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Color Changes Associated with Sandblasting, Hydrofluoric Acid Etching, and Er:YAG Laser Irradiation of Milled Feldspathic Porcelain Laminate Veneers

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Clinical Relevance

The Er:YAG laser irradiation can be considered as a biologically and environmentally safe method for surface treatment of thin, milled feldspathic porcelain veneers.

SUMMARY

Objectives: To evaluate color changes in milled feldspathic porcelain laminate veneers following hydrofluoric acid etching (HFA), sandblasting (SB), or Er:YAG laser irradiation (LI).

Methods and Materials: Disc-shaped specimens (thickness=1 mm, diameter=8 mm) were milled from feldspathic porcelain blocks (n=40). Glazed specimens were randomly assigned to four subgroups (n=10 each) according to surface treatment: negative control, HFA, SB, and LI. A layer of translucent, light-cured resin cement (thickness=0.1 mm) was then applied following silanization. The color was characterized by the L*, a*, and b* uniform color space (CIE) using a reflection spectrophotometer. CIEDE2000 (ΔE_{00}) was calculated to determine the color difference between each surface treatment and negative control groups. Data were statistically analyzed using analysis of variance (ANOVA), Kruskal-Wallis, and Dunn-Bonferroni post hoc tests.

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http://doi.org/10.2341/20-213-L

Results: There were no significant differences in CIEL* and CIEb* coordinates between negative control and all surface treatment groups ($p \geq 0.108$). The SB group demonstrated significantly lower mean CIEa* (higher greenish hue) compared to other groups ($p \leq 0.003$). HFA exhibited significantly higher CIEa* (closer to red) when compared to LI (p=0.039). LI induced the smallest overall color change compared to negative control (ΔE_{00}=1.43 [1.07]). However, the differences in ΔE_{00} values were not statistically significant (p=0.648).

Conclusions: The tested surface treatments did not affect the lightness or the yellowness of the 1-mm-thick milled feldspathic porcelain veneers. However, sandblasting resulted in a significant increase in the greenish hue. The Er:YAG laser resulted in the closest ΔE_{00} (1.43) to the 50:50% perceptibility threshold (ΔE_{00}=1.2).

INTRODUCTION

Laminate veneers (LVs) have gained wide popularity as a minimally invasive alternative to full coverage crowns. They can be effectively utilized to treat aesthetic disharmonies, including discrepancies in tooth size, position, shape, contour, alignment, and bleaching-resistant tooth discoloration.[1] Further, LVs have functional indications as they can be used for improving phonetics and incisal guidance.[1] LVs require no or minimal tooth preparation and can be adhesively bonded to the tooth structure and thereby can be effectively used in tooth surface loss cases.[2,3] Long-term clinical data demonstrated remarkably high success/survival rates, thanks to the ever-improving ceramic materials and adhesive bonding systems.[1,4]

Feldspathic porcelains have long been utilized to produce lifelike and highly aesthetic LVs due to their optimum optical properties.[1] The superior mechanical properties of leucite and lithium disilicate glass-ceramics expanded the applications of LVs.[5,6] Clinical studies demonstrated that reinforced glass-ceramic LVs are associated with higher survival/success rates compared to feldspathic porcelain counterparts.[7] The introduction of translucent zirconia allowed the production of ultrathin and yet mechanically reliable LVs.[8,9] Indirect resin-based composites attracted attention as a potential substrate for the construction of LVs for being less brittle and easier to repair when compared to ceramics.[10-12]

The widespread application of computer-assisted design/computer-assisted manufacturing (CAD/CAM) has revolutionized the fabrication of LVs. CAD/CAM technology can be utilized to fabricate full-contour monolithic LVs, cut-back cores ready to receive veneering porcelain, or wax patterns to be used for the production of any of the aforementioned using a heat-pressing technique. CAD/CAM allowed single-visit, chair-side fabrication of LVs for patients with pressing social and professional commitments and eliminated interappointment microleakage.

Adhesive bonding of LVs with resin composite cements to tooth structure is a key determinant for success and longevity.[7] Successful bonding requires appropriate surface modification of the fitting ceramic surface and conditioning of the tooth structure. Roughening of the fitting surface of LVs promotes micromechanical retention via the interdigitation between the ceramic material and the resin composite cement. Further, surface modification may promote chemical adhesion by increasing reactivity to the silanization process via condensation of the silanol groups in the vicinity of hydroxylated silica groups.[13] Glass-containing ceramics can be effectively treated chemically or mechanically. The amorphous glassy phase is highly susceptible to chemical dissolution by hydrofluoric (HF) acid.[14,15] Sandblasting can also effectively create the required microroughness.[16] HF acid is considered a biologically and environmentally hazardous agent and may generate a significant amount of crystalline debris that contaminates the etched surface.[17] Further, the high refractive index of residual sandblasting material may alter the optical properties of the ceramic material. Hence, meticulous post-treatment cleaning should be warranted following HF acid etching or sandblasting.[17] More importantly, both techniques can be deleterious to the mechanical reliability of the ceramic materials.[18-20]

Lasers have been considered as an effective and safe method for ceramic surface treatment.[21-24] The high energy delivered by laser irradiation leads to thermally or chemically induced morphological surface alterations. Several types of lasers have been advocated for etching dental ceramics, including CO_2, Nd:YAG, and Erbium (Er) lasers.[25] Several studies reported adequate resin bond strength to ceramic substrates following laser irradiation, while others demonstrated suboptimal performance.[25] The disparity in the findings can be attributed to the variations in the implemented techniques and irradiation parameters.

The Er:YAG laser is a solid-state laser that emits light within the infrared spectrum (2940 nm). It is widely used in dentistry as it is highly absorbed by hydroxyapatite.[25] Several studies have investigated the use of Er:YAG irradiation as a surface treatment to enhance adhesive resin bonding. Er:YAG laser irradiation resulted in inferior resin bond strength to feldspathic porcelain compared to HF/silane.[26-29] Aksakalli and others however, reported comparable resin bond strength to feldspathic porcelain upon applying HF/silane or Er:YAG irradiation surface treatments.[30] Higher, but not significantly different, resin shear bond strength to feldspathic porcelain was reported with Er:YAG laser irradiation compared to HF/silane.[31] The effect of an Er:YAG laser on surface roughness of, and resin bond strength to, leucite and lithium disilicate glass-ceramics and zirconia appears to be more pronounced.[22, 24,32-34]

The overall color of ceramic reconstruction can be influenced by: 1) reconstruction thickness,[35,36] 2) shade and film thickness of the luting agent,[35,36] and 3) color of the underlying tooth structure.[37] Polishing/glazing of the restoration's cameo surface may also affect the color, translucency, and texture of ceramic reconstruction.[38] Treatment of the fitting surface may also alter optical properties due to chemical/morphological alterations that may affect the refractive index or thickness of the reconstruction. One study reported a significant reduction of translucency of thin (thickness=0.5 mm), pressed lithium disilicate glass-ceramic LVs upon using Er:YAG laser or sandblasting compared with HF acid etching.[39]

Currently, there is limited evidence pertaining to the color changes with various surface treatments of contemporary CAD/CAM feldspathic porcelain substrates. The objective of this study was to compare color changes associated with the Er:YAG laser, sandblasting, and hydrofluoric (HF) acid surface treatments when used on CAD/CAM porcelain LVs. The null hypothesis of this study was that all surface treatments will not induce a significant color change in the tested feldspathic porcelain substrate.

METHODS AND MATERIALS

A commercially available CAD/CAM feldspathic ceramic substrate (VITABLOCS Mark II, VITA Zahnfabrik, Bad Säckingen, Germany) was used in this study as the LV material (shade A1). Forty disc-shaped specimens (diameter=8 mm, thickness=1 mm) were digitally designed (Ceramill Mind, Amann Girrbach AG, Koblach, Austria) and milled from fully sintered blocks using a 5-axis milling unit (Ceramill Motion 2, Amann Girrbach AG). All discs were finished and glazed according to the manufacturer's instructions (VITA AKZENT Plus, VITA Zahnfabrik).

Specimens were randomly divided into four groups according to the surface treatment type (n=10 per group):

- Negative control: No surface treatment.
- HF acid etching (HFA, positive control): The bonding surface of each disc was etched with 9.5% HF acid for 60 seconds. The acid gel was rinsed with water for 20 seconds and then dried using an oil-free airstream.
- Sandblasting (SB): The bonding surface of each disc was sandblasted with 50 μm Al_2O_3 particles for 20 seconds (pressure=2.5 bar, distance=10 mm).
- Laser irradiation (LI): An Er:YAG laser (Pluser, Doctor-Smile, Lambda SpA, Brendola, Italy) was used for laser irradiation. The optical fiber was aligned perpendicularly to the bonding surface of each disc at a distance of 1 mm. The whole surface of the disc received the laser irradiation according to the following parameters: pulse energy = 400 mJ, frequency = 20 Hz, power = 10 W, energy density = 40 J/cm^2 and pulse length = 150 μs.

Following surface treatment, all discs were cleaned in a distilled water ultrasonic bath for 10 minutes. Two coats of pre-hydrolyzed silane primer (Porcelain Primer, BISCO, Inc, Schaumburg, IL, USA) were applied to each disc and then dried with an oil-free airstream. A layer of light-cured, translucent resin cement was applied to the bonding surface of each disc (Choice 2, BISCO, Inc). The cement layer was adapted using a clean glass slab, which was then placed over the cement layer under a 1-kg weight for 30 seconds. Upon removing the weight and glass slab, the cement was cured using a light-curing tip applied from the glazed ceramic side for 60 seconds. Then, the cement layer was adjusted with wet silicon carbide paper (600 grit) to 0.1 ± 0.01 mm, yielding 1.1-mm-thick discs in all groups. An electronic digital caliper was used to verify thickness at various stages of the specimen preparation process (JOCAL, CE Johansson AB, Eskilstuna, Sweden).

A reflection spectrophotometer device was used for color measurements (VITA Easyshade, VITA Zahnfabrik) with white background and under a D65 (daylight) illuminant while specimens were placed in a lightbox to standardize the external lighting conditions. The spectrophotometer's probe was placed in the center of each disc, and measurement was repeated three times for each disc. For each specimen, a mean value was calculated for the three color coordinates of the Commission Internationale de l'Eclairage (CIE) system; L*: lightness: black-white; a*; greenish-redness; and b*: blueness-yellowness. Mean chroma or color saturation index (C) and hue angles were also calculated for all groups. The perceptible color difference metric CIEDE2000 (ΔE_{00}) was calculated using the following equation:

$$\Delta E_{00}=[(\Delta L\Delta/K_L S_L)^2+(\Delta C'/K_C S_C)^2+(\Delta H\Delta/K_H S_H)^2+ R_T(\Delta C\Delta/K_C S_C)\,(\Delta H\Delta/K_H S_H)]^{1/2}$$

The Shapiro-Wilk test indicated that some data sets did not follow a normal distribution ($p<0.05$). One-way analysis of variance (ANOVA) and Kruskal-Wallis tests were performed to examine statistically significant interactions between various surface treatments and control groups. Pairwise comparisons were performed using the Dunn-Bonferroni post hoc test ($\alpha=0.05$). All analyses were performed using the Statistical Package for Social Sciences software (Version 23, IBM SPSS Statistics, Armonk, NY, USA).

RESULTS

There were no significant differences in CIE L* and CIE b* coordinates between negative control and all surface treatment groups ($p\geq0.108$). HFA and LI groups exhibited no statistically significant difference in CIE a* compared to the negative control group ($p\geq0.246$). SB resulted in a statistically significant reduction in the mean CIE a* indicating a notable increase of the greenish hue (-1.23 [0.04], $p\leq0.003$) compared to the other surface treatment and negative control groups. The LI group exhibited significantly lower CIE a* (increased greenish hue) when compared to HFA ($p=0.039$). No statistically significant differences were observed in the chroma index (C) or hue angles when comparing all surface treatment and negative control groups ($p\geq0.408$). LI induced the smallest ΔE_{00} (1.43, [1.07]), the differences in ΔE_{00} between all surface treatment groups and negative control were however, not statistically significant ($p=0.648$). Table 1 summarizes mean and standard deviation values of CIE L*a*b* coordinates, ΔE_{00}, chroma index, and hue angle for all surface treatment and negative control groups.

DISCUSSION

The purpose of this laboratory study was to investigate the color changes associated with three surface treatment methods used on milled feldspathic porcelain LVs. Untreated samples were used as a negative control to compare the effect of HFA etching, sandblasting, and Er:YAG laser surface treatments on CIE L*a*b* color coordinates. Specimens were digitally designed to standardize the thickness (1 mm). Optimum color, translucency, and texture can be achieved with 0.5-1 mm thickness LVs.[40] Further, the manufacturer recommends 0.7-mm minimum thickness of the material used in this study at the incisal third of the LV. Thus, we investigated 1-mm-thick specimens to assess color changes that can be encountered in a clinical setting. A single experienced operator performed all surface treatments and color measurements to ensure standardized procedures. The used parameters for the three surface treatments in this study were reportedly associated with the highest resin bond strength or least reduction of mechanical reliability.[13,16,19,20] For laser surface treatment, the highest pulse energy (400 mJ) and the smallest possible distance between the optic fiber and specimen (1 mm) were used, as they were reportedly associated with the highest surface roughness and/or resin bond strength.[25,28,32] A digital spectrophotometer was also used in this study for objective evaluation of color changes. Such a device may be a reliable alternative or adjunct to conventional shade guides. A digital spectrophotometer allows exportation of numerical values for various CIE color coordinates, allowing precise and highly sensitive assessment of subtle color changes.[41] However, the output of such a device may vary due to inconsistent positioning of the probe tip.[42] In this study, this problem was avoided by positioning the probe tip at the center of each specimen guided by ruler measurements. ΔE_{00} was used to assess color change as it was found to correspond better to the way human observers perceive small color differences.[43]

Surface treatments, in general, may affect the color of the ceramic substrate as a result of the physical,

Table 1: *Mean (SD) Values for CIE L*a*b* Coordinates, Hue Angle, and ΔE_{00} for Surface Treatment and Negative Control Groups*[a]

	HFA	SB	LI	Control
L*	64.46 (1.31) a	65.39 (1.46) a	64.67 (1.62) a	64.67 (1.27) a
a*	-0.81 (0.14) a	-1.23 (0.05) b	-0.93 (0.24) c	-0.91 (0.06) ac
b*	5.48 (0.60) a	4.81 (0.85) a	5.04 (0.36) a	4.78 (0.85) a
C	5.37 (0.58) a	4.99 (0.80) a	5.13 (0.39) a	4.88 (0.84) a
Hue angle	179.55° (7.24)	180.65° (5.60)	180.77° (1.37)	184.74° (10.56)
ΔE_{00}/Control	1.72 (1.03) a	1.80 (0.87) a	1.43 (1.07) a	—

Abbreviations: a (green-red); b*(blue-yellow); C, chroma index; HFA, hydrofluoric acid; L* (lightness: black-white).*

[a]Similar letters indicate lack of statistically significant differences within the same row (p>0.05).

chemical, or mechanical interactions that lead to surface morphological alterations. The high energy delivered to the ceramic material surface upon laser irradiation can cause melting, phase transformation, micro-explosions, or bubble inclusion within the amorphous glassy phase that may alter the optical properties of the material.[25] Laser irradiation may also result in chemical reactions that can further change the surface characteristics of certain ceramic materials.[25] The null hypothesis of this study was partially rejected as sandblasting resulted in a significant increase of greenish hue of the studied porcelain LV material. The notable color changes associated with sandblasting can be attributed to the changes in the refractive index induced by such a process. Sandblasting may increase the refractive index by increasing surface roughness, altering the thickness of the material, and changing the chemical composition of the surface due to the incorporated alumina particles within the surface of the abraded ceramic substrate. From a clinical standpoint, such color change may result in a significant color mismatch, especially when using highly chromatic resin composite cements to mask discolored abutments. Contradictory findings were reported by another study, where sandblasting and Er:YAG laser irradiation resulted in significant changes of CIE L* and b* coordinates but not a* when compared to HF acid etching and control.[44] The disparity in the findings can be attributed to the differences in the chemical composition of the studied ceramic materials (leucite, lithium disilicate, and nano-fluorapatite) and the higher pulse energy (500 mJ) used in the latter study.

Overall color change (ΔE_{00}), in comparison to the negative control, was the highest with sandblasting (1.80 [0.87]) followed by HF acid etching (1.72 [1.03]). Both surface treatments resulted in clinically acceptable color changes according to the 50:50% acceptability threshold value (ΔE=2.7) determined in the ISO standards (ISO/TR 28642:2016). A nearly perfect color match in dentistry is a color difference at or below the 50:50% perceptibility threshold, which is designated as ΔE=1.2 in the same ISO standard. Er:YAG laser induced the slightest color change (ΔE_{00}=1.43 [1.07]), which was closest to the 50:50% perceptibility threshold for the perfect color match compared to the other experimental groups.

HFA is a highly toxic and corrosive agent. The inflected tissue damage is caused by three mechanisms:[45] 1) corrosive burn from H^+ ions, 2) chemical burn from F^- ions, and 3) insoluble fluoride salt formation with calcium and magnesium within the tissues. The severity of inflected damage depends on the concentration and duration of exposure.[45] Vital tissues exposed to such acid may exhibit immediate or delayed signs of tissue destruction.[45] Direct contact, inhalation, or ingestion of HFA may result in ocular, skin, gastrointestinal, pulmonary, and hard tissue damage.[45] Hence, HFA requires strictly controlled handling, storage, exposure protection, and disposal measures. Given the hazardous nature of HFA, an alternative surface treatment must be sought in order to promote a safe and environmentally friendly practice.

The Er:YAG laser is increasingly popular in various disciplines of dentistry. It is extensively used in soft and hard tissue surgical procedures, endodontics, and prosthodontics. It can be a promising alternative to HFA etching given the current study's findings and the growing evidence regarding its positive effects on surface roughness and resin bond strength of various types of ceramic substrates. The present study investigated a single CAD/CAM substrate that may limit the generalizability of the findings, which begs further research of different materials produced by other manufacturers. Further, more studies are still required to verify the effects of Er:YAG laser surface treatment on clinically related parameters, including biomechanical reliability, fatigue resistance, discoloration, and marginal and internal fit.

CONCLUSIONS

Within the limitations of this laboratory investigation, the following can be concluded:

1. No surface treatment affected the lightness or the yellowness of the 1-mm- thick milled feldspathic porcelain veneers,
2. Sandblasting resulted in a significant increase in the greenish hue. The greenish hue was less pronounced when using HF acid compared to Er:YAG laser,
3. The overall color changes induced by all investigated surface treatments compared to negative control were not significantly different. However, from a clinical standpoint, Er:YAG laser irradiation resulted in the least perceptible color change closest to the 50:50% perceptibility threshold of a perfect color match.

Conflict of Interest

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

(Accepted 19 June 2021)

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