 4% acetic acid). Immersion in pineapple juice, green mango juice, cola soft drink and 4% acetic acid for 16 hours produce significant increases in surface roughness for both types of ceramics investigated.*

KEY WORDS: Dental ceramics; Fluorapatite; Leucite; Surface roughness

INTRODUCTION

Dental ceramics have been increasingly used for various types of restorations such as inlays, onlays, crowns and fixed partial dentures. These are due to their excellent aesthetic properties compared with other tooth coloured material[1]. However, degradation or corrosion of dental ceramics can arise when ceramics are exposed to aqueous solutions or acidic agents[2-5]. This event results from selective leaching of alkaline metal ions which are far less stable in the glass phase than in the crystalline phase of dental ceramics[2]. Crack propagation in ceramics is then increased from inherent flaws or defects on the surface and body[2]. The results of ceramic degradation are roughness of the exposed surface[5,6], plaque accretion[2-7] and wear to antagonist materials[2]. Furthermore, an increasing in surface roughness of ceramics may decrease strength[8,9] and influence the clinical success and failure of ceramic restorations[10].

IPS d.SIGN is a feldspathic-based type ceramic containing dispersed fluorapatite ($Ca_{10}(PO_4)_6F_2$) and leucite crystals ($K_2O{\cdot}Al_2O_3{\cdot}4SiO_2$) in a feldspathic glassy matrix[11]. The leucite crystals are less than 3 µm in diameter and of a flower-like design, that present in the IPS d.SIGN ceramic contribute to the overall strength[12]. Currently, new all ceramic systems (IPS e.max) have been introduced into the market. IPS e.max Ceram is a veneering ceramic for this system, which is a feldspathic-based ceramic with a microstructure unlike IPS d.SIGN. IPS e.max Ceram consists of dispersed fluorapatite crystals in a feldspathic glassy matrix and has a microstructure dissimilar to that of any other commercially available dental ceramics[12]. Fluorapatite crystals, 2-5 µm in length and 300 nm in diameter of needle-like morphology, are known to be contained in natural bone and teeth. These fluorapatite crystals in dental microstructures result in optical properties such as translucence and opalescence, which markedly improve the aesthetics of IPS e.max Ceram restorations[13].

People who frequently consume acidic food and sour fruits and drinks often result in high incidence of dental erosion[14,15]. The potential erosive effect of these acidic food, sour fruits and drinks on enamel occurs primarily by dissolution of apatite crystals[15,16]. However, their effects on the ceramic restorations have not been clearly reported. Therefore, the present *in vitro* study was conducted to evaluate changes of surface roughness and surface characteristics of fluorapatite-leucite and fluorapatite ceramics after cyclically being immersed in acidic agents (citrate buffer solution, pineapple juice, green mango juice, cola soft drink and 4% acetic acid) and measured for titratable acidity of acidic agents. The hypothesis tested was that acidic agents under investigation would lead to significantly changed surface roughness and surface characteristics of fluorapatite-leucite and fluorapatite ceramics after the immersions.

MATERIALS AND METHODS

Specimen preparations

Two commercial dentin shade A3 ceramics were used; fluorapatite-leucite ceramics (IPS d.SIGN, Lot # H28470) and fluorapatite ceramics (IPS e.max Ceram, Lot # H18984). IPS d.SIGN and IPS e.max Ceram are indicated to be used as veneering ceramics for metal-ceramic and all ceramic restorations, respectively. Ninety-one disc specimens from each ceramic were fabricated. Briefly, the ceramic powder was mixed with deionized water and condensed into the silicone mold (Provil novo putty), 12.0 mm in diameter and 2.0 mm in thickness, with a condenser (Ceramosonic II). The filled mould was placed on a vibrating table of a condenser for 60 seconds. Excess water was brought to the surface of the specimen and blotted away using an

* DDS, MSc,
† DDS, MSc, PhD

absorbent paper. The specimen surface was levelled using a razor blade to provide specimens of uniform thickness before removal from the mould. Subsequently, the mixture was processed by heating to 403°C in a vacuum furnace (Progamat P300). The temperature was then increased at 60°C/minute to 909°C and held for 60 seconds for IPS d. SIGN, and increased at 50°C/minute to 849°C for IPS e.max Ceram according to the manufacturer's instructions. Subsequently, the specimens were polished (Phoenix model 4000) by hand under running water using 600 and 1,200-grit silicon carbide paper for 5 minutes each. Then the specimens were ultrasonically (Model PC3) cleaned in distilled water for 10 minutes. Finally, the specimens were submitted to self-glaze by heating to 403°C in a vacuum furnace (Progamat P300). The temperature was then increased, for IPS d. SIGN, at 60°C/minute to 829°C, and for IPS e.max Ceram, increased at 50°C/minute to 799°C according to the manufacturer's instructions.

The pH measurements

Five acidic agents were used in this study; citrate buffer solution (Lot # OC553005), pineapple juice (Tipco, Lot # 140807), green mango juice as prepared from fresh green mangoes, cola soft drink (Coca-Cola, Lot # 160982) and 4% acetic acid as diluted from 100% acetic acid (Lot # K327127630 347). The initial pH of each acidic agent was measured using a pH meter (Orion model 900A). Before doing so, the pH meter was calibrated at the start of each session using standard buffers of pH 4.0 and 7.0. Twenty milliliters of each acidic agent was measured at three times and calculated to give a mean initial pH and standard deviation (SD).

Titratable acidity measurement

Twenty milliliters of each acidic agent was titrated with 0.1 N sodium hydroxide (NaOH), added in 0.5 mL increments, until pH 5.5 and 7.0 were reached to assess titratable acidity[17]. Titrations were repeated three times to ensure reproducibility and to give a mean value and SD for each acidic agent.

Storage agent immersion and surface roughness measurements

Seventy ceramic discs of each type of ceramics evaluated were divided into 7 groups of 10 specimens. Each group was subjected to surface roughness measurement for baseline data (before immersion). Surface roughness determinations (4.0 mm in evaluated length) were measured by a profilometer (Surfcorder model SE-2300) with force 4 mN, speed of stylus 0.5 mm/second and with a cut-off of 0.8 mm. The surface roughness parameters used[18] (Ra, Rz, Rmax, and Sm) were evaluated. Ra is the arithmetical average of surface heights or the integral of the absolute value of the roughness profile height over the evaluated length. Rz is the average height difference between the ten highest peaks and ten lowest valleys within each cut-off length and is used to describe the degree of the surface roughness of the specimen. Rmax is the magnitude of the peak-to-valley height in all cut-off lengths or the vertical distance between the top of the highest peak and the bottom of the deepest valley within the evaluated length. Sm, finally, is the arithmetical average spacing between profile peaks at the mean line over the cut-off length. Sm is calculated by summing all the peak spacing and dividing by the number of spaces.

Five evaluations per specimen (1.5 mm apart) were taken, each before and after immersion in storage agents. Subsequently, the specimens were alternately immersed in 25 mL of an acidic agent for 30 minutes and in 25 mL of deionized water for 5 minutes for 7 cycles at 37ºC[19]. The same protocol was used with different types of acidic agents used in this study (citrate buffer solution, pineapple juice, green mango juice, cola soft drink and 4% acetic acid). The specimens' immersion protocol simulated an individual eating acidic food and sour fruits and drinks[19]. Total immersion time was 245 minutes. Two groups (4% acetic acid for 16 hours and deionized water) were continuously immersed in 4% acetic acid at 80ºC for 16 hours (as modified from ISO 6872[20]) and in deionized water at 37ºC for 245 minutes. After the immersion sequence was completed, the specimens were rinsed with deionized water, blot dried and subjected to surface roughness testing (after immersion).

Scanning electron microscope (SEM) analysis

To determine the effect of each storage agent on surface topography, three specimens from each of the seven storage agents of the two types of ceramics each were examined under scanning electron microscopy. The specimens were rinsed with distilled water for 5 minutes, dried and fixed onto an aluminum cylinder (13 mm in diameter and 10 mm in height). Subsequently, the specimens were sputter-coated with a gold-palladium alloy (SPI-Module sputter) and examined under high vacuum SEM (JSM-5800LV).

Statistical analysis

The data were statistically analyzed using a two-way repeated analysis of variance (ANOVA) performed for each of the roughness parameters to assess the influence of storage agents and ceramic on the surface roughness after immersion. A Tukey Honestly Significant Difference (HSD) multiple comparison was used in each of the parameters for comparing among the seven storage agents. A Students-*t*-test was used for comparing the surface roughness parameters before and after immersion for each acidic agent for the two ceramic types ($\alpha = 0.05$).

RESULTS

The mean pH and SD value of each acidic agent used and the titratable acidity of all 5 acidic agents were shown in Table 1. The pH was lowest for the green mango juice (2.39(0.01)) and highest for the citrate buffer solution (4.99(0.01)). Cola soft drink had the lowest titratable acidity (7.77(0.06) mL) while 4% acetic acid had the highest titratable acidity (200.43(0.11) mL).

The results of two-way repeated ANOVA for each of the parameters (4 parameters) revealed significant differences among 7 storage agents ($p < 0.05$ for all comparisons). All of the parameters had no significant interactions between the type of storage agents and ceramics ($p > 0.05$ for all comparisons). There was also no significant difference between the two types of ceramics ($p > 0.05$ for all comparisons).

The surface roughness values for Ra, Rz, Rmax and Sm parameters of the ceramics evaluated were shown in Tables 2 and 3. For IPS d.SIGN (Table 2), there were significant differences in Ra, Rz, Rmax and Sm between before and after immersion in pineapple, green mango, cola soft drink and 4% acetic acid for 16 hours groups ($p < 0.05$ for all comparisons). Tukey HSD multiple comparison tests determined significant differences for; Ra in 4% acetic acid for 16 hours, pineapple and green mango groups from all the remaining groups ($p < 0.001$); Rz in 4% acetic acid for 16 hours, pineapple and cola soft drink groups from all the remaining groups ($p = 0.008$); Rmax in 4% acetic acid for 16 hours, pineapple, green mango and cola soft drink groups from all the remaining groups ($p < 0.001$) and Sm in 4% acetic acid for 16 hours, pineapple, green mango and cola soft drink groups from all the remaining groups ($p = 0.009$). Similar to IPS e.max Ceram (Table 3), there were significant differences in Ra, Rz, Rmax and Sm between before and after immersion in pineapple, green mango, cola soft drink and 4% acetic acid for 16 hours groups ($p < 0.05$ for all comparisons). Tukey HSD multiple comparison tests determined significant differences for; Ra in 4% acetic acid for 16 hours, pineapple, green mango and cola soft drink groups from all the remaining groups ($p = 0.004$); Rz in 4% acetic acid for 16 hours, pineapple and cola soft drink groups from all the remaining groups ($p = 0.002$); Rmax in 4% acetic acid for 16 hours, pineapple, green mango and cola soft drink groups from all the remaining groups ($p = 0.008$) and Sm in 4% acetic acid for 16 hours, pineapple and green mango groups from all the remaining groups ($p = 0.001$). It has been noted that the Sm values of both ceramics had decreased after immersion in all storage agents. There were no significant differences between the two types of ceramic for all surface roughness parameters after immersion in all storage agents ($p > 0.05$ for all comparisons).

SEM photomicrographs taken of representative specimens for all groups of this study are presented in Figures 1 and 2. Exposure to all acidic agents of both ceramics showed surface changes in various degrees. The pineapple juice, green mango, cola soft drink, and 4% acetic acid 16 for hours group of IPS d.SIGN (Figures 1D, 1E, 1F and 1H, respectively) showed more roughening patterns than the 4% acetic acid group (Figure 1G). While the before immersion (Figure 1A) showed mostly a smooth surface and the deionized water (Figure 1B) and citrate buffer solution (Figure 1C) groups showed only a few rough surfaces. For IPS e.max Ceram, the pineapple juice, green mango, cola soft drink, and 4% acetic acid for 16 hours groups (Figures 2D, 2E, 2F and 2H, respectively) showed more roughening patterns than the 4% acetic acid group (Figure 2G). Similar to IPS d.SIGN, the before immersion (Figure 2A) showed mostly smooth surfaces and the deionized water (Figure 2B) as well as citrate buffer solution (Figure 2C) groups displayed only a few rough surfaces.

Table 1. *The mean pH and standard deviation and titratable acidity (volume of NaOH (mL) to bring pH to 5.5 and 7.0) of acidic agents tested*

Acidic agent	*pH(SD)*	*Volume of NaOH (mL) to bring pH to 5.5*	*Volume of NaOH (mL) to bring pH to 7.0*
Citrate buffer solution	4.99(0.01)	9.10(1.32)	21.23(1.18)
Pineapple juice	3.64(0.01)	20.17(0.35)	25.50(1.00)
Green mango juice	2.39(0.01)	64.83(0.29)	82.57(0.06)
Cola soft drink	2.41(0.06)	2.81(0.01)	7.77(0.06)
4% acetic acid	2.47(0.01)	180.57(0.40)	200.43(0.11)

SD: Standard Deviation of the mean

Table 2. *Mean and standard deviation of roughness parameter (Ra, Rz, Rmax and Sm) of IPS d.SIGN*

Group	*Surface roughness parameter (mean(SD))*							
	Ra (μm)		*Rz (μm)*		*Rmax (μm)*		*Sm (mm)*	
	Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
Deionized water	0.25 (0.15)	0.26 (0.15)^{b}	4.63 (1.88)	4.72 (1.53)^{b}	8.28 (1.92)	8.37 (1.08)^{b}	0.36 (0.15)	0.32 (0.13)^{b}
Citrate buffer solution	0.26 (0.05)	0.27 (0.08)^{b}	5.24 (1.11)	5.46 (1.32)^{b}	7.25 (1.87)	7.57 (1.15)^{b}	0.34 (0.13)	0.32 (0.11)^{b}
Pineapple juice	0.24 (0.05)	0.31 (0.09)*,^{a}	3.16 (0.71)	4.73 (0.99)*,^{a}	5.42 (1.05)	9.71 (1.19)*,^{a}	0.30 (0.12)	0.20 (0.09)*,^{a}
Green mango juice	0.24 (0.13)	0.29 (0.15)*,^{a}	4.83 (1.06)	5.23 (1.36)*,^{b}	7.44 (1.21)	9.06 (1.15)*,^{a}	0.29 (0.12)	0.20 (0.07)*,^{a}
Cola soft drink	0.22 (0.05)	0.25 (0.09)*,^{b}	4.50 (1.16)	5.15 (1.03)*,^{a}	8.41 (1.07)	10.39 (1.02)*,^{a}	0.36 (0.12)	0.25 (0.14)*,^{a}
4% Acetic acid	0.27 (0.11)	0.28 (0.16)^{b}	4.49 (1.58)	4.56 (1.80)^{b}	7.32 (0.93)	8.03 (1.08)^{b}	0.34 (0.14)	0.32 (0.15)^{b}
4% Acetic acid 16 hours	0.29 (0.15)	0.36 (0.12)*,^{a}	6.83 (1.07)	7.93 (1.09)*,^{a}	8.94 (1.07)	9.65 (1.32)*,^{a}	0.25 (0.04)	0.17 (0.05)*,^{a}

SD: Standard Deviation of the mean; Ra: the arithmetical average of surface heights; Rz: the average height difference between the ten highest peaks and ten lowest valleys within each cut-off length; Rmax: the magnitude of the peak-to-valley height in all cut-off lengths; Sm: The arithmetical average spacing between peaks at the mean line over the cut-off length

* indicates significant difference between before and after storage agent immersion in each group and parameter according to *t*-test ($p < 0.05$)

^{a,b,c} indicate significant differences in columns according to Tukey HSD test ($p < 0.05$)

Table 3. *Mean and standard deviation of roughness parameter (Ra, Rz, Rmax and Sm) of IPS e.max Ceram*

Group	*Surface roughness parameter (mean(SD))*							
	Ra (μm)		*Rz (μm)*		*Rmax (μm)*		*Sm (mm)*	
	Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
Deionized water	0.22 (0.17)	0.24 (0.18)[b]	3.75 (1.84)	4.05 (1.99)[b]	8.22 (1.56)	8.94 (1.22)[b]	0.36 (0.12)	0.27 (0.16)[b]
Citrate buffer solution	0.20 (0.06)	0.21 (0.04)[b]	3.66 (1.33)	4.69 (1.34)[b]	9.18 (1.38)	10.02 (1.05)[b]	0.28 (0.11)	0.24 (0.10)[b]
Pineapple juice	0.13 (0.05)	0.41 (0.11)*[,a]	2.03 (0.44)	3.66 (1.06)*[,a]	7.09 (1.11)	10.08 (1.15)*[,a]	0.39 (0.07)	0.31 (0.08)*[,a]
Green mango juice	0.20 (0.09)	0.47 (0.07)*[,a]	3.51 (1.02)	4.65 (0.76)*[,b]	8.70 (1.01)	10.88 (1.04)*[,a]	0.38 (0.11)	0.12 (0.09)*[,a]
Cola soft drink	0.23 (0.08)	0.45 (0.13)*[,a]	3.47 (1.21)	4.52 (1.07)*[,a]	7.41 (1.06)	9.65 (0.95)*[,a]	0.34 (0.08)	0.13 (0.07)*[,b]
4% Acetic acid	0.27 (0.07)	0.31 (0.10)[b]	4.85 (1.29)	5.43 (1.51)[b]	8.23 (1.45)	9.48 (1.39)[b]	0.26 (0.13)	0.24 (0.11)[b]
4% Acetic acid 16 hours	0.25 (0.04)	0.41 (0.11)*[,a]	5.08 (1.02)	6.72 (0.89)*[,a]	8.27 (0.92)	10.79 (1.02)*[,a]	0.39 (0.10)	0.23 (0.10)*[,a]

SD: Standard Deviation of the mean; Ra: the arithmetical average of surface heights; Rz: the average height difference between the ten highest peaks and ten lowest valleys within each cut-off length; Rmax: the magnitude of the peak-to-valley height in all cut-off lengths; Sm: The arithmetical average spacing between peaks at the mean line over the cut-off length

* indicates significant difference between before and after storage agent immersion in each group and parameter according to *t*-test ($p < 0.05$)

[a,b,c] indicate significant differences in columns according to Tukey HSD test ($p < 0.05$)

DISCUSSION

The results of this present study support rejection of the null hypothesis. This study was conducted to measure pH and titratable acidity of acidic agents (citrate buffer solution, pineapple juice, green mango juice, cola soft drink and 4% acetic acid) and evaluated the changes of surface roughness of two types of dental ceramics after exposure to acidic agents. The fruit juices tested in this study (pineapple and green mango) including cola soft drink, were shown to be acidic as acetic acid which has been shown to be highly erosive to ceramic. After immersion of dental ceramics in pineapple, green mango, cola soft drink and 4% acetic acid for 16 hours, there were significant changes of surface roughness to the ceramics evaluated. The pineapple juice had a pH value of 3.64 which gives more chemically basic than cola soft drink (2.39), but had greater titratable acidity (25.50(1.00)) than cola soft drink (7.77(0.06)) which pineapple juice could degrade ceramics to similar degrees. This confirmed that the pH value is not the only factor to affect corrosion, which corresponds to previous studies[21,22]. It has been known that acidity or the measured pH is an accurate indicator of the acidic potential of agents[23]. The pH values present only a measure of the free hydrogen ion concentration. Therefore, it does not present the hydrogen ion remaining in the undissociated form. It is now accepted that titratable acidity is a more accurate measure of the total acid content of agents and also the potential production as well as conjugation of the hydrogen ion[21,22]. Thus, the potential degradation of acidic agents should be considered for both the pH value and titratable acidity.

Pineapple, green mango and other sour fruits contain citric acid, which have been reported as a harmful acid that can cause dental erosion[14,16,23]. This acid might affect the change of surface roughness of ceramics due to its chelating effect[5]. Acetic acid is the acid used for chemical stability testing according to ISO standard 6872[20]. Although acetic acid is a weak organic acid, it is fairly corrosive to glasses due to its chelating effect. A similar effect has been found with citric acid. According to ISO 6872[20], the chemical stability of the ceramics is tested at a high temperature of 80°C, at which changes in surface roughness is normally recordable. These changes might not be found at lower temperatures, for example, at 37°C in the acetic acid group of this present study. These results clearly demonstrated the effect of high temperatures, which is another effect, on ceramic degradation.

The measurement methods for surface roughness which are currently used in dentistry have two methods, namely, a contact and non-contact method[24]. Non-contact methods use a light beam or a laser beam to obtain a surface profile. One of the disadvantages of this method is that shiny surfaces are sometimes difficult to measure because of the scattering effect of the reflected light. This can result in false values being recorded[24]. Therefore, this present study used a profilometer which is a contact method. Even though it has been claimed that, this contact method, the stylus tip may damage or alter the surfaces[18]; however, the result from this present study as seen from SEM showed that this method did not cause any damage to surfaces. There were no scratches observed from SEM because the force applied from the stylus tip was very little (4 mN).

The most commonly used roughness parameter in both dentistry and engineering is the Ra value[25]. However, the limitation of the Ra value is that it is two-dimensional and it only gives information on the roughness height. It also gives no information at all on the profile of the surface[18]. To resolve this limitation, this present study used additional roughness parameters; Rz, Rmax and Sm, including photomicrographs from SEM. These provide a qualitative value in three dimensions. The combination of quantitative measurements and qualitative data by microscopy supports an obvious characterization of the surface tested[24-26]. Additionally, roughness measurements obtained from relatively

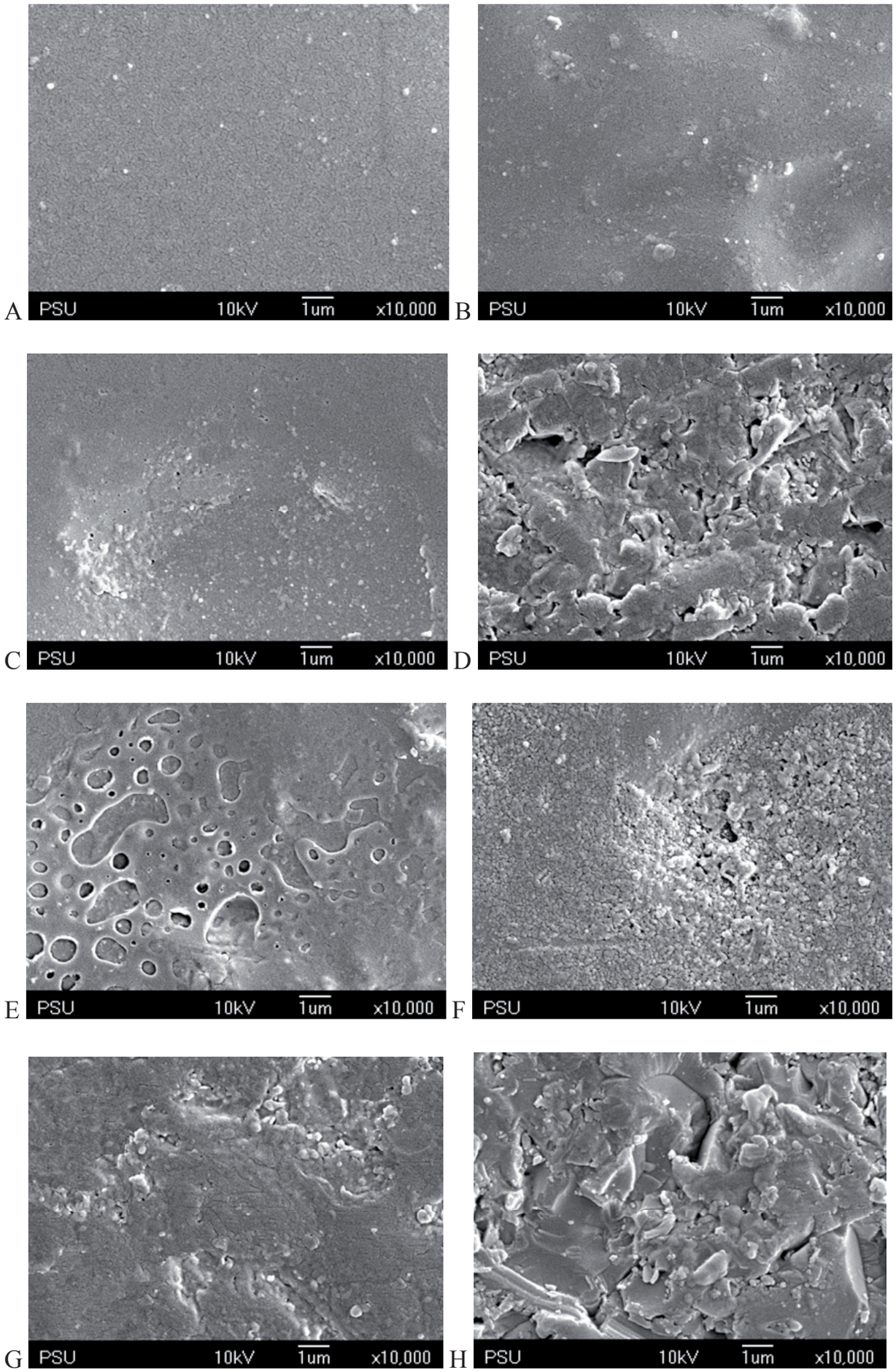

Figure 1. *SEM photomicrographs of IPS d.SIGN immersed in various storage agents. A: Before immersion, B: Deionized water, C: Citrate buffer solution, D: Pineapple juice, E: Green mango juice, F: Cola soft drink, G: 4% acetic acid, H: 4% acetic acid at 80°C for 16 hours.*

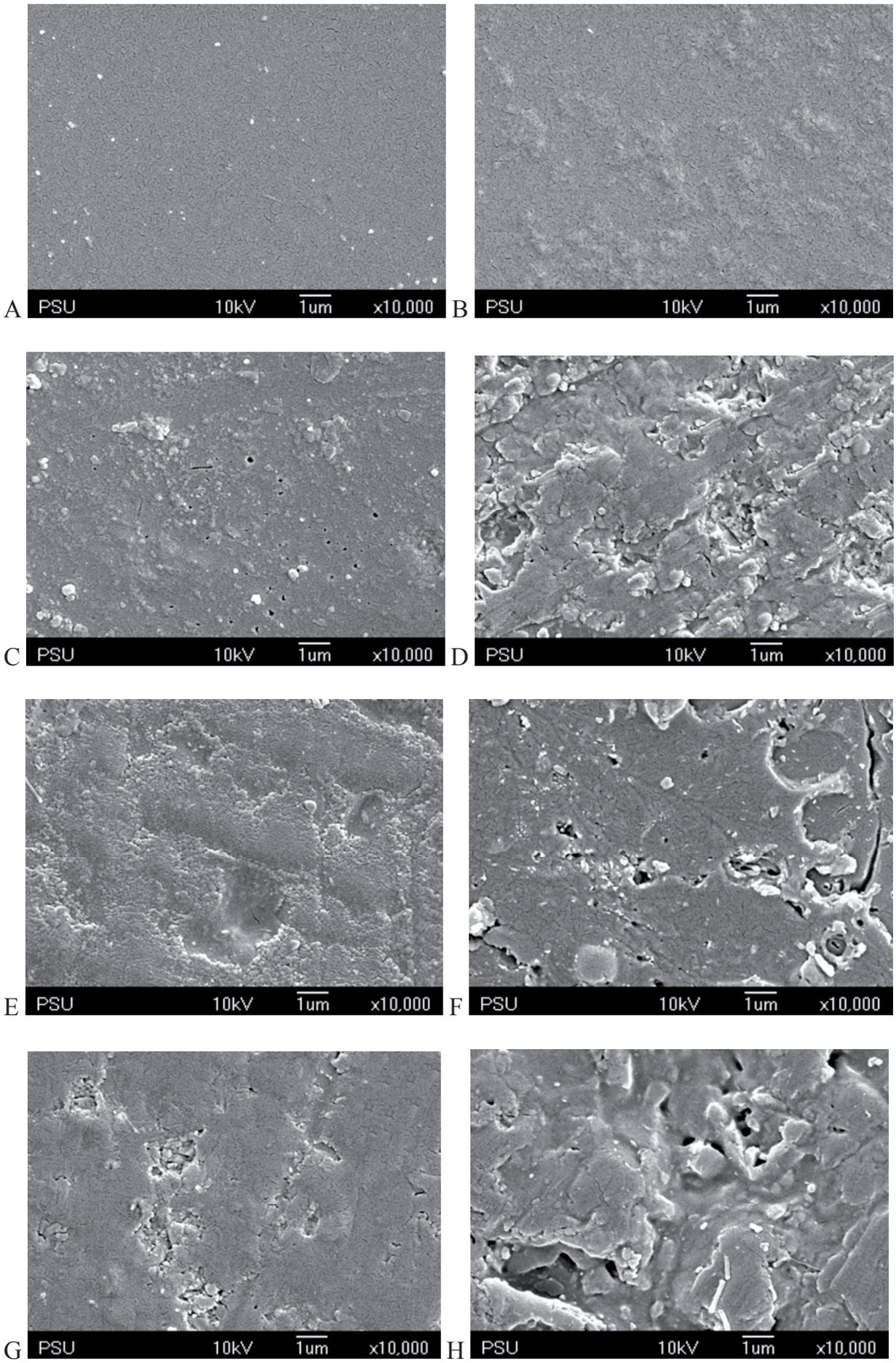

Figure 2. *SEM photomicrographs of IPS e.max Ceram immersed in various storage agents. A: Before immersion, B: Deionized water, C: Citrate buffer solution, D: Pineapple juice, E: Green mango juice, F: Cola soft drink, G: 4% acetic acid, H: 4% acetic acid at 80°C for 16 hours.*

short scans may not be representative for the whole surface. Therefore, many measuring scans are required when using a profilometer. This showed in the present study that the roughness values of the ceramics were in agreement with the other findings[24,25,27].

This present study only demonstrated that acidic agents caused rough surfaces to ceramics. Previous studies have reported that increasing surface roughness of ceramics may decrease strength[8,9]. The critical mean Ra for the adhesion and colonization of bacteria on restorative materials has also been reported to be 0.2 μm[28], which is equivalent to this present study. These results might lead to bacterial colonization and decease in strength of the ceramics evaluated, which would result in clinical failure of ceramic restorations. However, this present study did not evaluate this relationship. Therefore, further studies are required to examine this correlation.

This present study revealed that none of the ceramics evaluated were found to be chemically inert. A very low level of degradation was observed even in a neutral aqueous condition (the deionized water group), although there was no significant difference in surface roughness. Even though the dental ceramics are not simple sodium-silicate glasses, this material is governed by the glassy matrix and the reactions of the primary glass network former silica, mostly controlled the degradation process. It has been reported that two dominant mechanisms are responsible for the aqueous corrosion of sodium-silicate glasses, such as dental ceramics[2]. The first mechanism is the selective leaching of alkali ions. The second mechanism is the dissolution of the glass network (Si-O-Si). These mechanisms are controlled by the diffusion of hydrogen ions or hydronium ions (H_3O^+) from an aqueous solution into the glass and loss of alkali ions from the glass surface to maintain electrical neutrality. These result in rough surfaces as seen from SEM in this present study.

The most significant finding in this experimental study is that fluorapatite-leucite and fluorapatite ceramics could degrade in acidic agents or acidic food and drinks. However, it must be noted that there are some limitations to this study. The oral cavity presents a different testing condition such as the presence of water, temperature change, and pH level. This present study did not account for those conditions which could affect the results. In addition, the present study evaluated only fluorapatite-leucite (IPS d.SIGN) and fluorapatite (IPS e.max Ceram) ceramics. Therefore, further studies are required to elaborate the effect on other types of dental ceramics.

CONCLUSIONS

Within the limitations of this study, it can be concluded that the surface roughness of fluorapatite-leucite and fluorapatite ceramics were affected by the acidic agents tested; the pineapple, green mango, cola soft drink and 4% acetic acid at 80ºC for 16 hours. This should be taken into consideration when restoring the affected tooth with ceramic restorations in patients who consume acidic food, sour fruits and drinks.

MANUFACTURERS' DETAILS

- IPS d.SIGN, Ivoclar Vivadent AG, Schaan, Liechtenstein
- IPS e.max Ceram, Ivoclar Vivadent AG, Schaan, Liechtenstein
- Provil novo putty, Heraeus Kulzer GmbH, Hanau, Germany
- Ceramosonic II, Shofu, Kyoto, Japan
- Progamat P300, Ivoclar Vivadent AG, Schaan, Liechtenstein
- Phoenix model 4000, Buehler GmbH, Düsseldorf, Germany
- Silicon carbide paper, 3M ESPE, St. Paul, MN, USA
- Model PC3, L&R Manufacturing, Kearny, NJ, USA
- Citrate buffer solution, BDH Laboratory Supplies, Poole, England
- Tipco, Tipco Foods Co. Ltd., Prajuabkirikhan, Thailand
- Coca-Cola, Hadthip Ltd., Songkhla, Thailand
- Acetic acid, Merck KgaA, Darmstadt, Germany
- Orion model 900A, Orion Research Inc., Boston, MA, USA
- Surfcorder model SE-2300, Kosaka Laboratory Ltd., Tokyo, Japan
- SPI-Module sputter, SPI Supplies, West Chester, PA, USA
- Scanning Electron Microscope, JSM-5800LV, JEOL, Tokyo, Japan

ACKNOWLEDGEMENTS

The authors would like to thank Professor Peter A. Leggat, James Cook University, Townsville, Australia, for proofing the manuscript.

This study was supported in part by a grant from Graduate School, Prince of Songkla University.

ADDRESS FOR CORRESPONDENCE

Dr. B Kukiattrakoon, Department of Conservative Dentistry, Prince of Songkla University, Hat Yai, Songkhla, Thailand 90112. E-mail: boonlert.k@psu.ac.th

REFERENCES

1. Raptis, N.V., Michalakis, K.X., and Hirayama, H. Optical behavior of current ceramic systems. *Int. J. Periodontics. Restorative. Dent.*, 2006; **26**: 31-41.
2. Anusavice, K.J. Degradability of dental ceramics. *Adv. Dent. Res.*, 1992; **6**: 82-89.
3. Jakovac, M., Živko-Babić, J., Ćurković, L., and Aurer, A. Measurement of ion elution from dental ceramics. *J. Eur. Ceram. Soc.*, 2006; **26**: 1695-1700.
4. Jakovac, M., Živko-Babić, J., Ćurković, L., and Carek, A. Chemical durability of dental ceramic material in acid medium. *Acta. Stomatol. Croat.*, 2006; **40**: 65-71.
5. Milleding, P., Wennerberg, A., Alaeddin, S., Karlsson, S., and Simon, E. Surface corrosion of dental ceramics *in vitro*. *Biomaterials.*, 1999; **20**: 733-746.

6. Demirhanoğlu, Ş.T., and Şahin, E. Effect of topical fluorides and citric acid on overglazed and autoglazed porcelain surfaces. *Int. J. Prosthodont.*, 1992; **5**: 434-440.
7. Clayton, J.A., and Green, E. Roughness of pontic materials and dental plaque. *J. Prosthet. Dent.*, 1970; **23**: 407-411.
8. de Jager, N., Feilzer, A.J., and Davidson, C.L. The influence of surface roughness on porcelain strength. *Dent. Mater.*, 2000; **16**: 381-388.
9. Kelly, JR., Giordano, R., Pober, R., and Cima, M.J. Fracture surface analysis of dental ceramics: clinically failed restorations. *Int. J. Prosthodont.*, 1990; **3**: 430-440.
10. Goodacre, C.J., Bernal, G., Rungcharassaeng, K., and Kan, J.Y. Clinical complications in fixed prosthodontics. *J. Prosthet. Dent.*, 2003; **90**: 31-41.
11. Höland, W., Rheinberger, V., Apel, E., *et al*. Clinical applications of glass-ceramics in dentistry. *J. Mater. Sci. Mater. Med.*, 2006; **17**: 1037-1042.
12. Sinmazişik, G., and Oveçoğlu, M.L. Physical properties and microstructural characterization of dental porcelains mixed with distilled water and modeling liquid. *Dent. Mater.*, 2006; **22**: 735-745.
13. Höland, W., Rheinberger, V., and Schweiger, M. Control of nucleation in glass ceramics. *Philos. Transact. A. Math. Phys. Eng. Sci.*, 2003; **361**: 575-589.
14. Jaeggi, T., and Lussi, A. Prevalence, incidence and distribution of erosion. *Monogr. Oral. Sci.*, 2006; **20**: 44-65.
15. Khan, F., Young, W.G., Law, V., Priest, J., and Daley, T.J. Cupped lesions of early onset dental erosion in young southeast Queensland adults. *Aust. Dent. J.*, 2001; **46**: 100-107.
16. Imfeld, T. Dental erosion. Definition, classification and links. *Eur. J. Oral. Sci.*, 1996; **104**: 151-155.
17. Cairns, A.M., Watson, M., Creanor, S.L., and Foye, R.H. The pH and titratable acidity of a range of diluting drinks and their potential effect on dental erosion. *J. Dent.*, 2002; **30**: 313–317.
18. Stout, K.J. Surface roughness: measurement, interpretation and significance of data. *Mater. Eng.*, 1981; **2**: 260-265.
19. Sandee, S., Naowarat, P., Preamchaiprakarn, O., Palanukoolwong, O., Kukiattrakoon, B., and Hengtrakool, C. Changes in surface hardness of enamel immersed in erosive food. *J. Dent. Res.,* 2004; **83** (special issue B): IO-145 (Abst).
20. International Organization for Standardization. *ISO 6872 Dental ceramic*, Geneve: ISO, 1995; 8-9.
21. Grobler, S.R., Jenkins, G.N., and Kotze, D. The effects of the composition and method of drinking of soft drinks on plaque pH. *Br. Dent. J.*, 1985; **158**: 293-6.
22. Edwards, M., Creanor, S.L., Foye, R.H., and Gilmour, W.H. Buffering capacities of soft drinks: the potential influence on dental erosion. *J. Oral. Rehabil.*, 1999; **26**: 923-7.
23. Meurman, J.H., and ten Cate, J.M. Pathogenesis and modifying factors of dental erosion. *Eur. J. Oral. Sci.*, 1996; **104**: 199-206.
24. Whitehead, S.A., Shearer, D.C., Watts, D.C., and Wilson, N.H.F. Comparison of methods for measuring surface roughness of ceramic. *J. Oral. Rehabil.*, 1995; **22**: 421-427.
25. Sunnegårdh-Grönberg, K., and van Dijken, J.W. Surface roughness of a novel "ceramic restorative cement" after treatment with different polishing techniques *in vitro*. *Clin. Oral. Investig.*, 2003; **7**: 27-31.
26. Whitehead, S.A., Shearer, D.C., Watts, D.C., and Wilson, N.H.F. Comparison of two stylus methods for measuring surface texture. *Dent. Mater.*, 1999; **15**: 79-86.
27. Kamala, K., and Annapurni, H. Evaluation of surface roughness of glazed and polished ceramic surface on exposure to fluoride gel, bleaching agent and aerated drink: an *in vitro* study. *J. Indian. Prosthodont. Soc.,* 2006; **61**: 28-32.
28. Bollen, C.M., Lambrechts, P., and Quirynen, M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: a review of the literature. *Dent. Mater.*, 1997; **13**: 258-269.