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Effect of artificial accelerated aging on surface roughness and color stability of different ceramic restorations

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ABSTRACT

Aim: The purpose of the study was to evaluate the effect of artificial accelerated aging on surface roughness and color stability of three recently introduced CAD/CAM materials. The hypothesis was that artificial accelerated aging would have an effect on surface roughness and color stability of tested materials. **Methods:** A total of 21 ceramic discs were fabricated in this study, including translucent zirconia (InCoris TZI) and resin nano ceramic (Lava Ultimate) ceramic blocks for CAD/CAM and a set of bi-layered discs made of a zirconia CAD/CAM substructure (inCoris ZI) with VM9 hand-layered feldspathic veneering. Initial surface roughness measurements using a stylus profilometer and color measurements using a spectroradiometer were carried out. All specimens were subjected to artificial aging by means of a weathering process in a Weather-O-meter for 300 h. Additional surface roughness

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and color measurements were again carried out after artificial aging of the specimens. The Wilcoxon Signed Rank Test was conducted to determine significant differences in surface roughness among the 3 groups (α = 0.05). **Results:** Lava ultimate specimens showed a statistically significant difference in surface roughness before and after artificial accelerated aging (P = 0.028). There was no statistical significance in surface roughness of both the translucent zirconia TZ1 (P = 0.499) and the InCoris ZI with VM9 veneering (P = 0.398) specimens before and after aging. The amount of color change in the 3 ceramic groups was also not significant. **Conclusion:** Artificial accelerated aging did not affect the color stability of any of the 3 ceramic groups, however, it caused a significant decrease in the surface roughness of the resin nano ceramic group.

INTRODUCTION

The success of ceramic restorations and the advancements achieved in the development of improved dental ceramic systems have played a role in the increased popularity of and the shift towards these systems.[1,2] Dental ceramics are known for their excellent aesthetics and biocompatibility.[3,4] They have shown the most accurate reproduction of the appearance, color, and texture of natural teeth.[5,6]

Zirconia-based ceramics are among the most popular and the most widely used ceramics in the modern dental practice.[7,8] This can be attributed to their superior mechanical properties[7-10] and excellent biocompatibility[9,11-13] comparable to other dental ceramics.

The stability of dental ceramics in the oral environment is directly related to the high surface polish, subcritical crack propagation, and chemical inertness of these materials, which in turn enables them to resist degradation in the oral environment.[2] Surface roughness will jeopardize the biomechanical and esthetic value of a dental restoration, increasing its susceptibility to aging.[14] A rough-surfaced dental restoration will not only favor more plaque retention[15] and cause abrasive damage to opposing dentition,[16-19] but will also be weakened by the presence of these surface flaws that can, very often, be the starting point of material failure.[20]

The idea of combining ceramic with resin has always been an attractive idea. Combining the strength and color stability of ceramic with the resilience of resin decreases forces transmitted to underlying structures and decreases wear. This has led to the introduction of nano-hybrid ceramics. Lava Ultimate is a resin nano-ceramic material that holds a unique chemical composition consisting of 80% (by weight) nano-ceramic particles of zirconia, silica, and zirconia/silica cluster agglomerates which are bound in the resin matrix. It is possible that the chemical composition of the material and its resin content play a role in the way the material reacts to the accelerated aging process. The resin matrix, as a polymer-based substance, may undergo surface degradation and roughening as a result of clinical service[21] or due to artificial accelerated aging with UV-light-weathering.[22] The initial color match and color stability are crucial determining factors for both initial and the long-term esthetic success of a dental restoration.[23-25] However, the optimal match of a ceramic restoration to natural teeth depends not only on the color and translucency, but also depends on color changes which occur over time as the material ages.[5,23] Color shifting in dental restorative materials may occur over time,[25] hence, color stability arises as key to the long-term aesthetic success of dental restoration.[23-25]

Artificial accelerated aging is an experimental method used to simulate oral environmental conditions extra-orally.[3,23,26] A weathering process that involves exposure to ultraviolet light, fluctuant temperatures, and variable humidity has been used to artificially age prosthetic materials.[3,26]

The purpose of the study was to evaluate the effects of artificial accelerated aging on surface roughness and color stability of three ceramic materials. The hypothesis was that artificial accelerated aging will have an effect on the surface roughness and color stability of tested ceramic materials.

METHODS

A total of 21 disc-shaped specimens (2 mm thick and 10 mm in diameter) were fabricated for use in the study, divided equally into 3 groups (n = 7). These consisted of two different sets of monolithic discs and a set of bi-layered ceramic discs. Translucent zirconia ceramic blocks for CAD/CAM (inCoris TZI) were used for fabrication of the first set of monolithic discs (Group T), whereas resin nano-ceramic blocks for CAD/CAM (Lava Ultimate) were used for fabrication of the second set of monolithic discs (Group L). In addition, zirconia ceramic blocks for CAD/CAM (inCoris ZI) were used for the fabrication of 1 mm thick zirconia substructures (with a diameter of 10 mm) which were veneered by VM9 feldspathic porcelain using a traditional hand

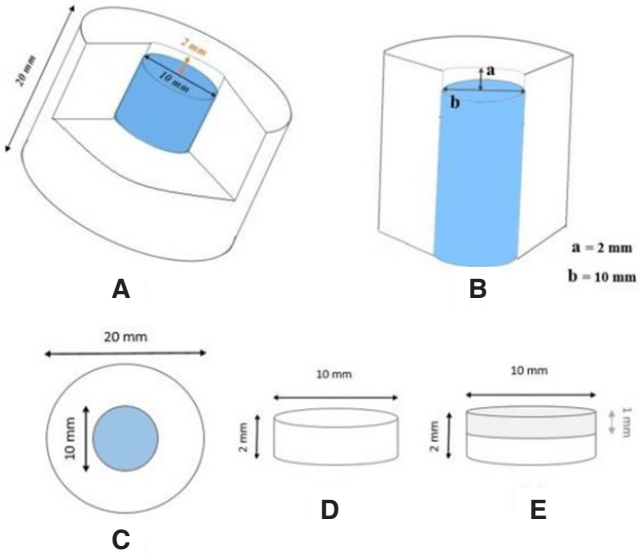

Figure 1: Schematic diagrams. (A) General view of the teflon mold constructed for specimen fabrication; (B): longitudinal section in the mold; (C): cross section of the mold; (D): a monolithic disc; (E) a bi-layered disc

layering technique to obtain bi-layered ceramic discs (Group F).

The CerecinLab MC XL was used for CAD/CAM fabrication of all specimens by fabricating 2 molds for the construction of the disc-shaped specimens. Each mold was constructed from dense Teflon in 2 parts, including a cylinder with a height of 20 mm, external diameter of 20 mm and an internal diameter of 10 mm, and a piston that fit tightly into this internal diameter [Figure 1]. When the piston was completely seated within the cylinder (placed flush on a flat surface) it was 2 mm shorter than the cylinder walls for the first mold, and 1 mm shorter for the second mold. In effect, this created a disc-shaped space with the dimensions of 10 mm in diameter × 2 mm in depth or 1 mm in depth, depending on the mold.

The mold with the 2 mm × 10 mm space was used for the fabrication of monolithic discs, while the mold with the 1 mm × 10 mm space was used for the fabrication of zirconia substructures that were later placed in the first mold occupying the bottom 1 mm of the 2 mm deep space. This left the superior 1 mm open for the veneering VM9 feldspathic porcelain which was done using a traditional hand layering technique.

The thickness of each disc-shaped specimen was confirmed to be 2.0 ± 0.1 mm using a digital caliper. Group T and group F specimens underwent further glazing whereas group L specimens underwent polishing only according to the manufacturer's instructions. All specimenswere then cleaned ultrasonically in a distilled water bath for 10 min, compressed-air-dried, and stored clean and dry in a dark environment until the time of measurement.

Color measurements in the current study were done prior to accelerated aging using a spectroradiometer (PR 705; Photo Research Inc., Chatsworth, California) and fiber optic light cable fixed to an optical table (MecomInc., Risingsun, Ohio). The fiber optic light cable was connected to a xenon arc lamp (300 W; Newport Corp-Oriel Instruments, Stratford, Conn). The spectroradiometer and the optic light cable, positioned at a 45-degree angle inferior to the horizontal plane, provided an optical configuration of 0-degrees of observation and 45-degrees of illumination to the object. For all color measurements in this study, spectral reflectance was obtained from 380 to 780 nm with a 2-nm interval (SpectraWin 2.0; Photo Research Inc.) and subsequently converted to CIELAB values (D65 illumination and 2-degree observer). The spectroradiometer was standardized to 8 cm to the measured object with a measurement aperture size of 1 mm.

The surface roughness profile of each disc was registered using a profilometer (SURFTEST-SV-600 s 178 Surface Roughness Tester, MITUTOYO, Co, Santo Amaro, São Paulo, Brazil) with a cut-off value of 0.25 mm. Three different regions were evaluated in each specimen to determine 3 Ra values and the final value to characterize each specimen was the arithmetic mean among them. Data of this initial surface roughness profile registration were recorded as Ra1 (Surface roughness prior to artificial accelerated aging).

All specimens were aged in an accelerated aging chamber (Atlas Ci35A Xenon® Weather-O-meter, Atlas Material Testing Technology LLC, Chicago, IL, USA) set to standard CAM 180 cycles. One surface of each specimen was exposed to a controlled irradiance xenon arc filtered through borate borosilicate glass at 0.55 W/m^2 at 340 nm, a black panel temperature of 70 °C (light cycle) and 38 °C (dark cycle), a dry bulb temperature of 47 °C (light cycle) and 38 °C (dark cycle), and a humidity of 50% (light cycle) and 95% (dark cycle). The test cycle was 40 min light only, 20 min light plus front water spray, 60 min light only, and 60 min dark plus back water spray. A total energy of 450 kJ/m^2 was conducted over the entire weathering process. All specimens underwent the same color and surface roughness measurements after the accelerated aging process.

The color difference (ΔE) values were evaluated by calculating the difference in color measurements of the specimens before and after artificial accelerated aging

Table 1: Comparative statistics of Wilcoxon Signed Rank Test, mean values ± SD of surface roughness (in μm) before aging, after aging and the difference between three ceramic groups

Ceramic group	Before aging	After aging	Difference	*P* value
Group F	2.5386 ± 1.25783	2.8795 ± 0.70405	0.3409 ± 1.21466	0.398
Group L	0.9371 ± 0.33515	0.6219 ± 0.28367	-0.3152 ± 0.35781	0.028*
Group T	0.3600 ± 0.06880	0.9738 ± 0.39798	0.6138 ± 0.40545	0.499

*Statistically significant difference ($P < 0.05$)

by using the following formula ΔE (L*a*b*) = [(L*1 - L*2)^2 + (a*1 - a*2)^2 + (b*1 - b*2)^2]$^{1/2}$, where numbers "1" and "2" refer to the color coordinates before and after artificial accelerated aging, respectively. The amount of surface roughness change was calculated for each specimen as Ra = Ra2 - Ra1, where Ra1 is the arithmetic mean roughness before aging and Ra2 is the arithmetic mean roughness after aging.

At a sample size of $n = 7$ and significance level of $\alpha = 0.05$, the statistical power value of the current study was 0.936. Power analysis was done using G*Power test (Version 3.1.9.2).

Values were presented as means ± standard deviation (SD) at a 95% confidence interval with a "*P* value" of 5% as the limit of statistical significance. The effect of artificial accelerated aging on surface roughness of each individual ceramic group was statistically analyzed using the Wilcoxon Signed Rank test.

RESULTS

The test results revealed that only group L specimens (Lava Ultimate ceramic) showed a statistically significant difference in surface roughness before and after artificial accelerated aging ($P = 0.028$). There was no statistical significance in surface roughness in both the T group ($P = 0.499$) and the F group ($P = 0.398$) before and after aging [Table 1].

With regards to color stability, the amount of color change (ΔE) was calculated using the CIELAB formula. The means of ΔE values of the 3 ceramic groups were ΔE* = 0.8743 ± 0.32837 for the T group, ΔE* = 2.29 ± 0.49866 for the L group, and ΔE* = 0.8514 ± 0.46763 for the F group.

DISCUSSION

The first hypothesis that artificial accelerated aging has an effect on the surface roughness of tested ceramic materials was accepted. There was a statistically significant difference in surface roughness of the L group (Lava Ultimate ceramic) ($P = 0.028$) before and after aging, which supported the hypothesis. However, accelerated aging did not have an effect on surface roughness of the other 2 groups of ceramics. Lee *et al*.[22] reported that after accelerated aging under xenon light and 90% relative humidity, the matrices of resin eroded, and as a result, the resin showed a chalky surface with increased surface roughness. However, this finding contradicted those of the current study; although a significant change in surface roughness of group L ceramics was observed, surface roughness decreased after artificial aging.

As zirconia ages, grain pull-out is reported as a sequela of the proposed aging process, with subsequent adverse effects on the surface finish and optical properties of these restorations. The surface roughness of materials may adversely influence their optical properties.[27,28] However, this was not shown by the results of this study. The other two groups, group T and group F, were not affected by the accelerated aging process, and the suggested sequela could not be confirmed.

The second hypothesis that artificial accelerated aging has a significant effect on the color stability of the three ceramic materials was rejected. With regards to color stability of tested ceramic materials, the perceptibility level set in this study was 2 ΔE units, whereas the clinical acceptability level was set to 3.7 ΔE units, as determined by many studies.[21,29,30] The 3 ceramic groups showed clinically acceptable color stability after 300 h of artificial accelerated aging, with the largest amount of color change observed in the L group, with a mean of 2.29 ΔE units. The lowest amount of color change was observed in the F group, with a mean of 0.85 ΔE units, while the T group was in the middle with a mean of 0.87 ΔE units. However, the amount of color change in ceramics of the L group was above the level of perceptibility, indicating that it was perceivable to the human eye, although it was still below the level of clinical acceptability.

Artificial accelerated aging is a method which claims to simulate intraoral conditions. The manufacturer claims that 300 h of weathering in a weather-O-meter equals one year of clinical service intraorally. However, there are no data to support this claim.[21] Many studies have used this weathering process to test various dental restorative materials for color stability and surface roughness, including dental composites,

resin cements, and dental ceramics.[3,21,26,31] However, use of this method to test performance and endurance of dental restorative materials in vitro is convenient and provides us with more realistic expectations of the long-term outcome of these restorations.[4,21] The method of artificial accelerated aging used in the current study is a weathering process marked as CAM 180. This method, as proposed by ASTM G155, is one of several cycles used for operating xenon-arc light apparatus for exposure of nonmetallic materials. It encompasses alternate exposures of darkness and light as well as intermittent exposure to a water spray. Validation of this method has been verified by previous studies.[21,26,31] It is unclear as to how many hours in an artificial accelerated aging instrument are equal to one year of clinical service. There is no established answer to this question in the literature. However, the manufacturer of the artificial aging chamber claims that 300 h in the weathering chamber is equivalent to one year of clinical service.[3,21,26,31] It has been suggested that color change caused by artificial accelerated aging involving UV irradiation is related to the internal color stability of the material itself, i.e. intrinsic factors within the material,[22] and occurs within 300 h of accelerated aging.[3,21,31]

In the current study, group L specimens (Lava Ultimate ceramic) showed the greatest amount of color change with a ΔE^* value of 2.28. Although the amount of color change in group L is still within the limit of clinical acceptability, it surpassed the level of perceptibility and showed the largest color shift among the 3 groups. The different structuring of the Lava Ultimate ceramic may have influenced the amount of change in color caused by artificial accelerated aging. The resin content of these ceramic blocks, although highly converted and cross-linked and fully cured, may have undergone chemical disassociation which triggered the intrinsic color shift. This pattern of chemical dissociation is claimed to be the way this method of artificial aging affects resinous substances.[4,21] In the other 2 ceramic groups, a slight and insignificant color change took place as a sequela to the artificial accelerated aging. The amount of color change observed in the F and T groups was insignificant, and was below both the clinical acceptability and perceptibility levels set in this study. The slight color change observed in these 2 groups may be due to breakdown of the metal oxide content of the colorants added to the ceramic itself, or due to the ceramic coloring liquid used to give the ceramic its appropriate shade match. The breakdown of metal oxides under ultraviolet radiation is followed by peroxide compound formation that would likely change the color of the shaded ceramic material.[3] Another potential cause of the difference in the amount of color change between the specimens is the difference in the fabrication procedure that was followed in this study, in accordance with the manufacturers' recommendations for each of the 3 groups. Per the manufacturer for Lava Ultimate, ceramic restorations should only be polished and are ready to be delivered. This is believed to be due to the high resin content which may be damaged by the high sintering and glazing temperatures. The zirconia polycrystals in these ceramic blocks are fully sintered. In contrast, the manufacturers' recommendations for the other 2 groups involved further sintering and glazing to give the material its final strength and characterization. Although polishing has been studied previously, and was proposed as a convenient method for producing surface smoothness comparable to that produced by glazing, researchers have continued to investigate the differences between polishing and glazing of dental ceramics.

Although laboratory surface roughness and color stability values after artificial accelerated aging may not reflect intraoral conditions, these values are nevertheless helpful in comparing materials under controlled situations and may be a helpful predictor of clinical performance. Further studies on Lava Ultimate resin nano ceramics are needed to investigate their performance and their ability to survive oral environmental conditions. Prolonged aging periods may be needed.

In conclusion, within the limitations of the current study it can be concluded that: (1) Bi-layered zirconia-based restorations (inCoris ZI substructure with VM9 feldspathic veneering) and monolithic zirconia-based restorations (inCoris TZI) showed clinically acceptable surface roughness and color stability after being subjected to artificial accelerated aging; (2) artificial accelerated aging significantly affects surface roughness of resin nano ceramic (Lava Ultimate ceramic), while it does not affect its color stability.

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Conflicts of interest

There are no conflicts of interest.

Patient consent

Not applicable.

Ethics approval

Not applicable.

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