Impact of resin composite cement on color of computer-aided design/computer-aided manufacturing ceramics

Anja Liebermann PD Dr. Med. Dent. MSc | Alicia Mandl Dr. Med | Marlis Eichberger CDT | Bogna Stawarczyk Prof Dr. Reer. Biol. Hum. Dipl. Ing. (FH), MSc

Department of Prosthetic Dentistry, LMU Munich, Munich, Germany

Correspondence
PD Dr. Med. Dent. Anja Liebermann MSc,
Goethestrasse 70, 80336 Munich, Germany.
Email: anja.liebermann@med.uni-muenchen.de

Abstract
Objective: To analyze the impact of the color of a resin composite cement (RCC) on the optical properties of different computer-aided design and computer-aided manufacturing (CAD/CAM) ceramics.

Materials and methods: Specimens (N = 220, thickness: 0.9 ± 0.03 mm) were fabricated from: leucite (Initial LRF Block/IPS Empress CAD), lithium disilicate (Amber Mill/IPS e.max CAD), lithium metasilicate (Celtra Duo), and lithium alumina silicate ceramic (n!ce) in translucency levels HT and LT. All specimens were bonded with an RCC (Light+/Warm+). Color was analyzed (spectrophotometer) initially as well as after bonding of RCC with CAD/CAM ceramics using CIELab and CIEDE2000. Kolmogorov–Smirnov test, one-way ANOVA and t test served for analyzing (α = 0.05).

Results: Highest impact on ΔE presented the choice of ceramic (ηp² = 0.155/p < 0.001), followed by translucency level (HT/LT; ηp² = 0.050/p = 0.001) as well as interaction between ceramic and translucency level (ηp² = 0.175/p < 0.001). ΔE00 was mainly influenced by the choice of ceramic (ηp² = 0.490/p < 0.001), the shade of resin composite (ηp² = 0.031/p = 0.012) as well as the interaction between ceramic and resin composite (ηp² = 0.258/p < 0.001).

Conclusions: RCC shades presented differential impacts on color change of CAD/CAM ceramics.

Clinical significance: Knowledge of the impact of available RCC shades on different CAD/CAM ceramics is crucial for an esthetic outcome and proper selection of ceramic restorations.

KEYWORDS
CAD/CAM ceramic, CIEDE2000, CIELab, color change, optical properties, resin composite cement
1 | INTRODUCTION

Silicate ceramics are frequently used to replace lost natural tooth structure, often in form of monolithic restorations, as they have good mechanical and, in particular, excellent esthetic properties. There is a large number of different silicate-based ceramics available, fabricated either by computer-aided design and computer-aided manufacturing (CAD/CAM) technology or with the help of press technology, varying in their material characteristics. These differences are based on their specific composition of diverse crystal structures embedded in a glass matrix, leading to variations such as leucite, lithium disilicate, lithium metasilicate, and lithium alumina silicate ceramics.  

The translucency and the different color values of a silicate ceramic play a decisive role for an optimal esthetic result, being usually determined using spectrophotometers. The color parameters are recorded within the L*a*b* color space for CIELab color system, which was established of the Commission Internationale de L'Eclairage (CIE) related to the human color perception with three directions of the color space: L* coordinate represents the lightness, a* green-red color coordinate, and b* blue-yellow coordinate. Another method to describe color and especially differences in color was developed more recently as CIEDE2000. Color differences calculated based on this formula correlate more properly with visually detectable color differences.  

The final esthetic result, however, is not only determined by the silicate ceramic selected and color values itself. There are further important factors affecting the final color of the restoration, the exact manufacturing (CAD/CAM) technology or with the help of press technology, varying in their material characteristics. These differences are based on their specific composition of diverse crystal structures embedded in a glass matrix, leading to variations such as leucite, lithium disilicate, lithium metasilicate, and lithium alumina silicate ceramics.  

The translucency and the different color values of a silicate ceramic play a decisive role for an optimal esthetic result, being usually determined using spectrophotometers. The color parameters are recorded within the L*a*b* color space for CIELab color system, which was established of the Commission Internationale de L'Eclairage (CIE) related to the human color perception with three directions of the color space: L* coordinate represents the lightness, a* green-red color coordinate, and b* blue-yellow coordinate. Another method to describe color and especially differences in color was developed more recently as CIEDE2000. Color differences calculated based on this formula correlate more properly with visually detectable color differences.

The decision for cementation of a silicate-based ceramic restoration with traditional cement or bonding with a RCC is significantly influenced by the silicate ceramic material used. Leucite ceramics should always be adhesively bonded due to their reduced flexural strength in contrast to lithium silicate ceramics for example. Lattice can be adhesively bonded or traditionally cemented, whereas in thinner layer thicknesses and esthetic areas, RCC should be preferred. Adhesive bonding procedures can be performed either with light or dual-cured resin composites with slight differences in color stability, whereas compounds such as reactive groups of tertiary amines and inhibitors may cause more changes in color in dual-curing materials into yellowish and reddish, especially after aging.

To authors' best knowledge, there is no information in the scientific literature on the impact of color of a RCC on the optical properties of different recently available CAD/CAM ceramics. The null hypothesis tested states that there is no impact of the type of ceramic, its translucency level and the shade of the RCC upon the final color of the tested CAD/CAM ceramics.

2 | MATERIALS AND METHODS

Two hundred and twenty specimens were fabricated from six CAD/CAM ceramics (Table 1, Figure 1). All specimens were bonded with a conventional RCC (Varolink Esthetic DC, Ivoclar Vivadent, Schaan, Liechtenstein, n = 20) in two different shades (n = 10 shade Light+, n = 10 shade Warm+). Color was analyzed initially for all CAD/CAM ceramics and both RCCs as well as color change after the combination between RCC together with CAD/CAM ceramics in the two different shades.

Cylinders with the length of 14 mm and diameter of 12 mm were milled out (Ceramill Motion 2, Amann Girrbach AG, Koblach, Austria) of the CAD/CAM ceramic blanks and disc-shaped specimens (thickness: 1.8 mm) were cut (Secotom-50, Struers, Ballerup, Denmark) at a constant speed of 0.05 mm/s under constant water irrigation. Then, the lithium disilicate ceramics ABM and IEM as well as the lithium metasilicate ceramic CEL were crystallized in a furnace (Programat EP 5000; Ivoclar Vivadent) according to the manufacturer's instructions with final temperatures of 815 °C (Amber Mill HT), 820 °C (IPS e.max CAD HT, IPS e.max CAD LT, Cera Duo LT and Cera Duo HT) or 840 °C (Amber Mill LT). One-sided of all specimens was polished (Abramir, Struers) under constant water cooling (Magnetic Disc diamond polishing disc with grain size 20/40 μm and DiaPro diamond and polishing suspensions; Struers) to a thickness of 0.95 mm (±0.03 mm) to generate a final layer thickness of approx. 1 mm, which is recommended by most manufacturers. The other side remained unpolished. Final thickness was verified with a digital micrometer (Mitutoyo, Andover, England). The specimens were etched for 20 sec with 9% hydrofluoric acid (Porcelain Etch, Ultradent) according to manufacturer's specifications on the unpolished side and cleaned for 1 min in an ultrasonic bath (L&R Transistor/Ultrasonic T-14, L&R Ultrasonics, Kearny, NJ, USA) filled with distilled water. For simulation impact of the cement color, the specimens were bonded (coated) with RCC using a special device to ensure a constant layer thickness of 0.08 mm (Figure 2). The RCC was light polymerized centrally for 20 sec and 4 times for 20 sec in the verge (Elipar E10, 3 M, Seefeld, Germany). The specimens were then stored for 3 days at 37 °C (HERA cell 150; Thermo Scientific, Heraeus, Hanau, Germany) prior to further analyze.

Color measurements (e.g., L*a*b coordinates) for determining color values were analyzed initially for all CAD/CAM ceramics and both RCCs specimen and all CAD/CAM ceramics after bonding with a UV/Vis spectrophotometer (Lambda 35, PerkinElmer, Waltham, USA). The intensity of the monochromatic light 10 and the light I was measured, which radiated through the specimen between wavelengths 400 nm and 700 nm (λ) with a white background. The associated software (Color Application Software V1.00, PerkinElmer Inc.) was used to carried out the color values. Color differences were calculated using the standardized CIELab formula (ΔE) and the newer CIEDE2000 formula (ΔE00) as follows: For the calculation of color difference using CIELab formula (ΔE), color values were analyzed initially for all CAD/CAM ceramics and both RCCs specimen and all CAD/CAM ceramics after bonding with a UV/Vis spectrophotometer (Lambda 35, PerkinElmer, Waltham, USA). The intensity of the monochromatic light 10 and the light I was measured, which radiated through the specimen between wavelengths 400 nm and 700 nm (λ) with a white background. The associated software (Color Application Software V1.00, PerkinElmer Inc.) was used to carried out the color values. Color differences were calculated using the standardized CIELab formula (ΔE) and the newer CIEDE2000 formula (ΔE00) as follows:
| Material class              | Product name       | Abbreviation | Manufacturer                          | Composition (wt%)                                                                 | Color shade | Lot No.      |
|----------------------------|--------------------|--------------|---------------------------------------|----------------------------------------------------------------------------------|-------------|--------------|
| Leucite ceramic            | Initial LRF Block  | LRF          | GC Europe, Leuven, Belgium            | Not available in detail                                                            | A2 LT       | 1,802,191    |
|                            |                    |              |                                       |                                                                                  | A2 HT       | 1,802,191    |
| IPS Empress CAD            | IPR                |              | Ivoclar Vivadent, Schaan, Liechtenstein | SiO$_2$: 60–65; Al$_2$O$_3$: 16–20; K$_2$O: 10–14; Na$_2$O: 3.5–6.5; other oxides: 0.5–7; pigments: 0.2–1 | A2 LT       | X18905       |
| Lithium disilicate ceramic | Amber Mill         | ABM          | Hassbio Corporation, Gyeonggi-do, Korea | Not available in detail                                                            | A2 LT       | EBE06KG0401  |
|                            |                    |              |                                       |                                                                                  | A2 HT       | EBE06KG0401  |
| IPS e.max CAD              | IEM                |              | Ivoclar Vivadent, Schaan, Liechtenstein | SiO$_2$: 57–80; Li$_2$O: 11–19; K$_2$O: 0–13; P$_2$O$_5$: 0–11; ZrO$_2$: 0–8; ZnO: 0–8; Al$_2$O$_3$: 0–5; MgO: 0–5; coloring oxides: 0–8 | A2 LT       | X30245       |
|                            |                    |              |                                       |                                                                                  | A2 HT       | X27104       |
| Lithium metasilicate       | Celtra Duo         | CEL          | Dentsply Sirona, Hanau, Germany       | SiO$_2$: 68–70; ZrO$_2$: 10.1; Li$_2$O: 18.5; others: 13.4                      | A2 LT       | 16,003,631   |
|                            |                    |              |                                       |                                                                                  | A2 HT       | 16,003,462   |
| Lithium alumina silicate   | n!ce               | NIC          | Straumann AG, Basel, Switzerland      | SiO$_2$: 57–80; Li$_2$O: 10.5–12.5; Al$_2$O$_3$: 10.5–11.5; Na$_2$O: 1–3; K$_2$O: 0–3; P$_2$O$_5$: 3–8; ZrO$_2$: 0–0.5; CaO: 1–2; coloring oxides: 0–9 | A2 LT       | R972         |
|                            |                    |              |                                       |                                                                                  | A2 HT       | RR733/16003462 |
| Resin composite cement     | Variolink Esthetic DC | VES        | Ivoclar Vivadent, Schaan, Liechtenstein | Anorganic fillers: 38 vol%; Ytterbium trifluoride, spheroidal mixed oxides, initiators, stabilizers, pigments Monomer matrix: Urethandimethacrylate, other methacrylate monomers | Light+      | X13506       |
|                            |                    |              |                                       |                                                                                  | Warm+       | X13483       |
\[ \Delta E = \left[ \left( L'^1 - L'^2 \right)^2 + (a'^1 - a'^2)^2 + (b'^1 - b'^2)^2 \right]^{1/2}, \]

with \( L^* \) coordinate representing the lightness, \( a^* \) green-red color coordinate, and \( b^* \) blue-yellow coordinate as well as with \( L^*1 - L^*2 \) representing \( \Delta L^* \), \( a^*1 - a^*2 \) representing \( \Delta a^* \), and \( b^*1 - b^*2 \) representing \( \Delta b^* \) with number 1 being initial values for CAD/CAM ceramic as well as number 2 being CAD/CAM ceramic combined with RCC, and

\[ \Delta E_{00} = \left[ \left( \frac{\Delta L'}{K_{L^*S^*}} \right)^2 + \left( \frac{\Delta C'}{K_{C^*S^*}} \right)^2 + \left( \frac{\Delta H'}{K_{H^*S^*}} \right)^2 + R_T \left( \Delta C' \frac{K_{C^*S^*}}{K_{H^*S^*}} \frac{\Delta H'}{K_{H^*S^*}} \right) \right]^{1/2}, \]

with \( \Delta L', \Delta C', \) and \( \Delta H' \) (\( \Delta \) corresponding to the explanation of the \( \Delta E \) formula) representing the differences in lightness, chroma, and hue; \( R_T \) as function (rotation function) of interaction between differences in chroma and hue in the blue region; \( S_1, S_2, S_3 \) as total color difference for variation in location of the color difference pair in \( L', a', \) and \( b' \) coordinates; \( K_{L}, K_{C}, K_{H} \) as parametric factors as correction terms for experimental conditions set as 1.

The normal distribution was analyzed with the Kolmogorov-Smirnov test. The determination of the partial eta square \( \eta^2 \) allowed an estimation of the effect size. For parametric analysis one-way ANOVA and t-test were used. All data were analyzed with SPSS IBM 26.0 (IBM SPSS Statistics, Armonk, New York, USA) at a significance level of \( \alpha = 0.05 \).

### Results

#### 3.1 CIE Lab: \( \Delta E \) Calculation–Global Analysis

For \( \Delta E \), the choice of CAD/CAM ceramic (shade change: \( \eta_p^2 = 0.155; \ p \leq 0.001 \)), followed by the translucency level (HT/LT) \( \eta_p^2 = 0.050; \ p = 0.001 \) as well as the interaction between ceramic and translucency level \( \eta_p^2 = 0.175; \ p \leq 0.001 \) revealed the highest influence.

#### 3.2 CIEDE2000: \( \Delta E_{00} \) Calculation–Global Analysis

The choice of CAD/CAM ceramic \( \eta_p^2 = 0.490/p < 0.001 \) showed the highest impact on \( \Delta E_{00} \), followed by the color of RCC \( \eta_p^2 = 0.031/p = 0.012 \) and the interaction between ceramic and RCC \( \eta_p^2 = 0.258/p < 0.001; \ Table 3 \).

#### 3.3 CIE Lab: \( \Delta E \) Calculation–Analysis Within RCC Shade

Within the Light+ shade, the translucency level LT presented higher \( \Delta E \) for the lithium disilicate ceramic ABM and the lithium metasilicate.
ceramic NIC than the translucency level HT (p ≤ 0.032). Within Light + shade, the translucency level HT revealed higher ΔE for the leucite ceramic LRF and the lithium metasilicate CEL than CAD/CAM blocks of translucency level LT (p ≤ 0.009).

Within Warm+ shade, the translucency level LT showed higher ΔE for the lithium disilicate ceramic ABM, the lithium disilicate ceramic IEM, and the lithium metasilicate ceramic NIC than the translucency level HT (p ≤ 0.034) (Table 2).

**Table 2** Descriptive statistics of color change (ΔE) represented with mean and standard deviation. CAD/CAM ceramics were arranged according to material groups and within these groups alphabetically.

| CAD/CAM ceramic | Translucency level | ΔE Light+ | ΔE Warm+ |
|-----------------|-------------------|-----------|----------|
| LRF             | LT                | 4.0        | 5.6       |
|                 | HT                | 6.0        | 4.7       |
| IPR             | LT                | 6.6        | 5.7       |
|                 | HT                | 4.2        | 4.4       |
| ABM             | LT                | 4.9        | 6.9       |
|                 | HT                | 4.0        | 5.6       |
| IEM             | LT                | 4.3        | 5.0       |
|                 | HT                | 4.4        | 5.0       |
| CEL             | LT                | 6.0        | 5.7       |
|                 | HT                | 4.2        | 4.4       |

Note: a,b,c letters show significant differences between CAD/CAM ceramics within translucency level LT and resin composite cement color Light+ with regard to ceramics. A,B,C letters show significant differences between CAD/CAM ceramics within translucency level LT and resin composite cement color Warm+ with regard to CAD/CAM ceramics. A,B,C letters show significant differences between CAD/CAM ceramics within translucency level HT and resin composite cement color Light+ with regard to CAD/CAM ceramics. A,B,C letters show significant differences between CAD/CAM ceramics within translucency level HT and resin composite cement color Warm+ with regard to CAD/CAM ceramics. z,y letters show significant differences between translucency levels LT and HT with regard to resin composite cement. I,II,III letters show significant differences between resin composite cements with regard to translucency levels LT and HT.

**Table 3** Descriptive statistics of color change (ΔE00) represented with mean and standard deviation. CAD/CAM ceramics were arranged according to material groups and within these groups alphabetically.

| CAD/CAM ceramic | Translucency level | ΔE00 Light+ | ΔE00 Warm+ |
|-----------------|-------------------|-------------|------------|
| LRF             | LT                | 2.1         | 3.6        |
|                 | HT                | 3.2         | 5.7        |
| IPR             | LT                | 2.4         | 3.6        |
|                 | HT                | 3.2         | 5.5        |
| ABM             | LT                | 2.4         | 3.8        |
|                 | HT                | 2.4         | 3.8        |
| IEM             | LT                | 2.3         | 3.0        |
|                 | HT                | 2.3         | 3.0        |
| CEL             | LT                | 1.2         | 1.8        |
|                 | HT                | 1.4         | 1.8        |

Note: a,b,c letters show significant differences between CAD/CAM ceramics within translucency level LT and resin composite cement color Light+ with regard to ceramics. A,B,C letters show significant differences between CAD/CAM ceramics within translucency level HT and resin composite cement color Light+ with regard to CAD/CAM ceramics. A,B,C letters show significant differences between CAD/CAM ceramics within translucency level LT and resin composite cement color Warm+ with regard to CAD/CAM ceramics. A,B,C letters show significant differences between CAD/CAM ceramics within translucency level LT and resin composite cement color Warm+ with regard to CAD/CAM ceramics. z,y letters show significant differences between resin composite cements with regard to translucency levels LT and HT.
3.4 | CIEDE2000: ΔE00 calculation–analysis within RCC shade

Within the Light+ shade, higher ΔE00 values were analyzed for the leucite ceramic LRF for translucency level HT, the leucite ceramic IPR for translucency level LT, and the lithium disilicate ceramic ABM for translucency level LT (p ≤ 0.038).

Within the Warm+ shade, higher values presented the leucite ceramic LRF for translucency level LT, the lithium disilicate ceramic IEM for both translucency levels LT/HT, and the lithium metasilicate ceramic NIC for translucency level LT (p ≤ 0.047; Table 3).

3.5 | CIE lab: ΔE calculation–analysis within translucency level

Within the translucency level LT, the lithium metasilicate ceramic CEL, the leucite ceramic LRF, and the lithium disilicate ceramic IEM presented the lowest ΔE (p ≤ 0.015) and the leucite ceramic IPR, the lithium disilicate ceramic ABM, and the lithium metasilicate ceramic NIC the highest ΔE values (p ≤ 0.015) combined with Light+ shade. Within the translucency level LT, the leucite ceramic IPR and the lithium metasilicate CEL belonged to the group with the lowest ΔE combined with Warm+ shade (p ≤ 0.047).

Within the translucency level HT, the leucite ceramic LRF, the lithium disilicate ceramic ABM, the lithium metasilicate CEL, and the lithium metasilicate ceramic NIC presented highest ΔE values (p ≤ 0.041) combined with Light+ shade. Within the translucency level HT combined with Warm+ shade, all groups ranged in the same values range (p ≤ 0.997) (Table 2).

3.6 | CIEDE2000: ΔE00 calculation–analysis within translucency level

Within the translucency level LT, the lithium disilicate ceramic ABM and the leucite ceramic IPR presented the highest ΔE00 values (p ≤ 0.021), while the lithium metasilicate ceramic NIC and the lithium metasilicate CEL showed the lowest values (p ≤ 0.012) combined with Light+ shade. Within the translucency level LT, the lithium disilicate ceramic IEM, the leucite ceramic LRF, and the lithium disilicate ceramic ABM showed the highest ΔE00 values (p ≤ 0.047) as well as the lowest ΔE00 values for the lithium metasilicate ceramic NIC, the leucite ceramic IPR, and the lithium metasilicate CEL (p ≤ 0.047) in combination with Warm+ shade.

Within the translucency level HT, color change (ΔE00 values) was highest for the lithium disilicate ceramic IEM, the leucite ceramic LRF, and the lithium disilicate ceramic ABM (p ≤ 0.049); the lowest ΔE00 values for the lithium metasilicate ceramic NIC (p ≤ 0.035) combined with Light+ shade. Within translucency level HT combined with Warm+, the lithium disilicate ceramic IEM, the leucite ceramic LRF, and the lithium metasilicate CEL presented the highest ΔE00 values (p ≤ 0.012) and the lithium metasilicate ceramic NIC the lowest (p ≤ 0.022; Table 3).

4 | DISCUSSION

The null hypothesis stating that there is no impact of the type of ceramic, its translucency level and the shade of the RCC upon the final color of the tested CAD/CAM ceramics could be rejected. The reasons are discussed in the following sections.

In the present study, the choice of CAD/CAM ceramics generally showed the greatest impact on the results for both ΔE and ΔE00, followed by the translucency level for ΔE and the color of the RCCs for ΔE00. Related to the materials themselves without the RCCs, the differences between the CAD/CAM ceramics in A2 shade in terms of color and translucency level for the same thickness are visualized in Figures 3 and 4. The different results and effects of RCCs on color values may have been influenced by this and illustrates the difficulty for the dental technician and dentist to find the final shade for the patient. Therefore, the results obtained could facilitate the appropriate choice for ceramic restorations in the dental practice. The color and translucency differences of the CAD/CAM ceramics, in the present study of the color A2, may be due to the various compositions, as the color and the final color perception are related to the crystal structure, especially the crystal size and the interface between glass phase and crystals due to the refraction and transmission of the different leucite, lithium disilicate, lithium metasilicate, and lithium aluminoisolicate crystals. In the literature, leucite ceramics exhibit high translucency values, which could be confirmed in the present initial results, at least with regard to both leucite ceramics tested. Further conclusions regarding the results achieved are hampered by the fact that detailed information on the compositions were not available for several materials. Furthermore, there are no comparable investigations of the tested CAD/CAM ceramics in the literature.

FIGURE 3 Schematic representation of different resin composite cement (RCC) shades (Light+/Warm+) in the CIELab color spectrum
In general, differences were found between the RCCs shades Warm+ and Light+, (Variolink Esthetic) used in the present investigation. Differences in the individual available shades of different RCCs of one manufacturer18 as well as between the same shades of different manufacturers16 have already been shown in the literature and the first statement partly confirm the present analyzed values. The different position in the three-dimensional color space was schematically illustrated in Figure 3. In contrast to Light+, shade, the color Warm+ lies further in the orange-red range, which suggests that Warm+ provides a greater impact on the color change during bonding procedure especially in combination with the translucency level HT. This was true as the color Warm+ presented a greater influence on the color change than the color Light+ in the present results, showing generally a higher increase in color differences (further into the minus range). However, the composition of the two shades is identical except for the added pigments. At this point, it should be noted that the shade descriptions of the RCC refer to the completed restoration and not to the shade of the RCC alone. Furthermore, it should not be forgotten that mathematically determined shade differences are not necessarily visible to the naked eye, whereas several investigations stated that the CIEDE2000 formula provided results better fitting to the color differences perceived by the human eye than the CIELab formula.30-32 The CIEDE2000 formula also revealed better indicators of human perceptibility and acceptability of color change.31 It must be noted that when color differences between two different materials are detected by 50% of the observers, this corresponds to the 50:50% perceptibility threshold. If the color differences are considered acceptable by 50% of the observers, this corresponds to the 50:50% acceptability threshold. Consequently, a perceptible color match or an acceptable color match is a color below the specific threshold, and several studies have already shown the differences in threshold values between ΔE and ΔE00.12,33 These results can be confirmed in the present investigation. In the literature, the perceptibility level for ΔE was between 1.0 and 3.7 and the acceptability level between 2.7 and 6.8, whereas the level for ΔE00 was found to be 1.2 for the perceptibility level and 2.7 for the acceptability level, respectively.12,33-35 One ΔE value (IPR LT with Warm+ shade) of the present findings was above the acceptability level with 6.9, all other values were in the same value range. In contrast to ΔE, 13 out of 22 (around 60%) ΔE00 values were above the acceptability level in all different material combinations and translucency levels.

The lithium metasilicate ceramic CEL revealed lowest ΔE and ΔE00 values. Reasons can possibly be found in their composition, as it consists of 58% silica, 18.5% lithium oxide, 10.1% zirconia and 13.4% other ingredients. Although zirconia is also included as an ingredient in several of the CAD/CAM ceramics tested, according to the available data, the percentage of zirconia in the available compositions is highest in this lithium metasilicate ceramic. In general, zirconia exhibits less optical properties such as lower translucency and may have had a slight additional influence on the results in this context. In combination with the RCC shade Warm+, the lithium alumina silicate ceramic NIC and the leucite ceramic IPR showed the highest ΔE values for the HT and LT translucency levels in contrast to the lowest values for ΔE00 concerning the lithium alumina silicate ceramic. In combination with the RCC shade Light+, both leucite ceramics, the lithium disilicate ceramic ABM, and the lithium metasilicate ceramic for the translucency level HT and LT showed the highest ΔE values, whereas the results were similar for ΔE00, except for the lithium alumina silicate ceramic. The results of DE and DE00 show that in many cases the values were similar in tendency, but as in the case of the lithium alumina silicate ceramic they can also give contrary results, which might be caused by the significantly different calculation formula. Different outcomes of the two formulas have already been analyzed in the literature as mentioned before.13,33 The CAD/CAM ceramics with highest values could achieve the greatest color changes in combination with the RCC shades. This means that minimal changes in the CAD/CAM ceramic shade could be achieved with the adhesive bonding procedure in order to find the optimum esthetic result.

In the present study the color measurements were mechanically performed using a spectrophotometer (Lambda 35), being a sensitive device that reacts to even the slightest inaccuracies as dust or dirt particles in the interior of the spectrophotometer leading to deviations in the measured values. The advantage of the spectrophotometer used, however, is the determination of the color values, which belong to a universally applicable and internationally used color system. For many years now, the analysis using the CIEDE2000 formula has been increasingly accepted. In the present study, therefore both formulas were used to better compare the analyzed values. Both color systems could be an obstacle for clinical application, since the values cannot be interpreted without consulting a color scale.

A limitation of the present study is the lack of clinical geometries, which may have led to changes in the results. A further limitation is the analysis of just one RCC from one manufacturer and just one thickness for all ceramic specimens; hence results only refer to this one product and ceramic thickness.

5 | CONCLUSION

Within the limitations of this study, following conclusions could be drawn:
• The choice of ceramic showed an impact on color change of the analyzed CAD/CAM ceramics ($\Delta E_0$ and $\Delta E_00$).
• The translucency level showed an impact on color change of the analyzed CAD/CAM ceramics ($\Delta E$).
• The RCC shade (Warm+ /Light+) showed an impact on color change of the analyzed CAD/CAM ceramics ($\Delta E00$).

ACKNOWLEDGEMENTS AND DISCLOSURE
The authors would like to thank all companies for providing the materials analyzed. The authors do not have any financial interest in the companies whose materials are included in this article. This research did not receive any specific grant from funding agencies in the public, commercial, or not-profit sectors. Open access funding enabled and organized by Projekt DEAL.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID
Anja Liebermann https://orcid.org/0000-0002-1385-2195

REFERENCES
1. Silva LHD, Lima E, Miranda RBP, Favero SS, Lohbauer U, Cesar PF. Dental ceramics: a review of new materials and processing methods. Braz Oral Res. 2017;31(1):658.
2. Sen N, Us YO. Mechanical and optical properties of monolithic CAD-CAM restorative materials. J Prosthodont. 2018;119(4):593-599.
3. Zaron F, Di Mauro MI, Ausiello P, Ruggiero G, Sorrentino R. Current status on lithium disilicate and zirconia: a narrative review. BMC Oral Health. 2019;19(1):134.
4. Bajraktarova-Valjakova E, Korunoska-Stevkovska V, Gigovski N, Bajraktarova-Misevska C, Grozdanov A. Contemporary Dental Ceramic Materials. A Review: Chemical Composition, Physical and Mechanical Properties, Indications for Use. Open Access Maced J Med Sci. 2018;6(9):1742-1755.
5. Fu L, Engqvist H, Xia W. Glass-Ceramics in Dentistry: A Review of New Materials and Processing Methods. Dent Med Probl. 2019;56(4):349-356.
6. Eldwakhly E, Ahmed DRM, Soliman M, Abbas MM, Badrawy W. Color and translucency stability of novel restorative CAD/CAM materials. Dent Mater Probl. 2019;66(2):103-111.
7. Wang F, Takahashi I, Iwasaki N. Translucency of dental ceramics with different thicknesses. J Prosthet Dent. 2013;110(1):14-20.
8. Ahn JS, Lee YK. Difference in the translucency of all-ceramics by the illuminant. Dent Mater. 2008;24(11):1539-1544.
9. Czigola A, Abram E, Kovacs ZI, Marton K, Hermann P, Borbely J. Effects of substrate, ceramic thickness, translucency, and cement shade on the color of CAD/CAM lithium-disilicate crowns. J Esthet Restor Dent. 2019;31(5):457-464.
10. Kang W, Park JK, Kim WC, Kim HY, Kim JH. Effects of different thickness combinations of core and veneer ceramics on optical properties of CAD-CAM glass-ceramics. Biomed Res Int. 2019;5856482.
11. Rosenstiel SF, Johnston WM. The effects of manipulative variables on the color of ceramic metal restorations. J Prosthet Dent. 1988;60(3):297-303.
12. Gómez-Polo C, Portillo Muñoz M, Lorenzo Luengo MC, Vicente P, Galindo P, Martín Casado AM. Comparison of the CIELab and CIEDE2000 color difference formulas. J Prosthet Dent. 2016;115(1):65-70.
13. Della Bona A, Nogueira AD, Pecho OE. Optical properties of CAD-CAM ceramic systems. J Dent. 2014;42(9):1202-1209.
14. Vichi A, Ferrari M, Davidson CL. Influence of ceramic and cement thickness on the masking of various types of opaque posts. J Prosthet Dent. 2000;83(4):412-417.
15. Al Ben Ali A, Kang K, Finkelman MD, Zendarsa P, Hirayama H. The effect of variations in translucency and background on color differences in CAD/CAM lithium disilicate glass ceramics. J Prosthodont. 2014;23(3):213-220.
16. Chang J, Da Silva JD, Sakai M, Kristiansen J, Ishikawa-Nagai S. The optical effect of composite luting cement on all cosmetic crowns. Int J Dent. 2009;37(12):937-943.
17. Terzioğlu H, Yilmaz B, Yurdukor U. The effect of different shades of specific luting agents and IPS empress ceramic thickness on overall color. Int J Periodont Restor Dent. 2009;29(5):499-505.
18. Dede DO, Ceylan G, Yilmaz B. Effect of brand and shade of resin cements on the final color of lithium disilicate ceramic. J Prosthodont. 2017;117(4):539-544.
19. Turgut S, Bagis B. Effect of resin cement and ceramic thickness on final color of laminate veneers: an in vitro study. J Prosthodont. 2013;19(9):179-186.
20. Chen XD, Hong G, Xing WZ, Wang YN. The influence of resin cements on the final color of ceramic veneers. J Prosthodont Res. 2015;59(3):172-177.
21. Gugelmin BP, Miguel LCM, Baratto Filho F, Cunha LFD, Correr GM, Gonzaga CC. Color Stability of Ceramic Veneers Luted With Resin Cements and Pre-Heated Composites: 12 Months Follow-Up. Braz Dent J. 2020;31(1):69-77.
22. Nakamura T, Saito O, Fuyikawa J, Ishigaki S. Influence of abutment substrate and ceramic thickness on the colour of heat-pressed ceramic crowns. J Oral Rehabil. 2002;29(9):805-809.
23. Stawarczuk B, Beuer F, Ender A, Roos M, Edelhoff D, Wimmer T. Influence of cementation and cement type on the fracture load testing methodology of anterior crowns made of different materials. Dent Mater. 2013;29(6):888-895.
24. Hitz T, Stawarczuk B, Fischer J, Hämmmerle CH, Sailer I. Are self-adhesive resin cements a valid alternative to conventional resin cements? A laboratory study of the long-term bond strength. Dent Mater. 2012;28(11):1183-1190.
25. Koishi Y, Tanoue N, Atsuta M, Matsumura H. Influence of visible-light exposure on colour stability of current dual-curable luting composites. J Oral Rehabil. 2002;29(4):387-393.
26. Buchalla W, Attin T, Hilgers RD, Hellwig E. The effect of water storage and light exposure on the color and translucency of a hybrid and a microfilled composite. J Prosthet Dent. 2002;87(3):264-270.
27. Almeida JR, Schmitt GU, Kaizer MR, Boscato N, Moraes RR. Resin-based luting agents and color stability of bonded ceramic veneers. J Prosthet Dent. 2015;114(2):272-277.
28. Castellanos M, Delgado AJ, Sinhoreti MAC, et al. Effect of Thickness of Ceramic Veneers on Color Stability and Bond Strength of Resin Luting Composites Containing Alternative Photoinitiators. J Adhes Dent. 2019;21(1):67-76.
29. Lee YK. Translucency of human teeth and dental restorative materials and its clinical relevance. J Biomol Opt. 2015;20(4):045002.
30. Chu SJ, Trushkowsky RD, Paravina RD. Dental color matching instruments and systems. Review of clinical and research aspects. J Dent. 2010;38(2):e2-e16.
31. Wee AG, Lindsey DT, Shroyer KM, Johnston WM. Use of a porcelain color discrimination test to evaluate color difference formulas. J Prosthet Dent. 2007;98(2):101-109.
32. Ghinea R, Pérez MM, Herrera LJ, Rivas MJ, Yebar A, Paravina RD. Color difference thresholds in dental ceramics. *J Dent*. 2010;38(2): e57-e64.

33. Paravina RD, Ghinea R, Herrera LJ, et al. Color difference thresholds in dentistry. *J Esthet Restor Dent*. 2015;27(1):S1-S9.

34. Paravina RD. Critical appraisal. Color in dentistry: match me, match me not. *J Esthet Restor Dent*. 2009;21(2):133-139.

35. Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. *J Dent Res*. 1989;68(5):819-822.

**How to cite this article:** Liebermann A, Mandl A, Eichberger M, Stawarczyk B. Impact of resin composite cement on color of computer-aided design/computer-aided manufacturing ceramics. *J Esthet Restor Dent*. 2021;33:786–794. [https://doi.org/10.1111/jerd.12738](https://doi.org/10.1111/jerd.12738)