Spectrophotometrical CIELab color space analysis of CAD-CAM dental ceramics optical properties changes before and after thermocycling

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Abstract

Background: CAD-CAM dental ceramic materials have highly advanced in the field of colors. One of the most effective methods to evaluate the optical changes, that ceramics might undergo, is by using a spectrophotometer before and after the ceramic thermocycling in different solutions.
Aim: To analyse the most recent literature work in order to compare, evaluate and assess the changes in CAD/CAM dental ceramics optical properties before and after thermocycling with different compounds and solutions.
Methods and materials: Analysis of literature was performed by using the PRISMA protocol. The search was done electronically in ScienceDirect, MEDLINE, Cochrane Library and Wiley Online Library databases. The focus question was developed by the PICO (population (P), intervention (I), control (C), and outcome (O)) study design protocol.
Results: Out of 212 articles that were found, and 103 records that were screened, 5 articles were included into the qualitative analysis. Four of the studies reported only slight color changes in CAD/CAM dental ceramic materials before and after thermocycling. One of the studies reported the changes to be more significant, and the variation depended on the type of the CAD/CAM material that was used.
Conclusions: CAD/CAM dental ceramic materials are highly resistant to color changes when exposed to thermocycling procedures.

Key words:

cad, cam, dental, ceramic, color, thermocycling

Introduction

Historically, CAD/CAM (computer aided design/computer aided manufacturing), usage was started around 1971 by Dr. Duret, but a commercial version was introduced in 1985, by Dr. Morman, who, along with his colleagues, created the system, known as CEREC, and by using it, made the first ceramic inlay [1, 2]. Nowadays, CAD/CAM is one of the most popular prosthesis manufacturing option in prosthetic dentistry due to its ease of use, fast restauration production time, and the ability to communicate easier with the dental technicians [3]. The material, that prosthodontists and their patients choose for their restorations most often, especially in the US (80,2%), is ceramics [4]. Also, the technologies, that were used before to get these restorations, by the lost-wax casting, has been drastically improved with the usage of CAD/CAM dental systems [5].

All of the progress in the CAD/CAM technologies, actuated the advancements of the materials used for aesthetic all-ceramic restorations, which would have excellent biomechanical properties [6]. One of the main aesthetical-optical properties, when considering a ceramic restoration, is its color and the way it is affected by different solutions, due to the constant compounds, solvents and fluids it is exposed to on a regular basis, when the person is masticating [7].

The evaluation of all-ceramic crown colors can be done by spectrophotometric analysis, which, by the use of a spectrophotometer, analyses different areas of the tooth or a restauration using CIELab (Commission Internationale de l'Eclairage) color coordinates L*, a*, b* (L^* for the lightness from black (0) to white (100), a^* from green (−) to red (+), and b^* from blue (−) to yellow (+)), and color difference ΔE [8].

One of the ways to test how a material changes its optical properties, is by thermocycling the ceramic with different dying liquids, which can affect the optical properties of a material, in e.g. decrease the translucency or affect the opalescence of a dental CAD/CAM ceramic, although other color difference formulas, rather than CIELab, might be used for these types of measurements [9; 10]. This is why testing by the following method and its alterations can greatly improve the knowledge about a material and suggest the best option for each clinical situation and manufacturing method.

Objective: The aim our work was to systematically review the most recent studies on spectrophotometrical color space analysis of CAD-CAM dental ceramics and asses the changes that occur while examining their optical properties digitally, by analysing CIELab color coordinates and their differences before and after thermocycling.

Material and methods

For this review, our aim was to evaluate the color properties and their changes, that occur, when CAD-CAM dental materials are exposed to thermocycling and their ageing is simulated according to the protocols described in the literature. This article was done according to the systematic review statement [11].

Focused question:

The focus question was developed to the PICO (population (P), intervention (I), control (C), and outcome (O)) study design protocol: How are the color space optical properties (L*, a*, b*) and their difference ΔE of different CAD/CAM dental ceramic materials affected after thermocycling?

Search Strategy:

Analysis of literature was carried out by following the PRISMA protocol. The search was performed in electronical literature databases: ScienceDirect, MEDLINE, Cochrane Library and Wiley Online Library. The time period of literature search was between 2020 September 10th and 30th and the articles were not older than 5 years old. Additional scientifical literature search was done manually. All of the related and similar articles were reviewed, including the references lists of the selected articles. If full-text publications were not found in the aforementioned databases, authors were contacted personally by e-mail or thru ResearchGate, with requests for a full-version of the articles. The keywords "cad; cam; dental; ceramic; color; thermocycling" and their variations were used, which provided the highest number of results. The references of the papers, that were included, were also investigated, in order to identify any potential additional results.

Selection of studies:

The articles were investigated independently by 2 authors. Researchers discussed and compared their selections and matched all the differences through discussion. The screening of all of the articles was done during the final stage. The exclusion of the articles was done after investigation of titles and abstracts. The decision, whether to include the publication or not, was done after the analysis of the full text, according to the inclusion and exclusion criteria.

Inclusion Criteria:

1. Studies were made with/including CAD/CAM ceramics;
2. Spectrophotometrical analysis was done;
3. Thermocycling procedure and its parameters were described;
4. ΔE was calculated and compared before and after thermocycling;
5. The lightness (L(*)), red-green color value (a(*)) and blue-yellow color value (b(*)) of all samples was analysed before and after the thermocycling processes;
6. Articles were not older than 5 years old;
7. Articles were in English.

Exclusion Criteria:

1. Studies did not include CAD/CAM ceramics;
2. No spectrophotometrical analysis was done;
3. Thermocycling procedure was not described;
4. ΔE was not taken into consideration and was not calculated;
5. No analyzation of the lightness (L(*)), red-green color value (a(*)) and blue-yellow color value (b(*)) of all samples was done before and after the ageing processes;
6. Articles, that were older than 5 years old;
7. Articles, that were written in other than English language.

Data extraction (table 1):

Table 1.
Synthesis of results

Study	Year	Population/Problem/ Sample size	Intervention	Comparison	Outcome
Yuan et al. [12]	2019	2 groups: Group 1: CAD lithium disilicate ceramic (N=90); Group 2: zirconia ceramic (N=90). 9 subgroups with different amounts of cycles each: 1. TC – thermocycling, 2. B - brushing, 3. TC+B – thermocycling and brushing.	Thermocycling: 6000, 12000 and 18000 cycles, temperature between 5°C and 55°C, baths with distilled water. Brushing: 50000, 100000, 150000 cycles (both interventions simulating oral environments of 5, 10, 15 years).	ΔE and ΔR_a were compared before and after the TC, B and B+TC procedures. Color measurements were obtained from a 380 to 780 nm spectral reflectance with a 5-nm interval (SpectraWin2; Photo Research Inc) before conversion to Commission Internationale d'Eclairage L*a*b* (CIELab) values.	CAD lithium disilicate ceramic showed no color differences after intervention and simulation (P>.05). Zirconia specimens had a significant color differences results in B, TC and B+TC and simulated years (P<.001).
Gurdal et al. [13]	2018	N=420 CAD/CAM blocks. (Lava Ultimate, Cerasmart, Cerec Bloc, Brilliant crios, IPS e.max CAD, IPS empress CAD, VITA suprinity). Different CAD/CAM blocks and resin composite cements, were analysed for ΔE value change before and after thermocycling	Thermocycling: light proof conditions, 5000 cycles, temperature between 5°C and 55°C, bath with distilled water.	ΔE values of CAD/ CAM materials were measured before and after thermocycling. CIELab parameters L, a, and b were determined using software (Color 3.0; PerkinElmer Inc).	CAD/CAM material and the cement had a significant effect on ΔE values. CAD/CAM materials thickness had no effect on ΔE value, which means, that it was insignificant (P=.179). 0,5 mm thick specimens b* values increased after thermocycling. Aging also increased L* value, regardless of the thickness of the sample materials.

Kyrana et al. [14]	2017	N=80 specimens. Made from: zirconia disks (BruxZir). 2 groups, N=40 each. Group 1: pre-shaded specimens (PS). Covers 16 VITA Classical shades. Group 2: white specimens (LC). Coloring liquids used in shades A2, B2, C2, D2. Each subgroup has N=10 specimens, according to shade.	Thermocycling: in 4 tanks with deionized water. 5000 thermal cycles for 15 seconds in each tank according to the following sequence: 5⁰C to 37⁰C to 55⁰C to 37⁰C according to ISO 4111405.	ΔE values of CAD/CAM materials were measured before and after thermocycling. A double-beam ultraviolet-visible light recording spectrophotometer was used to assess the color parameters L*, a*, and b* before and after thermocycling. ΔE color difference was calculated.	All of the sample groups had ΔE<1,2. No statistically significant ΔE was observed among the sample groups (P=.386). L*, a*, b* values, when compared before and after thermocycling, were affected insignificantly. The only statistically significant color parameter change was a*. Laboratory characterized zirconia was more stable regarding color, than preshaded monolithic zirconia.
Moaleem et al. [15]	2020	N=70 specimens. 4 groups: Group 1: glazed or polished feldspatic metal ceramic (N=20); Group 2: machinable feldspatic porcelain Vitablovks Mark II (N=20); Group 3: multilayer CAD/CAM zirconium porcelain (N=20); Group 4: natural teeth - central incisors without present caries (N=10). 2 subgroups N=70: glazed N=35 (N=10 from each specimen group) and polished N=35 (N=10 from each specimen group). N=5 natural teeth samples as control group for every subgroup.	Samples immersed in Khat leaves homogenate, with pH similar to oral cavity (by mixing in NaOH) for 30 days. Solution was changed every day. During immersion in Khat leaves homogenate - thermocycling: 3000 cycles (5⁰C cold water to 55⁰C hot water, 100 cycles a day). After removal from Khat solution, specimens dipped in distilled water – 10 times each.	VITA Easyshade® V spectrophotometer for analysis of color changes (ΔE) before immersion in khat homogenate and thermocycling, and then after removal.	Highest ΔE values were present in the natural teeth group: ΔE=2,12 before immersion and ΔE=3,45 after immersion (P<0,001). ΔE values were significantly different when compared between samples (both glazes and polished) and natural teeth (P>0,05).
Palla et al. [16]	2017	N=288 specimens. 4 groups: Group 1: IPS e-max computer-aided design (CAD) (n=72); Group 2: IPS e-max CERAM (CER n=72), Group 3: IPS e-max Press with glazing (PG n=72), and Group 4: IPS e-max Press without glazing (PNG n=72). Each group was divided into 4 subgroups, N=18 each: TC (thermal cycling), coffee, black tea, red wine.	Thermocycling: 21900 cycles (5⁰C to 37⁰C to 55⁰C to 37⁰C (3 years' clinical simulation). Immersion in coffee, black tea, wine: immersed into 48-well cell plates.	Color parameters L*, a*, and b* were assessed with an ultraviolet-visible spectroscopy recording spectrophotometer.	The majority of specimens presented slight color changes (ΔE<2) Glaze is important for the color stability of IPS e-max Press restorations. The presence of non- glazed surfaces, as after excessive occlusal adjustments, should be avoided by careful design of the restorations and thorough occlusal checking prior to definitive cementation. Computer-aided design and computer-aided manufacturing derived lithium disilicate appears to be a very color stable material.

The collection of data was done and summarized in the following fields:

1. Authors and year of publication;
2. P – Population/Problem/Sample size;
3. I – Intervention (describes the intervention, that was done to the samples);
4. C – Comparison (describes the control group samples);
5. O – Outcome (describes, whether the outcomes were successful).

Synthesis of results:

The results were synthesized, and all of the findings were put into a table format – Table 1.

Results

Study Selection:

The first initial data search displayed a total of 212 studies. After applying the 5-year filter, 103 studies were screened for eligibility. Out of those studies, the inclusion and exclusion criteria were applied. 11 studies full texts were analysed for eligibility. Six studies were excluded, because CIEDE2000 was used instead of CIELab and the materials were analysed with a spectroradiometer, not with a spectrophotometer, which means a different method and which was not our research object, and in one study, ΔE was neither measured, nor compared before/after thermocycling, which was one of our inclusion criteria [9; 17; 18; 19; 20; 21]. Consequently, 5 studies were included into the qualitative data synthesis, due to their relevance. The flow diagram is shown in Figure 1.

Study characteristics:

The data of interest of the studies, is shown in Table 1. The studies were made with CAD/CAM ceramic materials. All of the materials had their colour parameters analysed by CIELab (Commission Internationale de l'Eclairage) color coordinates L*, a*, b* (*L** for the lightness from black (0) to white (100), *a** from green (–) to red (+), and *b** from blue (–) to yellow (+)), and color difference ΔE was calculated. In one of the studies, the comparison of ΔE before and after thermocycling was also compared in regards to differently treated CAD/CAM ceramic surfaces [12]. In a few of the studies, the ΔE was measured before and after standard thermocycling procedure, without any modifications [13; 14]. Some of the studies also included different solutions, in which the thermocycling took place [15; 16].

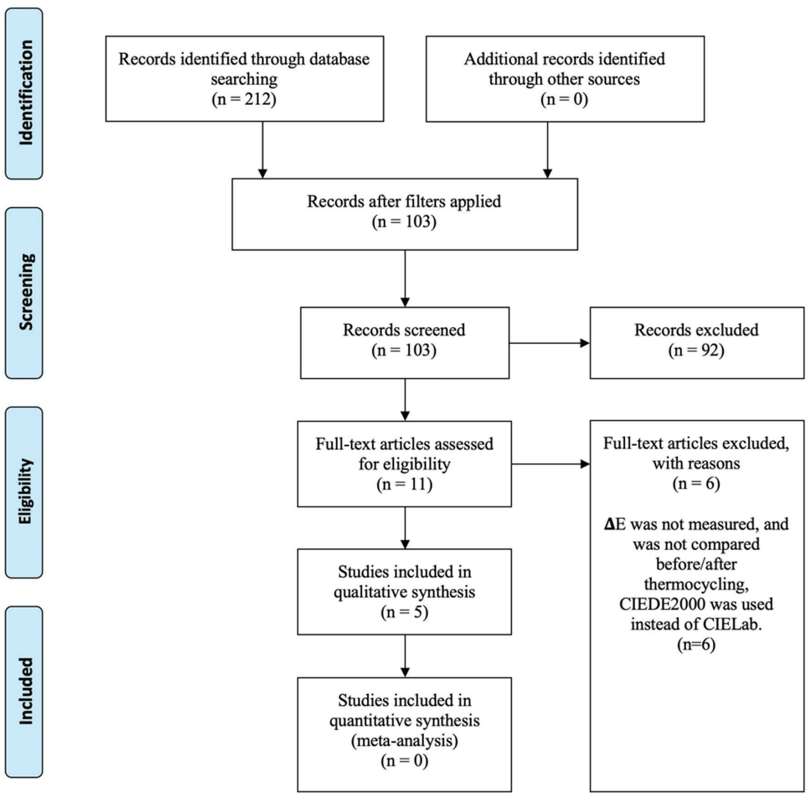

Fig. 1.
PRISMA flow diagram for systematic review.

Quality assessment:

The quality assessment was done using CRIS (Checklist for Reporting In-Vitro studies) [17]. It consists of sample size calculation, meaningful difference between groups, sample preparation and handling, allocation sequence, randomization and blinding and statistical analysis (Table 2). All of these criteria show a significant evidence value of the publication.

Qualitative synthesis of results:

All of the studies, that were included in this literature review, have used ΔE parameter (which was calculated according to the formulas stated in each article, including L*, a*, b* parameters calculations), as the main criteria, which indicated the color changes of described materials, out of which, CAD/CAM was in all of the reviews. Also, a comparison between CAD/CAM ceramic and other materials was done, in order to evaluate different ceramics reactions to thermocycling in regard to the color changes before and after the procedure [12-16].

The analysis revealed, that in Yuan et. al work, CAD lithium disilicate ceramic has shown no color differences after thermocycling for 6000, 12000 and 18000 cycles (temperature was between 5°C and 55°C, baths were used with distilled water) and after brushing for 50000, 100000 and 150000 cycles (which was done to stimulate the oral environment of 5, 10, 15 years) (P>.05) [12]. Although, the same scientists compared that with zirconia specimens, which underwent the same sample treatments, but the results have shown significant color differences in brushing, thermocycling, and also burshing+thermocycling groups (P<.001), although, the zìrconia group showed the mean color differences in the tolerance range, the perceptibility was ΔE=2,6 [12].

In comparison, work done by Gurdal et al., which tested 420 CAD/CAM blocks, and resin composite cements, which both underwent thermocycling for 5000 cycles (temperature between 5°C and 55°C, bath with distilled water under light proof conditions), showed positive results, that both materials have a significant effect on the ΔE values [13]. Although the thickness of the CAD/CAM material had no significance (P=.179), the lowest ΔE values were shown by Vita Suprinity (ΔE=3,46) and GC Cerasmart (ΔE=3,66) (P<.001), followed by Lava ultimate (ΔE=3,95), followed by Brilliant Crios ΔE =5,13. Ips e.max CAD ΔE=5,62, and Cerec Bloc ΔE=8,66. The highest ΔE values were observed for IPS Empress CAD (ΔE=10,24) [13].

Kyrana et al. have tested 80 specimens made from zirconia disk (BruxZir), which were separated in two groups – pre-shaded and white specimens with colouring liquid used on them. Thermocycling took place in 4 tanks with deionized wated, for 5000 thermal cycles (15 seconds in each tank according to the following sequence: 5°C to 37°C to 55°C to 37°C according to ISO 4111405) [14]. The ΔE calculations

Table 2.
Quality assessment.

No.	Publication authors, year, reference	Sample size calculation	Meaningful difference between groups	Sample preparation and handling	Allocation sequence, randomization and blinding	Statistical analysis
1.	Yuan et al., 2019 [12]	+/-	+/-	+	+/-	+
2.	Gurdal et al., 2018 [13]	+	+/-	+	+/-	+
3.	Kyrana et al., 2017 [14]	+/-	+/-	+	+/-	+
4.	Moaleem et al., 2020 [15]	+/-	+	+	+/-	+
5.	Palla et al., 2017 [16]	+/-	+	+	+/-	+

"+" - data is found; "-" - data is not found; "+/-" - data is found partially and analysis has shown, that all of the groups had ΔE<1,2, and no statistically significant ΔE was observed among the sample groups (P=.386). When analyzing the L*, a*, b* parameters, the only significant change occurred in a* [14].

The study of Moalleem et. al was done on 4 groups of materials – multilayer CAD/CAM zirconium porcelain, glazed or polished metal ceramic, machinable feldspatic porcelain and natural teeth (as the control group), which underwent thermocycling procedure (3000 cycles, 5^0C cold water to 55^0C hot water, 100 cycles a day), but with immersion into khat leaves homogenate (pH was similar to oral cavity) [15]. The ΔE changes in all groups were analysed, and the highest values were found in the natural teeth group (ΔE=2,12 before immersion and ΔE=3,45 after immersion (P<0,001)), and the lowest values were in the Polished Vitablocks Mark II ΔE=0,73 (P<0,001). Glazed MC ΔE= 0,56 and Vitablocks Mark II ΔE=0,28 (P<0,001) groups. The CAD/CAM Zircon polished was ΔE=2,52 and Zircon glazed ΔE=1,58 (P<0,001) in comparison to polished MC ΔE=1,34 (P<0,001). As the results have shown, ΔE values were significantly different when compared between samples (both glazes and polished) and natural teeth (P>0,05) [15].

Palla et al. conducted a study, which included 4 different groups of ceramics, consisting of a total of 288 specimens (IPS e-max CAD, IPS e-max CERAM, IPS e-max Press with glazing and IPS e-max Press without glazing) which ΔE changes were compared before and after thermocycling (21900 cycles (5^0C to 37^0C to 55^0C to 37^0C - 3 years' clinical simulation) and immersion into different coloring solutions (coffee, black tea, wine) [16]. The results have showed, that for the CAD group, ΔE<1 for all of the specimens, regardless of the aging process, and the majority of other specimens have showed only slight color changes of ΔE<2 [16].

Discussion

In this systematic review, we have studied the literature on Spectrophotometrical CIELab color space analysis of CAD-CAM dental ceramics optical properties changes before and after thermocycling. The aim of this study was to to analyse the most recent literature work in order to compare, evaluate and assess the changes in CAD/CAM dental ceramics optical properties before and after thermocycling, including different compounds and solutions. A total of 5 studies were included into the qualitative data synthesis, while the excluded ones did not have the research done on CAD/CAM ceramics, ΔE was not taken into consideration, or no spectrophotometrical analysis was done.

Although CIELab is one of the main choices when measuring color differences, scientists Gomez-Polo et al. did a research, in which, CIELab (ΔE^*_{ab}) and CIEDE2000 (ΔE00) formulas were compared in regard to which one reflects the difference in color perception most accurately. In this study, the result has shown, that formulas are very similar, for CIEDE2000 the linear correlation coefficient was 0.726 ($p < 0.001$) and for CIELab it was 0.719 ($p < 0.001$) [18]. The same scientists have also concluded that men were less sensitive to differences in color perception, than women [18]. Further research needs to be done comparing these two different formulas.

Also, although Gurdal et al. research proposed, that the thickness of the material has no significance on the ΔE changes, we also need to take into consideration the substrate, as Sari et al. suggested in their work, which investigated both the substrate shade and the thickness influence on the final color of an ultrathin laminate veneer, fabricated out of CAD-CAM feldspathic ceramic block [13; 19]. The analysis was also done with a spectrophotometer, ΔE was calculated and the following conclusions were done, that the substrate lighter shade, lighter restoration, a darker substrate shade, and a darker ceramic restoration change the color of the final restoration only minimally, and it is also important, that the ceramic thickness is the most crucial component which allows the masking of a substrate color [19].

It should also be noted that the thickness of the monolithic zirconia is a crucial part in trying to achieve an aesthetical result in the final restoration. Scientists Tabatabaian et al. conducted a research, in which they used CIELab color system, to analyse the minimum thickness of a zirconia restoration (A2 shade), in order to mask the color of a darker substrate (A4 shade) [20]. As the researchers put forward in their work, the minimum thickness of such restoration should be at least 0,9 mm, which a very important finding in regard to the clinical application of CIELab [20].

Adding to the following statements, the recent work of Li analysed ceramic veneers color differences to the ceramic shade tab, by using CIELab, and the results have shown, that the material thickness has an impact on the end result [21]. When the feldspatic ceramic discs were either 0,7 mm or 0,5 mm thickness, color matching with the shade tab was not achieved, and positive ΔE results were only attained with 1,0 mm thickness samples [21]. Additional research for these types of studies is required for other types of ceramics and their evaluation by using CIELab.

In our study, the translucency parameter was not included, but it should be mentioned, that by measuring the same L*, a*, b* parameters and using CIELab, it can also be analysed, and the results need to be taken into consideration, especially for clinicians. As Walczak et al. stated in one of their work conclusions, thermocycling, or artificial aging has an impact on the translucency of zirconia, but the end result is unlikely to be detectable clinically [22]. Further research needs to be done to assess this topic more thoroughly, with more different materials.

Conclusions

This systematic review states, that the following conclusions can be drawn:

1. CAD/CAM dental ceramic materials are resistant to color changes.
2. CAD/CAM dental ceramic materials ΔE before and after thermocycling is lower in comparison to natural teeth.
3. Preshaded CAD/CAM dental ceramic report higher ΔE changes.
4. CAD/CAM dental material thickness has no effect on the ΔE changes.

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