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REVIEW

Potential color change in ceramic-based restorations

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Keywords: Ceramics, color change, Lithium disilicate, Thermocycling, Zirconia

ABSTRACT

Ceramic materials are among the materials used in restorative dentistry. They are widely used for restoration in esthetically demanding areas. Consequently, this material requires excellent color stability on top of adequate strength and good biocompatibility to achieve prosthodontic treatment success, especially in the aesthetic aspect. Lithium disilicate and zirconia are two popular ceramic materials used in dentistry mainly due to their translucency and strength. This scoping review aims to evaluate the potential for ceramic materials, mainly lithium disilicate and zirconia, to change colors after thermocycling with or without the staining process. Thermocycling is a laboratory method used to simulate daily oral use in relatively short periods. Twelve (12) articles extracted from 172 articles in 3 database resources based on the inclusion and exclusion criteria (journal articles in English from 2017-2021 that evaluate the color change in ceramic materials after thermocycling with or without staining process) are reviewed for the color change of several ceramic restoration materials. All materials generally show color change; lithium disilicate and zirconia-reinforced lithium silicate show the slightest color change compared to zirconia, feldspathic, or hybrid ceramic materials. Glazed materials offer better color stability compared to polished materials. Several staining solutions significantly contribute to the color change: coffee, tea, and wine. The thickness of materials and adhesive cement may also contribute to the color change of ceramic materials. In conclusion, all materials show color change after the thermocycling process; however, only hybrid ceramics show a level of color change that is above the tolerated limit. (IJP 2024;5(1):34-43)

INTRODUCTION

The ongoing development of dental materials has made it possible to fabricate strong yet also aesthetic restoration materials. As the demand for the use of tooth-colored restorative materials especially in prosthetic dentistry increased, this development is a welcomed one.[1] Ceramic-based materials are the material of choice that has major advantages in the aesthetic aspects; Apart from that, this material also shows good biocompatibility and physical characteristics that continues to improve.[2,3] Also, by utilizing the CAD/CAM technology, it is possible to make the ceramic restoration with the minimum possible thickness, thereby reducing the amount of tooth structure that must be removed.[4]

Initially, there were still concerns regarding the physical strength of the latest ceramic-based materials which have a fairly thin thickness (1 mm or less). However, it is revealed that in general, the latest ceramic materials can be fabricated with a thickness of up to 0.5 mm and still have a fracture strength limit that is above everyday occlusal loads.[5] Ceramic-based indirect restorative materials can generally be divided into 2: silicate ceramics and oxide ceramics. Lithium disilicate is an example of a silicate ceramic material and zirconia is an example of an oxide ceramic material. Both are the main materials of choice for indirect restoration in areas that have a high level of aesthetic needs and have been widely researched with quite satisfactory results, both from an aesthetic, biological and mechanical perspective.[6]

One of the main reasons of tooth restoration replacement especially in anterior teeth, is discoloration of the restoration.[13,14] Therefore, color stability is an important factor to ensure that the restoration's aesthetics value can last a relatively long time so that the restoration does not need to be replaced within a short period after cementation. Various ceramic-based indirect restoration materials (including lithium disilicate and zirconia) are known to

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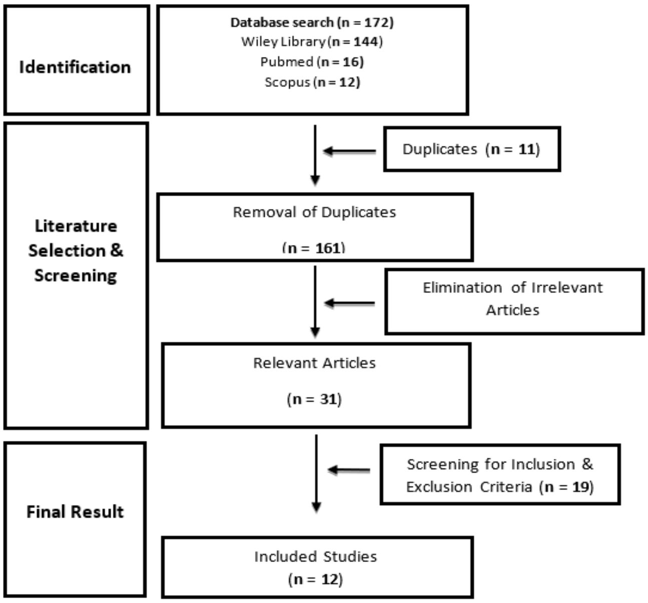

Figure 1. Literature Search Flow.

Table 1. Comparison of laser surface treatment and sandblasting.

Inclusion Criteria	Exclusion Criteria
Articles published from January 2017 - November 2021	Articles published before January 2017 with languages other than English
English articles	Case reports, finite element analysis (FEA) studies, systematic reviews, meta-analyses, clinical trials, or literature reviews articles
Articles that are available as full text	Articles that do not have a full-text version
Articles in the form of in vitro studies	
Articles that evaluate and discuss the effect of thermocycling process with/without staining process on the color stability of ceramic-based restorative materials	

have different physical properties so it is estimated that the color stability of these materials will also show different results. Several methods have been used to maintain the stability of the restoration color, i.e., through polishing and glazing processes on the surface of the materials.[11,15,16]

Several studies have tried to evaluate the color stability of ceramic materials. Color stability testing can be done by simulating the effect of oral environment daily use on the materials through a thermocycling process to evaluate changes in the structure and color of the material by using the microscopic and spectrophotometry analysis. Apart from thermocycling, the use of solutions such as coffee, tea, or soft drinks are also commonly used in several studies to evaluate the color stability of ceramic materials.[12,14,17,18] However, the studies above still provide quite diverse results and further information regarding the potential for changing the color of ceramic materials has not yet been widely discussed. So based on this, this paper aims to evaluate in more detail the potential for color changes of ceramic-based indirect restoration materials that have undergone a thermo-cycling process with/without a staining process. It is hoped that the information obtained regarding the potential for color changes from ceramic-based indirect restoration materials in this paper will be useful for fellow clinicians.

LITERATURE STUDIES

This paper is written as a scoping review that summarizes and examines the results of previous studies that have been carried out in relation to a particular topic or field of science. The stages carried out in preparing a scoping review consist of determining study questions, determining the type of relevant study, selecting studies based on predetermined keywords, collecting data in a chart, and preparing a report on study results in the form of a summary. The format of the scoping review will be based on Arksey's stage framework and the Preferred Reporting Items for Systematic Review Extension for Scoping Review (PRISMA-ScR) guidelines.[19,20]

The research question in this scoping review paper is "What is the potential for color changes in ceramic-based restoration materials after the thermocycling process with/without staining process?" The population chosen is ceramic-based restoration materials. The concept used in this paper is the stability of the color of the restoration material, while the context is the change in color of the restoration material before and after thermocycling treatment and/or staining process as a representation of daily use in oral environment.

A search for literature relevant to the research questions in this scoping review was carried out using the internet. Three source databases were used: PubMed, Wiley Library, and Scopus. The keywords used to search for literature were ("Color Stability" OR "Colour Stability" AND "Ceramic" OR "Lithium Disilicate" OR "Zirconia" AND "Thermocycling"). All articles were in English with full text available related to dentistry and published in the last 5 years (2017-2021). The inclusion and exclusion criteria can be seen in table 1.

The literature search flow can be seen in figure 1. Literature search on PubMed, Wiley Library, and Scopus produced a total of 172 articles, of which 144 articles were obtained from Wiley Library, 16 articles from PubMed, and 12 articles from Scopus. From this, irrelevant articles were filtered based on reading the title and abstract; 130 articles were eliminated based on selection of irrelevant titles and abstracts, leaving 42 articles. After that, there were 11 articles that were duplicated from the three sources; these were also eliminated and thus leaving 31 articles. The remaining literature was then further selected regarding articles that met the inclusion and exclusion criteria that had been set for this scoping review by reading the full text articles. Based on inclusion and exclusion criteria, 19 articles did not meet the inclusion and exclusion criteria. The final results of the screening obtained 12 articles which will be reviewed in this scoping review.

A summary of the literature results used in this paper can be seen in table 2 and table 3. Table 2 presents the demographic

Table 2. Demographic data of the included studies.

Author (year)	Research purpose	Samples	
Palla et al (2017)	To evaluate the color changes in various lithium disilicate material after thermal cycling and immersion in beverages	288 lithium disilicate (A2) specimens with a thickness of 1 mm:	IPS e-max CAD IPS e-max CERAM IPS e-max Press w/ glazing IPS e-max Press w/o glazing
Elter et al (2021)	To evaluate the color stability of various ceramic materials after thermocycling and coffee immersion	80 labial veneers (A2) (thickness 0.2-0.4 mm) from various ceramics cemented on cow teeth (light cure and dual cure cementation):	Lithium Disilicate (CAD) Nano-ceramic Resin Feldspathic Ceramic Leucite-reinforced Feldspathic
Seyidaliyeva et al (2019)	To evaluate the color stability of ceramic hybrids, composites, and lithium disilicate after thermocycling and immersion in various drinks	180 specimens of anterior tooth restoration material (Hybrid ceramic, lithium disilicate, composite resin; A3 HT) with a thickness of 2 mm:	Hybrid Ceramic Lithium Disilicate (CAD) Composite Resin Layered Zirconia
Aljanobi and Al-Sowygh (2020)	To evaluate the effect of thermocycling on the color stability of various ceramic restoration materials	48 specimens of various ceramic restoration material (A2) with a thickness of 1 mm:	Layered High Translucency - Zirconia Lithium Disilicate CAD ZLS
Ashy et al (2021)	To evaluate the color stability of high translucency monolithic zirconia and lithium disilicate materials cemented on premolars after the thermocycling process	40 specimens of 1 mm ceramic restorative material (A1) cemented with light cure or dual-cure resin cemen:	Lithium Disilicate (CAD) Monolithic Zirconia
Haralur et al (2019)	To assess the effect of thermocycling and immersion with drinks and mouthwash on the color stability of monolithic zirconia, bilayered zirconia, and lithium disilicate	90 specimens of ceramic restoration materials with a thickness of 2 mm:	Lithium Disilicate (Press) Monolithic Zirconia Bilayered Zirconia
Cakmak et al (2021)	To evaluate the effect of coffee thermocycling on color stability of zirconia reinforced lithium silicate (ZLS) ceramic	30 specimens of Zirconia-reinforced Lithium Silicate (ZLS) material with a thickness of 0.8 mm and 1.5 mm. Cementation with A2, A3, and Tr auto-cure resin cements	
Yuan et al (2017)	To evaluate the effect of thermocycling on the color stability of CAD-CAM ceramic restoration materials	180 specimens of ceramic-based restoration materials with a thickness of 4 mm and underwent glazing process after fabrication:	Lithium Disilikate (CAD) Zirconia
Aldosari et al (2021)	To evaluate the color stability of ceramic materials that have been thermocycled and immersed in coffee	96 specimens of CAD/CAM restoration materials with a thickness of 2 mm which are subsequently divided into glazed and polished groups:	Hybrid Ceramic ZLS Feldspathic Ceramic
Al Amri et al (2020)	To evaluate and compare the translucency and color stability of hybrid ceramic materials compared to conventional ceramic materials	80 specimens of CAD/CAM materials with a thickness of 1 mm which are polished after fabrication:	Lithium Disilicate Nano-ceramic resin 1 Nano-ceramic resin 2 Hybrid Ceramic Polymer 1 Hybrid Ceramic Polymer 2
Abdalkadeer et al (2020)	To evaluate the effect of Cola drinks and the surface treatment on the color stability of porcelain veneers with different thicknesses	96 ceramic-based material specimens with a thickness of 1 mm and 0.6 mm which are subsequently divided into glazed and polished groups:	Zirconia Lithium Disilicate CAD Lithium Disilicate Press
Al Moaleem et al (2020)	To evaluate and compare the effect of khat on surface roughness and color changes in ceramic-based materials	70 ceramic material specimens with a thickness of 2 mm which are subsequently divided into glazed and polished groups:	Feldspathic Metal Ceramic - (PFM) Feldspathic Ceramic Zirconia

Table 3. Evaluation of color stability of various ceramic materials

Author (year)	Treatment method	Results and summaries
Palla et al (2017)	- Water thermocycling (5-55^{0}C) for 21.900 cycles (simulation of 3 years of use in oral environment) - Immersion of the specimens in coffee, tea, and red wine solutions for 54 hours (simulation 3 years of use) - Color changes were measured based on spectrophotometric color parameters analysis	- IPS CAD showed a color change value (ΔE) < 1 in all - treatment methods - IPS Press material w/ glazing showed a ΔE value > 1 (1.39) after the thermocycling process and a ΔE value < 1 after the immersion process in all drinking solutions - IPS CERAM material shows a ΔE value >1 after thermocycling (1.61) and immersion in coffee (1.31); for immersion in other solutions the value is <1 - IPS Press material w/o glazing showed the highest ΔE >1 after immersion in tea (4.99), wine (1.85) and coffee (1.1) - CAD materials show better color stability
Elter et al (2021)	- Storage of specimens in distilled water (37^{0}C) for 24 hours - Thermocycling for 5.000 cycles (5-55^{0}C) in distilled water with a dwell time of 30 seconds - Immersion of the specimens in 37^{0}C coffee solution for 3 weeks (changed every 2 days) - Color change measurements were based on spectrophotometric color parameters analysis	- All materials showed a ΔE value <3.3 after the thermocycling process - Changes in material color after the thermocycling process and immersion in coffee showed significant differences between groups; nano-ceramic resin (ΔE = 13.67); lithium disilicate (ΔE = 4.2); feldspathic ceramic (ΔE = 5.76); leucite-reinforced feldspathic (ΔE = 3.77). All materials showed ΔE value of > 3.3 (tolerated limit value) - Light cure resin cement shows a lower degree of color change in ceramic materials compared to dual-cure
Seyidaliyeva et al (2019)	- Thermocycling for 10.000 cycles (6.5-60^{0}C) with 45 seconds dwell time - Storage of specimens for 4 weeks (37^{0}C) in a container containing 60 ml of red wine, cola, black tea, curry and water - Post-immersion polishing process for all specimens - Color change measurements were based on spectrophotometric color parameters analysis	- The thermocycling process showed a ΔE value < 0.8 on all materials - The ΔE value at 4 weeks of immersion: hybrid ceramic 4.5; composite resin 5.0; lithium disilicate 3.0 (ΔE>1.8 - tolerated limit value) - Polishing process àThe ΔE value for hybrid ceramic and composite resin >0.8 but <1.8; lithium disilicate showed a ΔE value <0.8 - Red wine caused the highest discoloration of all materials and showed ΔE value >1.8 (hybrid ceramic 11.6; resin composite 13.2; lithium disilicate 5.9) - Lithium disilicate was a material with minimal color changes compared to other materials, including after polishing process
Aljanobi and Al-Sowygh (2020)	- Thermocycling 10.000, 30.000, and 50.000 cycles, simulating 1, 3, and 5 years, respectively (5-55^{0}C and 30 seconds dwell time) - Color change measurements were based on spectrophotometric color parameters analysis	- Lithium disilicate à significantly higher translucency parameters compared to other materials in all thermocycling phases - All materials showed gradual color change as thermocycling time progresses; ZLS was the material with the lowest level of color change, followed by lithium disilicate - Zirconia (conventional and high translucency) à highest color change compared to lithium disilicate and ZLS - All materials, when compared with the established clinical tolerance threshold (ΔE = 3.3), showed color change below this value
Ashy et al (2021)	- Thermocycling for 3.000 cycles (5-50^{0}C and 15 seconds dwell time) - Color change measurements were based on spectrophotometric color parameters analysis	- Zirconia and lithium disilicate à statistically significant color change after thermocycling; The average ΔE value was 3.59, this value was still below the specified tolerance limit value of 3.7 - The color change of lithium disilicate (ΔE 3.67-3.99) was greater than zirconia (ΔE 3.22-3.49) regardless of the type of cement used - The type of resin cement did not affect the color change; however, it was found that the dual-cure cement (b*=5.2) showed a significantly yellower color compared to the light-cure cement (b*=4.2)

Table 3. Evaluation of color stability of various ceramic materials

Author (year)	Treatment method	Results and summaries
Haralur et al (2019)	- Thermocycling for 3.000 cycles in distilled water (5-55^{0}C) - Immersion of the specimens in solutions of tea, coffee (15 grams each in 250 ml of water), and 0.2% chlorhexidine mouthwash for 7 days at an average temperature of 37^{0}C - Color change measurements were based on spectrophotometric color parameters analysis	- Lithium disilicate showed ΔE values of 1.788 (coffee), 2.241 (tea), and 1.588 (chlorhexidine); monolithic zirconia showed ΔE values of 5.602 (coffee), 5.192 (tea), and 4.866 (chlorhexidine); bilayered zirconia showed ΔE values of 4.299 (coffee), 2.191 (tea), and 1.438 (chlorhexidine), respectively - Lithium disilicate color changes were generally lower compared to both type of zirconia materials for all groups especially in coffee immersion group - Bilayered zirconia à color changes were lower on tea and chlorhexidine immersion compared to lithium disilicate, but the difference was not significant - The clinical tolerance limit value of ΔE was set at 3.5 à lithium disilicate was the only material that showed a ΔE value below 3.5 for all immersion groups
Cakmak et al (2021)	- Thermocycling for 5.000 cycles (5-55^{0}C and 30 seconds dwell time) in 1 tablespoon of coffee solution - Color change measurements were based on spectrophotometric color parameters analysis	- The thermocycling process reduced translucency in all ZLS samples (both 0.8 mm and 1.5 mm thickness) regardless of the cements used - A material thickness of 0.8 mm showed a higher degree of translucency than 1.5 mm; This thickness also caused significantly greater color changes although the value was still below the determined tolerance threshold value (ΔE<1.77) - The color of the cement did not significantly affect the final color of the material that has been thermocycled; Cement color mostly affected the color of ZLS before thermocycling at both thicknesses - Regardless of all treatment, color changes in all specimens were still below the tolerance threshold value
Yuan et al (2017)	- Thermocycling for 6.000, 12.000, and 18.000 cycles (5-55^{0}C and 30 second dwell time) in distilled water, simulating 5, 10, and 15 years of use, respectively - Color change measurements were based on spectrophotometric color parameters analysis; surface roughness analysis was carried out using Interferometry Microscopic analysis	- Thermocycling process for 18.000 cycles (simulation of 15 years routine oral use) à significant changes in surface roughness on both materials; however, there was no correlation between roughness and color change - Lithium disilicate showed better color stability than zirconia in all thermocycling cycles - Both lithium disilicate and zirconia showed color change values below the specified clinical tolerance limits (ΔE=2.6) after thermocycling treatment
Aldosari et al (2021)	- Immersion of the specimens in hot coffee solution (30 g, 1 liter of 100^{0}C water) and cold coffee solution. The solutions were changed every day - Thermocycling process on the specimens for 5.000 cycles (5-55^{0}C) for 30 days - Grouping the specimens into glazed and polished groups - Color change measurements were based on spectrophotometric color parameters analysis; surface roughness analysis was carried out using SEM analysis	- Hybrid ceramic showed the highest roughness (0,51) in the glazing group while feldspathic ceramic material showed the highest roughness (0,79) in the polishing group. Overall, the hybrid ceramic (0,59) showed the highest roughness regardless of the surface treatment performed - Hybrid ceramic showed the highest color change (ΔE = 3.07) compared to ZLS (ΔE = 1.96) and feldspathic ceramic (ΔE = 2.65) - The glazing process generally provided a lower level of surface roughness than the polishing process and thus providing lower color change value - The color changes that occurred in the three materials were still below the clinically acceptable color change threshold (ΔE<3.7)
Al Amri et al (2020)	- Phase 1 thermocycling for 5.000 cycles (5-55^{0}C and 30 seconds dwell time) - Immersion of specimens in a coffee solution (15 grams, 250 ml hot water) and distilled water - Phase 2 thermocycling for 5.000 cycles - Color change measurements were based on spectrophotometric color parameters analysis	- Nano-ceramic resin specimens showed the highest translucency among the material specimens, followed by lithium disilicate; hybrid ceramic specimens showed the lowest translucency - Translucency did not show significant changes in all specimens after phase 1 thermocycling except for hybrid ceramic 1 - Hybrid ceramic 2 shows significant changes in translucency after immersion and thermocycling phase 2

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Table 3. Evaluation of color stability of various ceramic materials

Author (year)	Treatment method	Results and summaries
		- The largest color change occurred in the nano-ceramic resin group (1 and 2) after immersion in the coffee solution and thermocycling - Color changes in lithium disilicate were found to be minimal (0.29) compared to nano-ceramic and hybrid ceramic resin materials; nano-ceramic resin showed the greatest color change (2.45)
Abdalkadeer et al (2020)	- Immersion of the specimens in Cola solution for 4 weeks - Thermocycling for 10 cycles every day for 4 weeks (5-55^{0}C, total 400 cycles) - Color change measurements were based on spectrophotometric color parameters analysis	- The specified ΔE tolerance limit value is 4.2 for all samples - ΔE value for specimens with a thickness of 0,6 mm à zirconia glazed (1.79) & polished (4.41), lithium disilicate Press glazed (1.88) & polished (5.3), lithium disilicate CAD glazed (1.62) and polished (4.81) - ΔE value for specimens with a thickness of 1 mm à zirconia glazed (2.39) and polished (4,39), lithium disilicate Press glazed (2.0) and polished (4.7), lithium disilicate CAD glazed (1.55) and polished (4.32) - Materials that underwent the polishing process showed color changes above the specified tolerance limits - Lithium disilicate CAD showed the least color change for both material thicknesses, especially for the glazed group - The color change between the 2 material thicknesses within each material is not significantly different
Al Moaleem et al (2020)	- Immersion of the specimens in khat solution for 30 days - Thermocycling for 100 cycles every day for 30 days (5-55^{0}C, total 3000 cycles) - Color change measurements were based on spectrophotometric color parameters analysis; surface roughness was measured using a profilometer device	- Surface roughness in the polished group (PFM 1,18; feldspathic 1,93; zirconia 2,23) > glazed group (PFM 0,83; feldspathic 1,26; zirconia 1.32) for all materials - Both glazed and polished groups showed that the lowest color change was found in feldspathic materials (0.28 and 0.73) followed by PFM (0.56 and 1.34) and zirconia (1.58 and 2.52) - All materials showed significant changes in surface roughness and color changes after immersion and thermocycling process

data of the articles (name of authors, publication year, research purpose, and samples) while table 3 presents the treatment methods and research results. All research articles used in this scoping review are in vitro studies with a cross-sectional design.

DISCUSSION

The success of fixed prosthodontics treatment depends, in part, on its ability to restore function and aesthetics to the patient. The operator's ability to match the color of the fixed prosthesis to the adjacent teeth is one of the criteria for the success of the treatment in achieving its aesthetic function. Not only that, the color of these restorations, especially for ceramic-based materials such as zirconia and lithium disilicate, is also expected to last as long as possible to maintain optimal aesthetic function.[13] On the basis of this, several studies have tried to evaluate the potential for color change (color stability) on ceramic restoration materials that have been given various treatments such as thermocycling and immersion in several commonly used daily solutions. This scoping review paper aims to summarize and present the results of previous research regarding the color stability of ceramic-based restoration materials that have undergone a thermocycling process with/without immersion in staining solution. A total of 12 articles that had met the inclusion and exclusion criteria were reviewed, all of which are in vitro studies; The literature discussed shows that there are variations in treatment methods for ceramic materials as well as the types of ceramic materials studied.

The thermocycling process is used as a method for simulating the oral condition and its influence on the materials. Oral environment regularly experiences temperature changes and through the thermocycling process, the specimens are exposed to temperatures that have extreme differences which are repeated until a predetermined cycle. It is hoped that through this thermocycling process, thermal stress simulations can be obtained on materials that are aging through daily use in the mouth in a relatively short period.[12] However, until now there is no standard regarding the number of thermocycling cycles, time, and temperature that can be used, although there is general agreement regarding the use of temperatures between 5^{0}C and 55^{0}C which corresponds to fluctuations in oral cavity temperature.[23] All studies apply a thermocycling process with a temperature range between 5^{0}C and 55^{0}C, but there are variations in dwell time and number of cycles performed.

Nine studies evaluate lithium disilicate material, [1,3,6-8,13,21-24] 3 studies used ZLS (zirconia-reinforced lithium silicate) material,[612,21,22] 6 studies used zirconia material (monolithic and layered),[6,7,13,18,21,24] 3 studies used feldspathic ceramic materials,[8,12,18] and 4 studies used polymer-based materials (composite resin, hybrid ceramic, and nano-ceramic resin).[1,8,12,23] In particular, 1 study specifically studied the effect of lithium disilicate processing methods (CAD, CERAM, and Press with/without glazing) on the color stability.[3] All studies applied a thermocycling process to the research samples, but there were variations in the number of cycles carried out, with a range between 400 to 50,000 cycles , and dwell time in the range of 15-45 seconds. It should also be noted that not all studies wrote the dwell time applied to the thermocycling process. In regards to the immersion process, 3 studies did not carry out the immersion process, 8 studies carried out the sample immersion process in coffee, tea, wine, cola, mouthwash or curry solutions, and 1 study carried out immersion process in khat solution. The differences in the 12 articles discussed are factors for consideration related to variations in research results.

For lithium disilicate materials, two studies[3,24] compared the color change in variations of lithium disilicate materials fabrication (CAD, Press, and CERAM) and examined the effect of the glazing process on the color stability of lithium disilicate. Lithium disilicate fabrication from CAD technique shows the lowest level of color change compared to other fabrication types (Press or CERAM) after the thermocycling and coloring process. Lithium disilicate fabricated using the Press technique and did not undergo a glazing process shows the highest level of color change and is declared unacceptable clinically.[3] CAD type lithium disilicate has the best color stability because the material structure is quite stable and does not change easily after going through the thermocycling process. This good structural quality was also confirmed in the study through X-Ray XRD and infrared FTIR analysis. The glazing process aims to provide an additional layer on the surface of the ceramic material, so that the rough surface can become smooth.[3,24,26] This could be the reason why the materials that did not undergo a glazing process show the highest level of color change. Rough surfaces can increase the risk of water penetration which can then dissolve the silica components in lithium disilicate, resulting in decreased crystallinity and increased adsorption of color pigments. Seyidaliyeva et al in their research found that lithium disilicate material still experienced color changes and its potential was higher when immersed in several solutions compared to other materials studied. However, it is estimated that the color change that occurs is an external color change because the polishing process can return the color of the lithium disilicate back to before the solution immersion process was carried out.[1]

Zirconia material was evaluated in 6 studies[6,7,13,18,21,24] and gave varied results, although in general lithium disilicate showed equal or better color stability than monolithic or layered zirconia. The high potential for color change in zirconia material when compared to lithium disilicate is most likely caused by the zirconia crystal density that is not as good as that of lithium disilicate, causing more coloring pigments to penetrate. This occurs due to the low-temperature degradation (LTD) effect that occurs when zirconia is exposed to a wet environment. The LTD phenomenon is known to degrade the zirconia crystal structure from a tetragonal to a monoclinic structure, resulting in an increase in the material wear rate and an increase in surface roughness.[6,18,27] This surface roughness was also confirmed in several studies which found that zirconia materials, either standard or high translucency, has a larger surface particle size and a rougher texture compared to lithium disilicate and ZLS through SEM micrographic analysis.[18,21,28] However, all studies also concluded that the color changes that occur in zirconia materials are still below the clinical tolerance threshold, especially for the glazed materials . The results of these studies are also in accordance with the study by Subasi et al which stated that there was no significant difference in color changes between CAD-CAM monolithic ceramic-based materials after the thermocycling process.[29]

An exception was found in the study by Ashy et al which found that lithium disilicate material showed a greater color change (ΔE) compared to zirconia material in cementation scenarios with resin cement (both light cure and dual cure) although this difference was not statistically significant. However, the same study also noted that the differences in results were likely caused by variations in specimen preparation, simulation methods, and differences in the material composition used in each study.[7] This was also shown in the study by Haralur et al who used various staining solutions to examine potential color change between lithium disilicate, monolithic zirconia, and layered zirconia. Immersion of the materials in tea solution and chlorhexidine mouthwash showed the lowest level of color change in layered zirconia material, but this difference was not significant when compared to lithium disilicate.[13] In their research, Haralur et al used Press type lithium disilicate followed by a glazing process. Based on a study by Palla et al and Abdalkadeer et al, litihium disilicate Press showed greater color changes compared to lithium disilicate CAD and zirconia.[3,24]

Layered zirconia material shows better color stability which is thought to be due to the material's higher resistance to LTD. This higher resistance is reported to be due to having a higher crystal density and smaller crystal size making it more resistant to crystal transformation compared to monolithic zirconia. Not only that, microleakage that occurred due to the thermocycling process are not exposed because the zirconia is protected by the porcelain that coats the material.[13,30]

Polymer-based materials were evaluated in 4 studies.[1,8,12,23] Elter et al, Al Amri et al, and Aldosari et al evaluated nano-ceramic resin and hybrid ceramic materials, while Seyidaliyeva et al evaluated the color change in composite resin and nano-ceramic resin materials. All studies found that polymer-based materials showed the highest levels of color change compared to other materials including lithium disilicate. The results of these studies are also in accordance with previous research by Gawriolek et al which evaluated color changes in composite resin materials. This material's susceptibility to color changes is caused by the internal characteristics of resin-based materials which can experience imperfect polymerization, tend to be more porous, and easily absorb water so that it is easier to capture color pigments over time.[31] Not only that, the surface of the composite resin material also tends to become rougher than ceramic-based materials when the thermocycling process is carried out, so it is easier to catch color pigment particles over time if polishing is not carried out regularly. Routine polishing of resin-based materials is a vital control step to prevent permanent color changes. However, this polishing cannot return the color of the material back to its original color because over time internal discoloration will still occur.[1,32] Hybrid ceramic and nano-ceramic resin materials also did not show promising results due to the physical properties of polymer-based materials that have been described above although it gives slightly better results compared to composite resin; overall nano-ceramic resin showed higher color change but better translucency.[8,23]

Porcelain-based materials were studied in 3 studies.[8,12,18] Elter et al evaluated the color change in feldspathic ceramic and leucite-reinforced feldspathic ceramic and found that leucite-reinforced material provided better color stability when compared to other materials including lithium disilicate although in their study all materials showed color change that was above the clinical tolerance threshold after the thermocycling process and immersion in coffee solution were carried out. Additionally, the difference in color change with lithium disilicate was also found to be insignificant. It was also showed that feldspathic ceramic materials showed significantly greater color changes than leucite-reinforced materials. Most likely this is caused by the surface treatment process carried out on the sample material. Elter carried out a polishing process on all research samples. The polishing process based on a study by Aldosari et al showed greater surface roughness on feldspathic ceramic materials compared to the glazing process. This surface roughness is likely to have an influence on the color stability of the feldspathic ceramic material compared to leucite-reinforced feldspathic material. The addition of leucite components can provide a microstructure with less empty space so that it is more resistant to color changes.[3,8,12] The study by Al Moaleem et al used 2 types of feldspathic ceramic: CAD/CAM feldspathic and low-fusing feldspathic that will be fused to metal coping (PFM). It was found that low-fusing feldspathic showed lower surface roughness and thus better color stability. Al Moaleem et al proposed that this was due to the material having stable surfaces especially compared to zirconia.[18]

The ZLS is a modified material from lithium disilicate which combines zirconia crystals into a silicate glass matrix from lithium disilicate. Adding zirconia crystals aims to improve the mechanical characteristics of lithium disilicate so that it has better physical characteristics without reducing the aesthetic quality provided by lithium disilicate.[22] In this review, a total of 3 studies[12,21,22] used ZLS material to evaluate its color stability. The study of Aldosari et al and the study of Aljanobi and Al-Sowygh showed that the level of color change of the ZLS material was significantly below that of other materials after the thermocycling process including lithium disilicate in the study of Aljanobi and Al-Sowygh. However, it should also be noted that the translucency level of ZLS is still below lithium disilicate. The main composition of ZLS, which is still dominated by lithium disilicate, also helps the resistance of ZLS to discoloration because the material surface is relatively smooth compared to other materials such as zirconia and hybrid ceramic. The glass matrix plays a role in maintaining bonds between the ceramic particles, providing a protection to water infiltration.[12,21] The study by Cakmak et al specifically only examined ZLS material but with different thicknesses. In this study, a thickness of 0,8 mm showed a greater color change compared to a material thickness of 1,5 mm.[22] This result was in accordance with a previous study by Kandil et al which found that ZLS material with a thickness of under 1 mm showed a significant color change after immersion in coffee solution.[33] However, Cakmak et al also concluded that the color change that occurred in ZLS material with a thickness of 0.8 mm after the thermocycling process in coffee solution was still clinically acceptable.[22]

It was also found that several staining solutions, especially drinks, also influence color change parameter in ceramic-based materials. In this review, 9 studies examined the effects of various types of drinks other than water on temporary color changes in ceramic materials, although there were 4 studies[8,12,22,23] that only used coffee solution as the coloring solution. Based on studies by Palla et al, Seyidaliyeva et al, and Haralur et al, it is known that red wine, tea and coffee are the 3 main drinks that can significantly change the color of restoration materials over time.[1,3,13] These results are also in accordance with previous studies which found that these three types of drinks could significantly change the color of ceramic restoration materials. Specifically for red wine, it is estimated that the alcohol content in red wine plays a role in the degradation of the surface of the material, making it easier for water to penetrate and dye particles to enter/stick. Resin-based materials are very susceptible to color changes due to the influence of this alcohol.[8,34,35] Specifically for coffee drinks, which is one of the most favorite drinks in Indonesia above tea,[36] all studies show that coffee drinks can cause significant color changes. on restorative materials, specifically nano-ceramic resins, composite resins, and monolithic zirconia. However, for ceramic materials, a study by Seyidaliyeva et al showed that the discoloration disappeared after polishing the ceramic material. It is very likely that if routine polishing is carried out, the color of the restoration material that has been changed by drinking coffee (and other drinks) can be returned to its original color.[1]

On the other hand, cola solution was evaluated in 2 studies[1,23] and both provided quite contradicting results. Abdalkadeer et al showed that when immersed in cola solution, it would cause a color change in materials that is well above the tolerated threshold value, meanwhile Seyidaliyeva et al showed a relatively minimal change in material color. This is found after comparing the polished group in Abdalkadeer et al study with Seyidaliyeva et al study which only use a polishing process after material fabrication. This difference may be due to variation in color change measurement device or the difference in material thickness used in both studies. However, both studies also agreed that cola immersion may increase the surface roughness of the materials due to its acid content (phosphoric acid) and thus glazing may be more effective in preventing the color change given the fact that glazing process provide smoother surface than polishing process.[12,23] Finally khat was evaluated in one study by Al Moaleem et al.[18] Khat is a plant that regularly used for chewing in some middle-east countries. It is also known that khat may alter the surface of the enamel and thus also may increase the surface roughness of several restorative materials. In their study, Al Moaleem found that khat indeed caused the color change in materials tested, however the changes were found to be lower than that of natural teeth. They also concluded that more studies need to be conducted in order to clarify this finding.

Apart from the type of drink, several factors such as material surface treatment, material thickness, and cement type may also influence the material color changes to some degrees. Surface treatment is known to influence the surface roughness of the material. Studies by Palla et al, Aldosari et al, Al Moaleem et al, and Abdalkadeer et al found that materials subjected to the glazing process showed minimal surface roughness and thus also showed minimal levels of color change.[3,12,18,24]

For the material thickness, regardless of the translucency parameter, the material with a higher thickness will indicate a more minimal degree of discoloration. However, the thickness of the material will also affect the level of translucency and clinically this has the consequence of removing more tooth tissue.[22] Despite the results, it was also found that the color change was not significantly different between two different material thickness.[22,24]

Cement type independently does not significantly influence material color changes based on 2 studies[7,8]; material color changes are mostly influenced influenced by the physical characteristics of the material, the roughness of the material surface, and the type of staining solution exposed to the material. However, both studies also noted that light cure type cement was slightly better in terms of color stability compared to dual cure cement; specimens cemented with dual cure cement showed yellower color parameters after the thermocycling process. These results are also in accordance with several previous studies which found that dual cure cement showed greater discoloration. It is very likely that the effect of the amine accelerator content undergoing oxidation plays a role in this yellow color change.[37,38]

There are several limitations to this scoping review. The details of the thermocycling process, especially the number of cycles used and their daily use equivalence, still vary. Apart from that, not all of them use the same staining solution so they may give different research results. Also, several specimen details such as the thickness of the material and the brand of material used vary quite widely between the studies examined in this review. This could influence the results of research related to changes in material color. The existence of these factors in the literature reviewed in this scoping review could potentially cause confusion in the results of the study. Several variables such as cement type and material thickness were only evaluated in 2 studies each, so definite conclusions cannot be drawn regarding the influence of these variables on the color stability of ceramic-based restoration materials. In addition, all of the studies are in vitro studies, most of which are cross-sectional studies. The results of the studies discussed in this scoping review cannot necessarily be fully applied to clinical conditions in patients, considering that there are many variables that have not been precisely measured in this study, such as the number of drinks consumed, oral health conditions, material exposure to the oral environment, and others.

CONCLUSION AND SUGGESTION

Based on the 12 studies reviewed in this paper in relation to the evaluation of the potential for color changes (color stability) of ceramic-based restoration materials that have undergone a thermocycling process with/without additional staining processes, it can be concluded that: Lithium disilicate-based materials (including ZLS) generally have better color stability (lower potential for color change) compared to other ceramic materials (zirconia and feldspathic) and polymer-based materials (including hybrid ceramic); The thermocycling process causes an increase in the surface roughness of the material, changes in the crystal structure of the ceramic, and changes in the translucency of the material, causing statistically significant color changes among the materials studied, however, the changes are still within the tolerable clinical limits; Wine, tea, and coffee may cause significant discoloration of ceramic materials, significantly higher than other type of drinks; Glazing process on the ceramic surface may significantly lower color change potential compared to the polishing process; The surface roughness of lithium disilicate-based materials is lower compared to other restoration materials reviewed in this paper; The thickness of the restoration may influence the discoloration; restorations with a thickness of more than 1 mm show relatively minimal discoloration on ceramic materials with high translucency; The use of light-cured resin cement shows slightly less color changes compared to dual-cured resin cement; dual-cure cement shows a yellower color, although this difference is not statistically significant.

Considering the limitations of this scoping review, it is suggested that further investigations are needed in regards to the effect of material thickness and type of resin cement to the ceramic color changes. Also, more studies from more databases may be collected so a uniform data may be collected and thus more robust conclusion can be pulled.

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