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The Effect of Brushing on Coffee Stainability of Ceramic Crowns Constructed from Repeatedly Processed Lithium Disilicate Ceramic Ingots: An In Vitro Study

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Abstract: Heat-pressed lithium disilicate (LDS)-based glass–ceramic ingots are widely used for the fabrication of dental restorations. Repressing or repeat processing the remaining parts of these ingots has been reported to not adversely affect their mechanical properties. However, there is not enough information on the stainability of crowns constructed from these repeated heat-processed LDS ceramic ingots. Seventy-two identical ceramic crowns were constructed from three different repeated heat-processed LDS ceramic ingots representing three groups (n = 24): E-max (Ivoclare), Lisi (GC), and Celtra (Dentsply Sirona). Each group was subdivided into two subgroups (n = 12) representing experimental (coffee) and control groups. Color changes were assessed according to the CIE L * a * b * system and measured initially, after coffee staining and after brushing. All groups were susceptible to staining; however, they showed different behaviors with respect to the three axes of the CIE L * a * b * system. In general, immersion in coffee followed by brushing decreased the staining of all tested ceramic crowns to the acceptability threshold of color change (ΔE = 2.7). Routine brushing of coffee-stained ceramic crowns made from repeatedly processed LDS, LDS-HDM, and ZLS ceramic ingots restored their color to clinically acceptable levels.

Keywords: lithium disilicate; repeated processing; repressing; stainability; color stability

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1. Introduction

Dental lithium disilicate (LDS) ceramics are supplied either as ingots for heat pressing or as blocks and discs for computer-aided manufacturing (CAM). Some of the drawbacks of CAM fabrication techniques are the material waste and its inability to reuse the remaining parts of the milled blocks and discs. LDS ceramics are characterized by a unique crystal phase (with 70% lithium disilicate crystals), which naturally reflects light on their surfaces [1,2].

Ceramic restorations are subject to surface degradation when exposed to aqueous solutions or changes in pH [3–5]. Additionally, this process can be intensified by temperature differences [6], which leads to undesirable outcomes for the restoration, such as microbial plaque accumulation and changes in color and appearance [7]. Many in vitro studies have shown that the color of restorative materials can be significantly changed as a result of exposure to common beverages, such as coffee [8–10].

It is possible to interpret color changes (ΔE) based on perceptibility (PT) and acceptability (AT) thresholds. This aids in selecting dental materials, evaluating their clinical performance, and interpreting visual and instrumental observations [8,9]. Recently, levels of color change PT and AT in dentistry were determined at ΔE = 1.2 and ΔE = 2.7, respectively [9].

The measurement of the color of restorative materials using digital methods eliminates human subjectivity [10,11]. The spectrophotometer is a commonly used and accurate digital

device developed to measure color changes in restorative materials. It uses a specific light that is reflected on the observed object to calculate the L, a, and b values of that object. Portable spectrophotometers have been used in the color research of dental materials; some of these devices, such as the Spectro Shade Micro, can detect the shade of the entire buccal surface of the teeth, while others, such as the Vita Easy shade device, can detect the shade of the small, rounded area of the buccal surfaces [12].

A key factor in determining the clinical success and longevity of restorative materials is their stainability over time [13].

The E-max press of Ivoclar Vivadent and Celtra press of Denstply Sirona (10% zirconia-reinforced lithium silicate, ZLS) are examples of conventional lithium disilicate glass–ceramics [14]. In newly developed lithium disilicate high-density micronization (LDS-HDM) glass–ceramics, such as Initial LiSi (GC), the entire glass matrix is filled with evenly distributed lithium disilicate microcrystals instead of larger crystals.

Color stability refers to the change in color of restorative materials due to immersion in saliva. Stainability means the change in color of restorative materials due to immersion in staining solutions such as coffee. Previous studies on the color stainability of different ceramic materials have concluded that lithium-disilicate-based glass–ceramics was the most color-stable material [15,16].

However, previous studies [2,3,13,15,17–22] on the stainability of ceramic restorations have had several limitations. For example, the tested ceramic discs were immersed in the staining solutions so that the specimens were exposed to staining from both sides; this is not similar to clinical situations. Furthermore, the thickness of the ceramic discs used was greater than the actual thickness of ceramic restorations used clinically. Color stainability studies conducted using crown-shaped specimens may be a better representation of the clinical situation, provided that the specimens are identical and the measurement method is standardized and repeatable.

The remaining part of the heat-pressed ceramic ingot is usually removed after pressing and thrown away. However, some dental laboratories repress the remaining ingot before disposing of it. It has been reported that, when heat-pressed ceramic ingots are pressed again, their flexural strength is not adversely affected [23–25]. However, there is currently no information available on whether repressing ceramic materials affects their color stainability. Therefore, this study was conducted to test the effect of brushing on the coffee stainability of ceramic crowns constructed from three different repeatedly processed lithium disilicate ceramic ingots. The null hypothesis was that the immersion of ceramic crowns constructed from repeatedly processed LDS, LDS-HDM, and ZLS in coffee solutions, followed by brushing, will result in a color change below the AT threshold of 2.7.

2. Materials and Methods

This was an experimental in vitro study that evaluated the color change of ceramic crowns constructed from three different repressed ceramic ingots (LDS, LDS-HDM, and ZLS) after immersion in coffee solution.

2.1. Sample Size Calculation

The sample size was determined based on reviewing previous studies on the color stainability of lithium disilicate ceramics. A sample size of 12 per group was used [18,26]. The study included a total number of 72 identical crowns representing 3 groups: E-max, Lisi, and Celtra (n = 24). After measuring the starting point (baseline) color coordinates L, a, and b, each group was subdivided into 2 subgroups (n = 12) representing an experimental group (coffee) and a control group, in which the specimens were immersed into an artificial saliva solution.

2.2. Preparation of the Sample

A maxillary central incisor typodont tooth (Fit Dental Model; Nissin dental products Inc., Kyoto, Japan) was prepared for a ceramic crown as per the textbook guidelines

of Rosenstiel et al. [27]. The prepared tooth was then removed out of the typodont. The whole tooth was scanned, and the STL file was imported into 3D printing software to print 72 identical resin dies from the virtual design of the prepared typodont tooth.

The prepared crown of one resin die was then digitally scanned with an extraoral scanner (Ceramill map 400, Amann Girrbach GmbH, Koblach, Austria). The virtual wax pattern was designed using CAD design software (Ceramill Mind; Amann Girrbach GmbH, Koblach, Austria). The same virtual wax pattern design was used to produce seventy-two identical wax patterns with the same virtual cement gap proposed by the software. The milling was performed using a 5-axis milling machine (Ceramill Motion 2; Amann Girrbach GmbH, Koblach, Austria) and Ceramill wax blanks (Ceramill WAX white 71L, Amann Girrbach GmbH, Koblach, Austria) according to the manufacturer instructions. All the CAD/CAM wax patterns were checked over the corresponding 3D resin dies, and necessary adjustments were made to ensure an accurate fit. The wax patterns were then sprued, invested, and burnt out following the same protocol as the lost wax casting technique.

The heat-pressed ceramic ingot was first used to fabricate single-unit restorations that were not used in the study. The remaining parts of the ingots were then divested and cleaned to be repressed.

The previously pressed ceramic ingot was inserted in the sprue channel, and a new alumina plunger (Alox Plunger; Ivoclare Vivadent; Vienna, Austria) was dipped into the special Alox separator powder to prevent it from sticking to the ceramic ingot. The plunger was then inserted into the sprue channel over the ingot. The assembly was then placed in the special automated pressing furnace (Programat EP3010; Ivoclare Vivadent, Vienna, Austria)). After heating to 1165 °C, the softened ceramic was slowly pressed into the mold under a vacuum after selecting the specific pressing program of the ceramic material used E-max (Ivoclare Vivadent, Vienna, Austria), Lisi (GC corporation, Tokyo, Japan), or Celtra (Dentsply Sirona Inc., Fort Worth, TX, USA). After cooling to room temperature (approximately 60 min), the specimens were divested, and the reaction layer was removed. The sprue was removed with an appropriate disc, and the crowns were then refitted to the corresponding resin dies.

To polish the crowns, an Optrafine (Ivoclare Vivadent, Vienna, Austria) multi-step finishing and polishing system was used in accordance with the Ivoclare protocol, using an electric handpiece with water irrigation. The crowns were finished using Optrafine F, polished using Optrafine P, and then highly polished using Optrafine HP nylon brushes and polishing paste.

Following the clinical protocol for cementing lithium disilicate crowns, all crowns were cemented to the 3D-printed dies. A 10% hydrofluoric acid solution (Porcelain Etch, Ultradent products Inc., South Jordan, UT, USA) was used to etch the intaglio surfaces of the crowns for 20 s. To clean the crowns, they were first given a 60 s rinse with water after the acid had been applied, were placed in an ultrasonic bath with distilled water for five minutes, and then were air-dried for 30 s. Following that, a silane coupling agent (Monobond N, Ivoclar Vivadent, Vienna, Austria)) was applied to all surfaces and evaporated for 60 s. A translucent dual-cure adhesive resin cement (Calibra Ceram, Dentsply Sirona; Dentsply Sirona Inc., Fort Worth, TX, USA) was used for cementation. The mixed cement was then loaded onto the intaglio surfaces of the crowns. The crowns were then seated manually over the corresponding dies. A microbrush was used to remove the excess cement. Each surface was then light-cured for 20 s, finished, and polished with the appropriate kit.

A dental handheld spectrophotometer (Spectro Shade Micro; MHT Optic Research, Niederhasli, Switzerland) was used for all color measurements according to the CIELab system. It emits light with a range of 410 to 680 nm; data are calibrated between 400 nm and 720 nm with a 10 nm pass for the captured image. It measures light at 2 × 45°, polarization at 0°, and telecentric polarization. It has an 18 mm × 14 mm reading area on 640 × 480 points. The digital resolution is 307,200 × 640 (n. of spectral curves), and in terms of optical resolution, each point is approximately 0.03 mm × 0.03 mm. Repeatability for teeth is $\Delta E < 0.5$. The inter-instrument agreement for the teeth is $\Delta E < 1.0$. It features a

black-and-white CCD sensor for reading spectral data. This handheld spectrophotometer has a built-in computer with analytical software and internal memory for the storage and the transfer of images and spectral data. Additionally, dental shades can be read in any lighting situation (natural or artificial light, fluorescent light, etc.). The CIELab system is a uniform color scale, where the L * value measures the lightness or luminosity of an object; a * is a measure of redness (positive) or greenness (negative); and b * is a measure of yellowness (positive) or blueness (negative). The color difference (ΔE) of a test sample is reported by delta values, ΔL *, Δa *, and Δb *, compared with standard conditions. These differences are calculated according to the following formula: [ΔE = [(ΔL *)2 + (Δa *)2 + (Δb *)2] 1/2] [28].

The tooth positioning angle control guidance system of the Spectro Shade Micro (MHT Optic Research, Niederhasli, Switzerland) device was used to ensure the standardization and repeatability of the measurements. This system was displayed on the LCD touchscreen (Figure 1). By using the angle control system, the colorimetric and morphological properties of the oral cavity can be considered. Calorimetrically, the gums are red, the teeth are white, and the oral cavity is black. Therefore, the angle control will not work if an image of a crown inserted into a white stone model is acquired, since the SpectroShade Micro will not recognize the components. To obtain the benefit from the angle control guidance system of the Spectro Shade Micro device, the crowns were fitted into a typodont model to simulate the oral cavity's morphology, as shown in Figure 2.

Figure 1. Standardization of the measurement method through the tooth positioning guidance system of the Spectro Shade Micro device (Spectro Shade Micro, MHT).

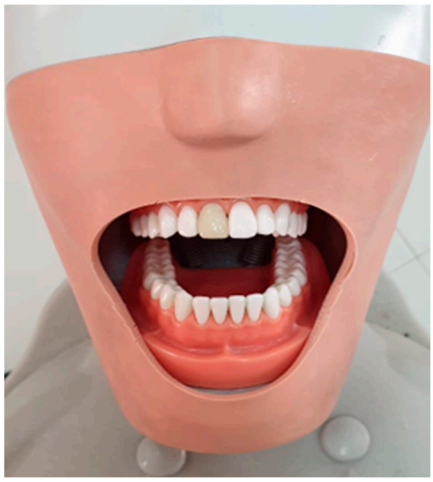

Figure 2. The crowns fit into the typodont model to obtain the benefit from the guidance system of the Spectro Shade Micro device for the standardization of shade measurements.

The color of crowns was determined following the same steps used for shade selection in clinical situations, as follows: The device was calibrated on the white and green backgrounds provided on the device base. The Optic Handpiece was positioned at a 90-degree angle to the target tooth and flushed against the gum line. Using the tooth positioning guidance system, which displayed two yellow bars and a yellow frame overlaying the live image, the tooth under measurement was centered in the image. As the two bars crossed, they formed a yellow cross at the center of the acquisition window and the frame. There was no movement of the yellow frame or yellow cross. With the target tooth framed within the yellow frame as much as possible, some graduated references appeared on the yellow vertical bar. A vertically moving horizontal line indicates the acquisition angle by varying the angle-shot between the Optic Handpiece and the target tooth. The closer the horizontal line to the horizontal bar, the closer to the optimal angle-shot the angle is. The shot was taken when the line was green and superimposed on the yellow horizontal bar. The crowns were kept wet to optimize the color reading and the light reflection.

One liter of laboratory-prepared artificial saliva solution containing water, KH2PO4, KCl, NaCl, and Tris Buffer with pH = 7.0 was used in the control group [29]. The coffee solution (Al Khair Turkish Original Taste Coffee, brown) was prepared according to the manufacturer's instructions. One cup of water was put in a small coffee pot, and two small spoons of the coffee were added and stirred over a low heat.

To record the baseline color coordinates (L0, a0, and b0), the images of all crowns in the 3 groups E-max (Ivoclare Vivadent, Vienna, Austria), Lisi (GC corporation, Tokyo, Japan), or Celtra (Dentsply Sirona Inc., Fort Worth, TX, USA) were captured with the Spectro Shade Micro and stored in the device's SD card. After that, each group was subdivided into 2 subgroups.

The samples in the control subgroups were immersed in artificial saliva at 37 °C in an incubator (HWB Series, Electric Thermostatic Water Bath, West Tune, Hangzhou, China) for 54 h, equivalent to 3 years of clinical simulation [18]. Meanwhile, the samples in the experimental subgroup were immersed in the prepared coffee solutions in an incubator for 54 h. The samples were immersed individually in 24-well cell culture plates inside the incubator [18].

For color measurement after immersion, the crowns were removed from the coffee and saliva and rinsed with distilled water to remove any residue. Photos were then taken with the device. Using the compare tool integrated into the Spectro Shade device (Figure 3), the baseline crown photos were compared with the crown photos after staining. Baseline color coordinates (L0, a0, b0), indicated on the left, and the color coordinates after staining (L1, a1, b1), indicated on the right, were calculated automatically and displayed on the device screen. In addition, the color difference (ΔL1, Δa1, Δb1) and the overall color change, ΔE1, was automatically calculated and displayed. It was considered that $\Delta L1 = L1 - L0$, $\Delta a1 = a1 - a0$ and $\Delta b1 = b1 - b0$. An outstanding feature of this tool is that the shade of an automatically generated equal area of the two crown photos can be compared, as shown in Figure 3. For repeatability, we selected a square area of the crown labial surface where the upper side of the square was formed by a line connecting the mesial and distal tips of the interdental papillae, and the lower side was formed by the line representing the incisal edge of the crown.

To measure color change after brushing, the crowns were brushed with toothpaste and artificial saliva using an electric toothbrush (Oral-B Professional Care OxyJet +3000; Braun, Frankfurt, Germany). The standardized speed and pressure of the brushing were 59.5 rpm and 2 N, respectively [30]. One operator performed the brushing for all specimens. Again, the crown photos after brushing were compared with the photos after staining using the same procedure, in which the following parameters were automatically calculated and displayed on the device screen: L2, a2, b2, ΔL2, Δa2, Δb2, and ΔE2. It was considered that $\Delta L2 = L2 - L1$, $\Delta a2 = a2 - a1$ and $\Delta b2 = b2 - b1$.

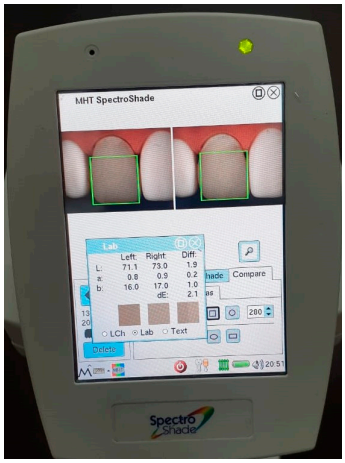

Figure 3. Using the compare tool to automatically calculate the color coordinates and color change before and after immersion.

IBM SPSS software package version 20 (IBM Corp., Armonk, NY, USA) was used for statistical analysis. The Kolmogorov–Smirnov test was used to test for normality. A repeated-measure ANOVA with Tukey's post hoc test was conducted to analyze the color coordinates L, a, and b. Meanwhile, a one-way ANOVA was employed to examine the color change variables (ΔE, ΔL, Δa, Δb), followed by Tukey's post hoc test to determine significant differences between the groups. The significance level was set at $p \leq 0.05$.

3. Results

3.1. Color Measurement (L, a, and b Values)

3.1.1. L Values

The results of the statistical analysis of the lightness, darkness, and luminosity values (L) are shown in Figure 4. The three crown materials, E-max, Lisi, and Celtra, presented different degrees of luminosity. There was a significant difference in the luminosity of Celtra compared to E-max and Lisi ($p < 0.05$). Regarding the color measurements at baseline, it was observed that the L values of all materials decreased after immersion in the saliva, resulting in a darker color ($p > 0.05$). After brushing, the L values of all crown materials did not change significantly (Figure 4A).

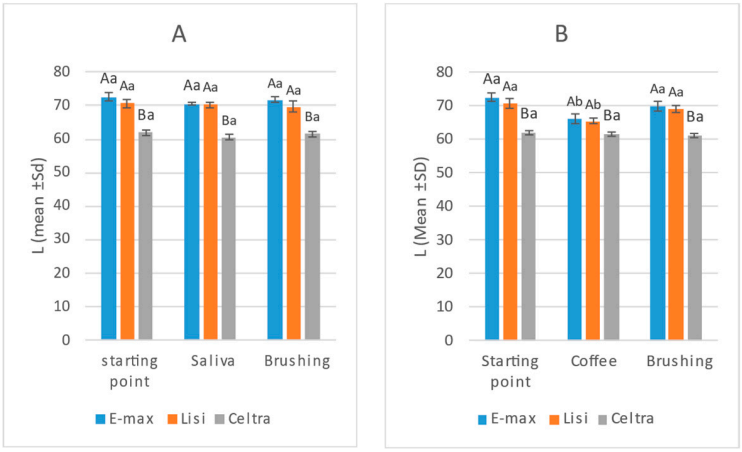

Figure 4. Mean ± SD of L values (**A**) at the starting point, following immersion in artificial saliva and following brushing; (**B**) at the starting point, following immersion in coffee and following brushing. Different letters denote statistically significant differences. The comparison of different crown materials at the same measurement time point is indicated by upper-case letters. The comparison of the same crown material at different measurement time points is indicated by lower-case letters.

Regarding the color measurements at baseline, it was observed that the L values of all materials decreased after immersion in coffee, resulting in a darker color ($p < 0.05$). There was a significant difference in the luminosity of Celtra compared to E-max and Lisi ($p < 0.05$). Nevertheless, after brushing, the L values of all crown materials were analogous to the baseline values (Figure 4B).

3.1.2. a Values

The results of statistical analysis of the red–green color component, or a values, are shown in Figure 5. The three crown materials, E-max, Lisi, and Celtra, had positive a values, demonstrating red components. The a value was significantly higher in Celtra ($p < 0.05$) than in E-max and Lisi, as shown in Figure 5A.

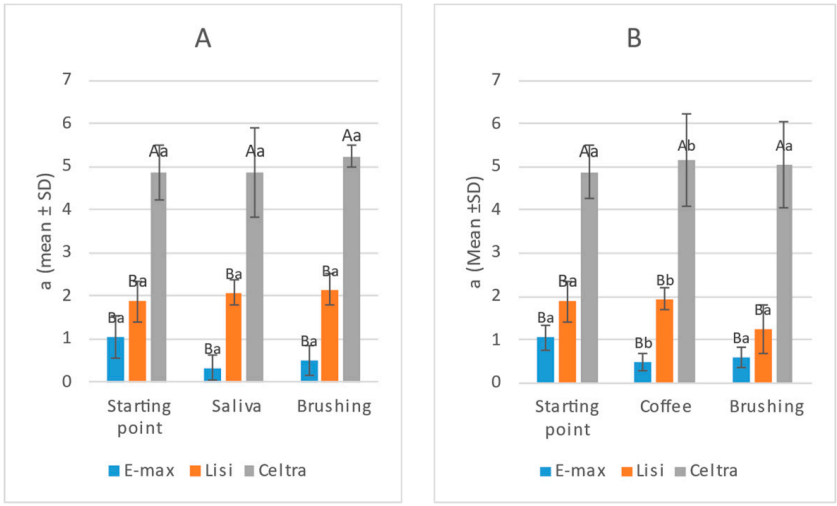

Figure 5. Mean ± SD of a values (**A**) at the starting point, following immersion in artificial saliva and following brushing; (**B**) at the starting point, following immersion in coffee and following brushing. Different letters denote statistically significant differences. The comparison of different crown materials at the same measurement time point is indicated by upper-case letters. The comparison of the same crown material at different measurement time points is indicated by lower-case letters.

Regarding a values after immersion in saliva/coffee and after brushing, all the groups showed a positive red component. The changes in the red component values were significant only for Celtra ($p < 0.05$), as shown in Figure 5A,B.

3.1.3. b Values

The results of the statistical analysis of the yellow–blue color component, or b values, are shown in Figure 6. The three crown materials, E-max, Lisi, and Celtra, had positive b values, demonstrating yellow components. The b value was significantly low in Celtra ($p < 0.05$) compared to E-max and Lisi, as shown in Figure 6A.

Regarding the b values after immersion in saliva and coffee and after brushing, all the materials showed a positive yellow component. The changes in the yellow component values were significant only for Celtra ($p < 0.05$), as shown in Figure 6A,B.

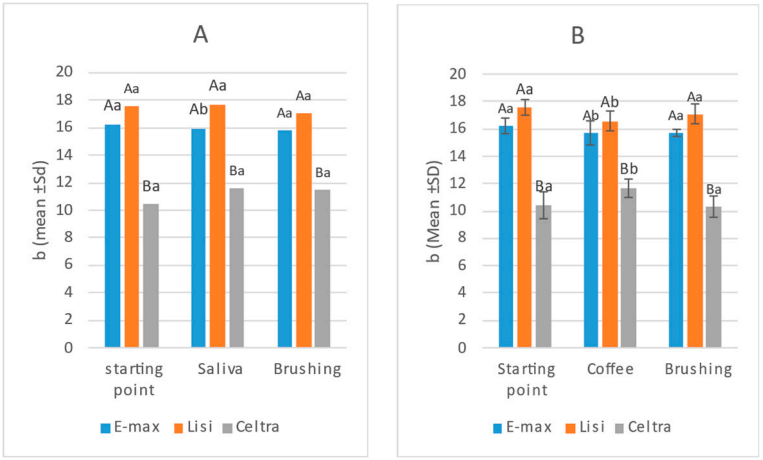

Figure 6. Mean ± SD of b values (**A**) at the starting point, following immersion in artificial saliva and following brushing; (**B**) at the starting point, following immersion in coffee and following brushing. The comparison of different crown materials at the same measurement time point is indicated by upper-case letters. The comparison of the same crown material at different measurement time points is indicated by lower-case letters.

3.1.4. Color Change (ΔE, ΔL, Δa, and Δb)

Overall Color Change (ΔE)

Figure 7 shows that all the groups presented a change in color after immersion in saliva and coffee. Regarding color change in crowns after immersion in saliva and at baseline, all groups showed a significant color change; however, it was smaller than the perceptibility threshold PT (1.2) and acceptability threshold AT (2.7). Mean ΔE values varied from 1.02 to 0.82. E-max and Celtra crowns showed greater color change compared with Lisi crowns ($p < 0.001$) (Figure 7A). The color change was not significant after brushing ($p > 0.05$), and was smaller than PT and AT.

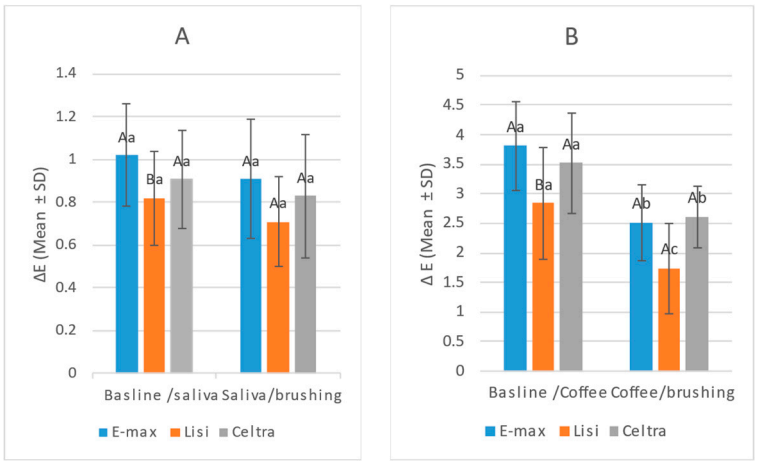

Figure 7. Mean ± SD of ΔE values (**A**) between immersion in saliva and the starting point, and between saliva and brushing; (**B**) between immersion in coffee and the starting point, and between coffee and brushing. Different letters denote statistically significant differences. The comparison of different materials at the same measurement time point is indicated by upper-case letters. The comparison of the same material at different measurement time points is indicated by lower-case letters.

Regarding coffee and the baseline color change, Figure 7B shows that all groups showed a significant color change greater than the PT and AT. E-max and Celtra presented a comparable color change ($p > 0.05$), while Lisi showed lower values ($p < 0.05$). After brushing, the three crown materials showed a significant color change ($p < 0.05$); the

mean ΔE values were 2.51 ± 0.64, 2.34 ± 0.76, and 2.61 ± 0.52 for E-max, Lisi, and Celtra, respectively. All the color changes were below the acceptability threshold (2.7).

Lightness Difference (ΔL)

Figure 8A shows that the lightness difference between crowns after immersion in saliva and at the baseline was negative for all three materials. E-max showed significantly lower mean ΔL values than Lisi and Celtra ($p < 0.05$). All the crowns immersed in saliva presented an increase in the mean ΔL values when followed by brushing.

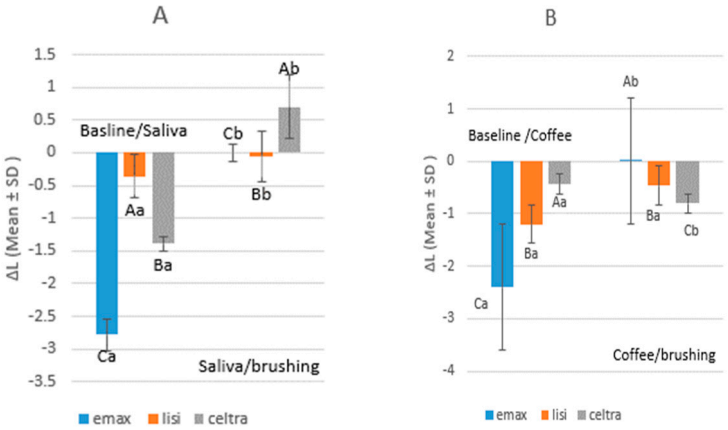

Figure 8. Mean ± SD of ΔL values (**A**) between immersion in saliva and the starting point, and between saliva and brushing; (**B**) between immersion in coffee and the starting point, and between coffee and brushing. Different letters denote statistically significant differences. The comparison of different crown materials at the same measurement time point is indicated by upper-case letters. The comparison of the same crown material at different measurement time points is indicated by lower-case letters.

Regarding the difference in lightness between immersion in coffee and at baseline, Figure 8B shows that coffee significantly decreased the luminosity for the three crown materials ($p < 0.05$). All crowns showed a significant increase in luminosity after brushing ($p < 0.05$).

Redness-Greenness Difference (Δa)

Considering the analysis of Δa, Figure 9A shows that Lisi and Celtra crowns presented redness after immersion in saliva and at the baseline, while E-max presented greenness (Δa = −0.4 ± 0.14). After immersion in saliva and followed by brushing, all the crown materials showed redness.

Regarding the difference in redness–greenness between immersion in coffee and at baseline, Figure 9B shows that E-max and Celtra crowns presented greenness, while Lisi presented redness. Interestingly, E-max showed a significant difference compared to other groups ($p < 0.05$). After brushing, E-max showed redness, while Lisi and Celtra presented greenness with a significant difference compared to other groups ($p < 0.05$).

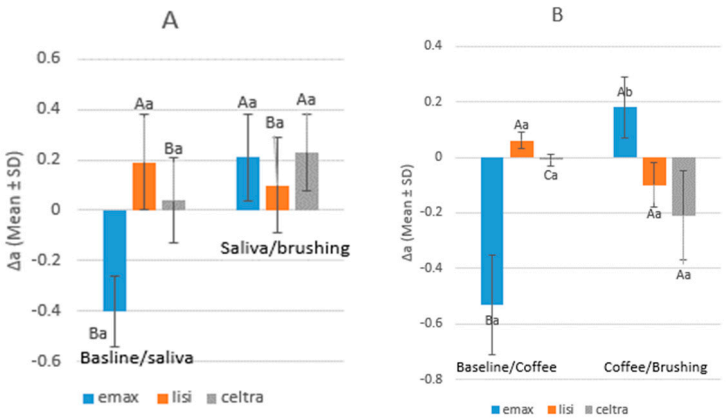

Figure 9. Mean ± SD of Δa values (**A**) between immersion in saliva and the starting point, and between saliva and brushing; (**B**) between immersion in coffee and the starting point, and between coffee and brushing. Different letters denote statistically significant differences. The comparison of different crown materials at the same measurement time point is indicated by upper-case letters. The comparison of the same crown material at different measurement time points is indicated by lower-case letters.

Yellowness-Blueness Difference (Δb)

Considering the analysis of Δb, Figure 10A shows that Lisi and Celtra crowns after immersion in saliva and at baseline presented positive differences, indicating yellowness, while E-max showed negative differences, indicating blueness. After immersion in saliva followed by brushing, all the crown materials showed slight Δb differences with comparable results ($p > 0.05$). E-max and Celtra presented positive differences, indicating yellowness, while Lisi showed negative differences, indicating blueness.

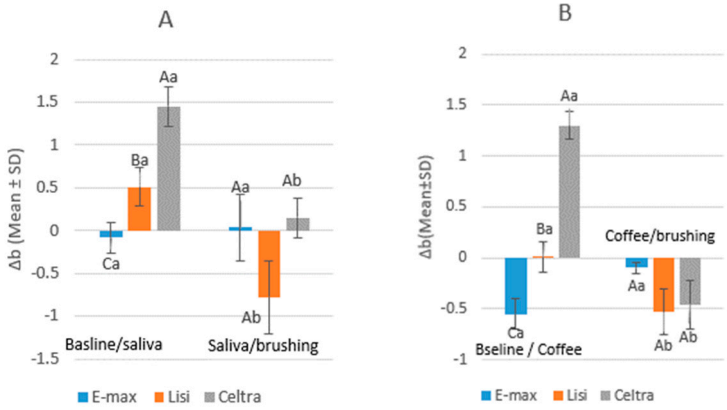

Figure 10. Mean ± SD of Δb values (**A**) between immersion in saliva and at the starting point, and between saliva and brushing; (**B**) between immersion in coffee and the starting point, and between coffee and brushing. Different letters denote statistically significant differences. The comparison of different crown materials at the same measurement time point is indicated by upper-case letters. The comparison of the same crown material at different measurement time points is indicated by lower-case letters.

Regarding the difference in yellowness–blueness between immersion in coffee and at baseline, Figure 10B shows that different materials showed different behaviors. Lisi and Celtra showed positive differences, with a highly significant difference between the two materials ($p < 0.001$), while E-max presented negative differences. After immersion in coffee followed by brushing, all materials showed a negative difference that was significant only for Lisi and Celtra ($p < 0.05$).

4. Discussion

In this study, the color stainability of ceramic crowns after immersion in coffee followed by brushing was investigated. The crowns were constructed from three repeated heat-processed lithium disilicate ceramic ingots (E-max, Lisi, Celtra). It was evident that the three tested crowns were all susceptible to staining after immersion in coffee. However, with respect to the three axes of the CIE L * a * b * system, various behaviors were seen. In general, immersion in coffee followed by brushing decreased the staining of all tested ceramic crowns to the acceptability threshold of color change (ΔE = 2.7); thus, the null hypothesis was accepted.

The results of color measurements agreed with previous studies that indicated that exposure to common beverages such as coffee resulted in a reduction in the luminosity and a darker color in the specimens, with decreased L * values [18,29,31]. This pigmentation may be caused by chromogens in the coffee, which are substances that can stick to ceramic crown surfaces and cause discoloration [31]. Coffee contains various compounds that contribute to its characteristic color. The staining composition of beverages in general can vary depending on factors such as the brewing method, preparation, and additives. Coffee is typically made from roasted coffee beans and contains a variety of compounds such as caffeine, chlorogenic acid, and melanoidins. These compounds contribute to the dark color and staining properties of coffee. Additionally, coffee can contain significant amounts of oils and fats that can adhere to surfaces and contribute to staining.

Since the baseline L, a, and b values of the various materials differ, it is essential to assess color changes in the specimens using the ΔE values rather than the L, a, and b values obtained after aging/staining [19,32]. Furthermore, the formula for the calculation of color changes (ΔE) commonly used in previous studies is dependent on values of L, a, and b. This discussion therefore focuses on the results of color changes rather than discussing L, a, and b values one by one.

Regarding the color measurements (L, a, and b) and differences (ΔL, Δa, and Δb), a significant difference was observed between Celtra and the other two groups, E-max and Lisi. This may be due to the zirconia content of Celtra, which is not present in E-max or Lisi.

Regarding the color changes (ΔE), all groups showed a significant color change from baseline to post-saliva immersion. However, the reported ΔE values (E-max = 1.02 ± 0.24, Lisi = 0.82 ± 0.22, and Celtra = 0.91 ± 0.23) were smaller than the PT thresholds (ΔE = 1.2). After brushing, the color changes (E-max = 0.91 ± 0.28, Lisi = 0.71 ± 0.21, and Celtra = 0.83 ± 0.29) were not significant in any of the groups ($p > 0.05$).

On the other hand, in the experimental groups, all groups showed a significant color change from baseline to post-coffee immersion, with values above the PT thresholds (ΔE = 1.2).

Lisi showed a smaller degree of color change (ΔE = 2.84 ± 0.95) that was significant ($p < 0.05$) compared to E-max (ΔE = 3.81 ± 0.75) and Celtra (ΔE = 3.52 ± 0.84). These results may be related to the possible highly smooth surface of Lisi, which contains equally dispersed small-size microcrystals (HDM) compared to the large-size lithium disilicate crystals in E-max and Celtra [20], making it difficult to be stained. However, this explanation cannot be confirmed, as we did not measure the surface roughness of the crowns. There is evidence in the literature that repressing lithium disilicate ceramic results in the growth of crystals due to the Ostwald ripening phenomenon [25]. Therefore, the large crystals of E-max and Celtra may become larger with repeated pressing, leading to greater color changes due to additional crystal boundaries that facilitate water and pigment penetration [18]. After brushing, all groups showed a significant reduction in ΔE values (E-max = 2.51 ± 0.64, Lisi = 1.74 ± 0.76, and Celtra = 2.61 ± 0.52). However, all the reported ΔE values after brushing were above the PT and below the AT. Again, a significant reduction in color change was reported in the Lisi group ($p < 0.05$).

According to the results of this study, all the tested crowns constructed from repressed lithium disilicate ceramics were vulnerable to staining when immersed into coffee solution. This finding is consistent with previous studies investigating the stainability of

ceramic restorative materials [18,21,29]. Fortunately, the clinically acceptable color of the stained ceramics was recovered after manual routine brushing with a toothbrush and cavity fighter toothpaste, which may be considered additional evidence supporting the reuse of previously pressed lithium disilicate ceramic ingots.

The overall color of ceramic restorations is affected by many factors, such as the shade and thickness of the ceramic, the cement shade and thickness, and the processing technique [33]. In this study, the prepared typodont tooth was duplicated with 3D printing to produce 72 identical abutment teeth [34]. The same virtual wax pattern design and cement space parameters were used in all specimens. These measures were followed to standardize the specimens and cement thickness. Translucent cement shade was used for all groups to standardize its effect on the color measurements [35].

The color of dental restorations can be evaluated using spectrophotometers, colorimeters, or digital cameras [36]. A spectrophotometer was selected for our study because it measures the wavelength reflected or transmitted by one object at a time, without being affected by subjective interferences [37]. In addition, the irregular surface of human teeth makes the color measurement of human teeth very difficult, because the reproducibility of the measurement itself is poor [38]; however, with the aid of the compare tool available in the Spectro Shade Micro portable dental spectrophotometer, the color of an equal area of the labial surface of teeth crowns can be compared, as well as the measurements reproduced before and after different treatments of the surface [39]. A recently published in vivo study [40] used a putty index for each patient to ensure the repeatability of measurements. However, the device (VITA Easy shade) used for measurement in that study only measured the color change in a small, rounded area of the teeth labial surfaces, unlike the Spectro Shade Micro device used in our study, which could measure the color change of the whole labial surface of the tooth [12].

The color stability of dental ceramics can be investigated using a variety of aging methods. Extrinsic factors, including exposure to the environment, are considered in most methods. In our study, we chose to use coffee, as it is among the most commonly consumed beverages [37,41]. The incubation period was selected based on the following association: 3 Cs per day correspond to an exposure of 1 min per cup, which equals 1095 min or 18 h each year [18]. It has been reported that coffee preparation and concentration have an impact on the level of color shift [36]. As a result, the study's solutions were created with daily use in mind [42].

This study was conducted outside the oral cavity. In vitro studies have the advantage of simulating long-term intraoral service in a short amount of time as compared to clinical research. As a result, the color stainability can be evaluated by submerging the samples in a variety of beverages for a short period of time rather than waiting for the material to degrade over an extended period of time [43].

When evaluating the color of in vitro samples, an especially critical issue is to standardize illumination and background. The Spectro Shade Micro device used in this study has its own light source; thus, it can be used under any light source. In clinical situations, the darkness of the oral cavity represents the background. In this study, the color of the crowns was recorded while the typodont model was attached to a phantom head to mimic the oral cavity [44].

The main limitation of our study is that the effect of different finishing and polishing protocols on the stainability of ceramic restorations was neglected. The crowns were only polished, as the consensus about the association between stainability and roughness is inadequate [19]. Yuan et al. reported statistically insignificant relations between stainability and roughness [22]. In addition, the current evidence on the relation between finishing protocols and the stainability of pressable ceramic is related to first heat pressing, not repeated pressing, as is the case in this study.

Another limitation is that the oral environment cannot be precisely replicated in an in vitro study. This study was designed to mimic the intraoral situation as closely as

possible; as a result, it is important to carefully speculate and formulate assumptions about how well these materials will function in oral settings.

Additionally, the crowns were only immersed in the staining solutions for 54 h, which is equivalent to three years. This is considered a limited duration for ceramic restoration. The color stainability of mouthwashes or fruit juices should be investigated in future studies for a prolonged aging time. The combined effects of other factors, including sunlight, salivary proteins, and smoking, should also be evaluated for optimized clinical simulations.

5. Conclusions

We drew the following conclusions:

1. The immersion of ceramic crowns constructed from repeated processed LDS, LDS-HDM, and ZLS into coffee resulted in perceivable color change.
2. The clinically acceptable color of coffee-stained ceramic crowns constructed from repeated processed LDS-based ingots can be restored with routine tooth brushing.

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