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Influence of different luting agents and associated factors on the color of ceramic laminate veneers: A systematic review

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Abstract

The luting agent plays a significant role in the appearance of ceramic laminate veneers (CLV), allowing improved/stable shade matching with adjacent teeth. A systematic review was conducted to investigate the influence of light-cured & dual cured luting agent and color stability of ceramic veneers & associated factors aiming to draw guidelines for stable shade matching of CLV.A search of *in vitro* studies that investigated the influence of light-cured & dual cured luting agents on the color of CLV was conducted. PubMed/MedLine, EBSCO, Google scholar and Web of Science databases were explored until February 2020 with no year limit. Data regarding the effect of light-cured & dual cured luting agent, ceramic systems & effect of accelerated aging on color change were collected. After duplicates' removal, 1278 studies were identified, 42 were selected for full-text analysis, and 10 remaining papers met the inclusion criteria and were included in this systematic review. The effect of luting agent & its shade on the color of veneers is greatly affected by ceramic thickness and opacity. The dual-polymerizing cement had higher color variation than the light-polymerized materials when used for bonding ceramic veneers to enamel.

Keywords: Ceramic veneers, Luting agent,bonding agents, Spectrophotometry, Flowable composites, Accelerated aging, Light cured cement, Dual cured cement, Esthetics, spectrophotometer.

Introduction

Ceramic laminate veneers are the most desired cosmetic treatments because they present the possibility of lighter teeth, preparation with minimal wear, the ability to change shape, and improved aesthetics.[1] Currently, there is a wide variety of dental ceramics available for indirect restorations that can be used for the manufacture of thin laminate veneers, including conventional sintered or machined feldspathic ceramics, heat-pressed or machined glass ceramics, and some resin-matrix ceramics, such as resin nano ceramics (e.g., Lava Ultimate) and glass-ceramic in a resin interpenetrating matrix (e.g., Vita Enamic).[2&3]

Laminate veneers have long been the ultimate esthetic treatment for anterior teeth.[4] Due to improvements in bonding systems and resin cements, more long-lasting, reliable results are expected.[5] These treatments can provide patients with satisfying dental restorations. Unfortunately, the long-term success of porcelain laminates is tied to the color stability of resin composites used to lute them. Resins with different polymerization methods are available for luting indirect esthetic restorations, each having specific advantages and disadvantages.

Thin & translucent ceramic laminate veneers have their final aesthetic appearance markedly influenced by light reflection, transmittance, and scattering within and through the restoration.[6&7] Therefore, determining factors for shade of restorations include: restorative material, underlying dental structure, and shade and composition of the resin-based luting agent.[8,9,10]

The luting agent & its shade is known to play a significant role in the final appearance of CLVs. Luting agent, its' thickness, composition and shade of the ceramic system and the aging of these restorations , have been investigated in several *in vitro* studies to affect the color of CLVs.[11&12]

It is important to note that the influence of different shades of dual-cured and light-cured cements underlying ceramic restorations and their long-term discoloration is little known. Also, this discoloration becomes much more important beneath thin-translucent ceramic veneers. Because there are few studies on the long-term (more than one year) color stability of cemented thin ceramic veneers with resin cements having various shades and curing modes. The objective of this study was to evaluate the color stability of cemented thin ceramic laminate veneers as a function of the curing mode and shade of resin cements, effect of accelerated aging and ceramic systems.

Material and Methods

Eligibility criteria

Inclusion criteria

- Articles published in English literature
- *In vitro* essays that quantitatively evaluated the color of CLVs with respect to influence of light-cured & dual cured luting agents and other color-associated

factors, such as the ceramic thickness, shade and type, as well as the influence of the substrate and aging.

Exclusion criteria

- Studies that evaluated crowns rather than CLVs.
- Did not use light-cured &/or dual cured resin luting agents.
- Color evaluated using qualitative scales (e.g. Vita Classical) rather than quantitative systems.
- Articles published in languages other than English.
- Case reports & series of cases and other clinical studies were excluded.

The following PICOT format was used: (i) Population: ceramic laminate veneers (ii) Intervention: 'cementation' with light-cured & dual cured resin-based luting agents (iii) Comparison: light & dual cured resin luting agents and other color-associated factors (iv) Outcomes: color of CLVs (v) Type of study: *in vitro* experiments. The research question was: How light cured & dual cured resin luting agents and color-associated factors affect the aesthetic appearance of CLVs?

Search strategy: The MEDLINE (PubMed), Google Scholar, Web of science and EBSCO search were conducted with the purpose of identifying all articles that investigate the influence of luting cements on aesthetic outcome of CLV_s.

The following MeSH terms, search terms, and their combinations were used:

Ceramic veneers, Luting agent,bonding agents, Spectrophotometry, Flowable composites, Accelerated aging, Light cured cement, Dual cured cement, Esthetics, spectrophotometer.

Study selection, data extraction & data analysis: Titles and abstracts of all studies identified by the search strategy were screened independently by two reviewers. Studies that seemingly met the eligibility criteria and those classified as unclear by title and abstract readings were selected for full-text assessment. After reading full papers, only those that fulfilled all the eligibility criteria and surpass the exclusion criteria were included in this systematic review and processed for data extraction, while reasons for exclusion were recorded. In each search step, two reviewers compared their list of papers; in case of disagreement, final decision on inclusion or exclusion was made following discussion and consensus with a third researcher. The study design, type and shade of luting agents, ceramic material and its shade and thickness, color measurements, type and shade of background described in the papers were recorded. Due to variability of data findings meta analysis was not possible. Results were grouped into three categories for evaluation: (1) luting agent, (2) effect of accelerated aging, and (3) ceramic systems.

Results

Among 1273 potentially relevant records, 173 records were selected for abstract reviews amongst them 15 were selected for the full text analysis and after thorough evaluation 10 were selected in the systematic review. (Fig. 1). All the 10 eligible studies were in vitro studies which had compared different luting cements. The extracted data from included studies are presented in Table 1.

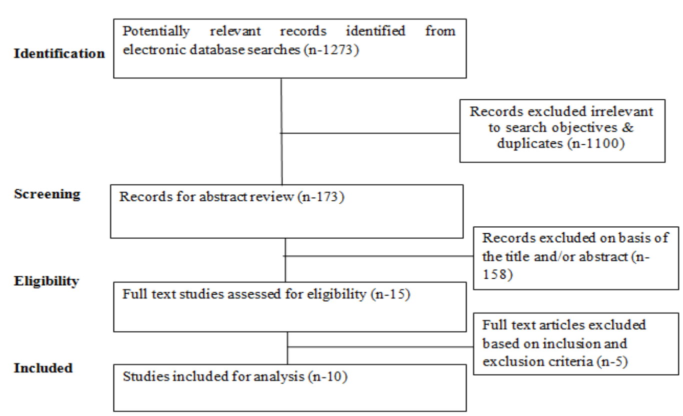

Fig.1: Flowchart of the systematic review according to PRISMA Statement

Table 1: summary of all included studies

Sr No.	Authors	Year	Factors affecting the veneer shade	Ceramic systems (Shades)	Luting agents (Brand names)	Methods of evaluation	Main conclusions
1.	Elgergawim et al.[13]	2019	Luting agents, veneer thickness and accelerated aging	IPS e.max Press (A2) IPS e.max CAD (n.i)	Light cured cement(n.i) Dual cured cement (n.i)	Initial color readouts & spectrophotometer	The conventional dual and light-cured cements presented greater color change when used for bonding thinner veneers, with statistically significant difference ($p < 0.05$) in comparison with the 0.8 mm thick veneer. The discoloration observed after the ageing process was within a

							clinically acceptable level and could not be detected visually.
2.	Pissaia et al.[14]	2019	Luting agents and shade of the luting agents	Vitablocs Mark II (2M1)	NX3 Light-cured NX3 Dual-cured Allcem light cured Allcem light cured	Spectrophotometer	This study demonstrated that light-cured resin cements were less susceptible to color change than dual-cured cements. After 2 years of follow-up, all cements presented ΔEab values above the acceptability threshold.
3.	Tabatabaei et al.[15]	2019	Luting agents and accelerated aging	IPS e.max press (A2)	Relyx U200 Choice 2	Spectrophotometer	The self-adhesive dual-cure cement showed color stability comparable to

							that of the total-etch light-cure cement for cementation of IPS e.max ceramic laminates.
4.	Haralur et al.[16]	2017	Luting agents and accelerated aging	IPS Empress Esthetic (ETC1)	Variolink Veneer Rely X ARC Panavia F 20 Rely X unicement	Spectrophotometer	light cure luting cements were found to be less susceptible for colour changes under accelerated aging.
5.	Almeida et al.[17]	2015	Luting agents and accelerated aging	Super Porcelain EX-3 (Incisal E1)	RelyX Veneer Filtek Z350 Flow Filtek Z350 XT Relyx ARC	Spectrophotometer	The dual-polymerizing cement had higher color variation than the light-polymerized materials when used for bonding ceramic

							veneers to enamel. Flowable and preheated composite resins had similar color stability to that of light-polymerizing resin-based cement.
6.	Magalhaes et al.[18]	2014	Accelerated aging and color difference calculation	IPS Empress Esthetic (ET1)	Variolink II base paste	Spectrophotometer	No relevant differences were found between the two activation modes in color change. When submitted to aging, dual- and light-cured modes of the resin cement showed visually perceptible (ΔE* > 1.0)

							color changes; however, within the threshold of clinical acceptance (ΔE* > 3.3).
7.	Turgut et al.[19]	2013	Ceramic shade, veneer thickness, luting agent & shade of the luting agent	IPS e.max Press (A1, A3, HO, HT)	RelyX Veneer Maxcem elite Variolink II	colorimeter	The results indicated that the color of porcelain disks changed significantly after cementation Most of the color changes appeared after cementation. The smallest color change was obtained from light cured luting cement.
8.	Kilinc et al.[20]	2011	Luting agents and accelerated	IPS Empress Esthetic (ETC1)	Nexus2 Appeal	Spectrophotometer	Light-cure groups showed better color

			aging		Calibra		stability in all three resins but only in Appeal resin cement, the dual-cure group discoloured significantly more ($p<0.001$). More discoloration was recorded on uncovered cement groups that represented the exposed cement at the margins. There was no visible color change ($\Delta E>3$) through the ceramic surface on any veneered group.

9.	Turgut et al.[21]	2011	Type of ceramic, veneer thickness, and surface treatments	IPS Empress Esthetic (A1, A3, EO, ET)	RelyX Veneer Variolink Veneer Maxcem elite	Colorimeter (Shade Eye Ex, Shofu, Japan)	There is no significant difference on the colour change of dual or light cured resin cements, which were polymerized beneath the porcelain substructure with 0.5mm thickness. Cementation of laminates with either dual or light-cure resin cements does not effect the long term colour stability differently.
10.	Ghavam et al.[22]	2010	Luting agents and accelerated aging	Ceramco (A3)	Variolink Veneer Variolink II base paste	Spectrophotometer	None of the groups showed significant differences in

							ΔE before and after aging (p>.05).ΔE remained in the range of clinical acceptance.

*ni-not informed

Table 2: luting agents evaluated in the included studies

Sr no.	Luting agent	manufacturer	Classification (curing method)	Composition
1.	Allcem	FGM	Dual cured cement	TEGDMA,BisEMA,BisGMA,camphoroquinone,barium-aluminum-silicate microglass,silica nanoparticles.
2.	Allcem	FGM	Light cured cement	Methacrylate monomers, camphorquinone, co-initiators, stabilizers, pigments, silanized barium-aluminosilicate glass particles, and silicon dioxide
3.	Appeal	Ivoclar Vivadent	Light cured cement	Urethane dimethacrylate, decandiol dimethacrylate
4.	Appeal	Ivoclar Vivadent	Dual cured cement	Urethane dimethacrylate and decandiol dimethacrylate
5.	Calibra	Dentsply	Light cured cement	Bisphenol-A-glycidyl dimethacrylate, other polymerizable dimethacrylates, bariumboron fluoroalumino silicate glass, hydrophobic amorphous fumed silica, titanium dioxide, dl-camphorquinone
6.	Calibra	Dentsply	Dual cured cement	Dimethacrylate resins
7.	Choice 2	BISCO	Light cured cement	BIS-GMA,amorphous silica, strontium glass.
8.	Filtek Z350	3M ESPE	Light cured flowable composite	Bisphenol-A-glycidyl

	flow		resin	dimethacrylate, triethyleneglycol dimethacrylate, 6-ethoxylated bisphenol-A dimethacrylate, dimethacrylate functionalized polymer, silanized ceramic silica/zirconia particles
9.	Filtek Z350 XT	3M ESPE	Light cured preheated resin	Diurethane dimethacrylate, 6-ethoxylated bisphenol-A dimethacrylate, bisphenol-A-glycidyl dimethacrylate, polyethylene glycol dimethacrylate, triethyleneglycol dimethacrylate, hydroxybutyl toluene, silanized ceramic silica/zirconia particles
10.	Maxcem elite	Kerr	Dual cured cement	GPDM & co monomers, minerals, ytterbium fluoride
11.	Nexus2	Kerr	Light cured cement	Bisphenol-A-glycidyl dimethacrylate, other dimethacrylates
12.	Nexus2	Kerr	Dual cured cement	Bis-GMA and dimethacrylate
13.	NX3 cement	Kerr	Light cured cement	Uncured methacrylate ester monomers, inert mineral fillers, free tertiary amines, benzoyl peroxide, stabilizers, radiopaque agent, glycerine, water, fumed silica, and inert glass powder.
14.	NX3 cement	Kerr	Dual cured cement	Uncured methacrylate ester monomers, HEMA, PTU, CHPO, free tertiary amines and benzoyl peroxide, inert mineral fillers, titanium dioxide, radiopaque agent, and pigments
15.	Panavia F20	Kuraray Medical Inc	Light cured cement (self- etch)	10-MDP,BPEDMA,hydrophobic & hydrophilic methacylate,silanated silica,silanated barium glass, sodium fluoride.
16.	RelyX	3M ESPE	Dual cured cement	Bis-GMA,TEGDMA,silane treated

	ARC			silica, functionalized dimethacrylate polymer, 2-benzotriazed 4-methylphenol,4-benzeethanol,benzoyl peroxide.
	RelyX ARC	3M ESPE	Light cured cement	dimethacrylate functionalized polymer, triphenyl antimony, Silanized ceramic and silica particles
17.	RelyX veneer	3M ESPE	Light cured cement	Bisphenol-A-glycidyl dimethacrylate, triethyleneglycol dimethacrylate, zirconia/silica filler
18.	RelyX unicement	3M ESPE	Light cured cement (self-adhesive)	Methacrylated phosphoric acid esters, triethylene glycol dimethacylate,silanized glass powder,silica,sodium persulfate,calcium hydroxide,substituted pyrimidine.
19.	RelyX U200	3M ESPE	Dual cured cement	2-methyl1,1'-1,2-ester dimethaacrylate,TEGDMA,dimethacrylate ,1,12 dodocane dimethacrylate
20.	Variolink II (base)	Ivoclar Vivadent	light cured cement	Bisphenol-A-glycidyl dimethacrylate, urethane dimethacrylate, triethyleneglycol dimethacrylate, ytterbium trifluoride, barium glass, barium aluminum fluorosilicate glass, spheroid mixed oxide, catalysts, stabilizers, pigments
21.	Variolink II	Ivoclar Vivadent	Dual cured cement	BIS-GMA,TEGDMA,UDMA,triethylene glycol dimethacylate.
22.	Variolink veneer	Ivoclar Vivadent	Light cured cement	Urethane dimethacrylate, triethyleneglycol dimethacrylate, silicon dioxide, ytterbium trifluoride, initiators, stabilizers, pigments

Information in this table is from manufacturers' published documents or from published papers.

Table 3: Ceramic systems evaluated in the included studies

Sr no.	Ceramic systems	Manufacturer	classification	Description of ceramic
1.	Ceramco	Dentsply, York, PA, USA	Slip cast	Feldspathic ceramic
2.	IPS e.max CAD	Ivoclar Vivadent, Schaan, Liechtenstein	CAD/CAM	Lithium disilicate glass-ceramic
3.	IPS e.max Press	Ivoclar Vivadent	Pressable	Lithium disilicate glass-ceramic
4.	IPS Empress Esthetic	Ivoclar Vivadent	Pressable	Leucite-based glass-ceramic
5.	Super Porcelain EX-3	Kuraray Noritake Dental Inc, Tokyo, Japan	Slip cast	Porcelain
6.	Vitablocks Mark II	Vita Zahnfabrik	CAD/CAM	Feldspathic ceramic

Information in this table is from manufacturers' published documents or from published papers.

Discussion

This systematic review investigated the influence of light-cured luting agents and color-associated factors on the color of CLVs. Findings were discussed in three categories as follows :(1) luting agent, (2) effect of accelerated aging and(3) ceramics system.

Luting agents

The luting agents produced clinically perceptible color changes on the CLVs.[11] Twenty two light-cured luting agents (Table 1) were evaluated in the included studies, which were divided into two types: light cured resin cements & dual cured resin cements. These materials have compositional differences, which influence their optical properties.[23&24] However; manufacturers disclosed only limited information about proportion of monomers and filler particles and did not describe type and concentration of silane, pigments, opacifiers, and polymerization promoters. Thus, it is unlikely that the optical performance of a commercial luting agent can be predicted based solely on the available compositional information.

Among the included studies, several factors affecting color measurements were identified. Particularly the presence, type, and color of the substrate used for cementation, and the color readings used to calculate ΔE. The effect of luting agent shade can be investigated by calculating color difference (Δ E) between color of [veneer + substrate] and color of [veneer + luting agent + substrate].[10]

A compilation of these data is presented in Table 1. Some authors concluded that light cured luting agent has good color stability .[14,16,17,19,20,22] In contrast to that other studies concluded that there is no significant difference between light cured and dual cured luting agents.[13,15,18,21]

The magnitude of color change with translucent & shaded dental luting agents was regarded to the type of luting agent, thickness of ceramic veneers rather than individual shade of luting agents. Here all the included white opaque cements yielded significant color variation due to different composition of luting agents & brand of luting agents.

Pissaia *et al*.[14] compared different resin cements & concluded that color stability of the light-cured cements remained for longer periods of time below the 50:50% acceptability threshold of 2.66 when compared to the dual-cured cements. The difference in color stability between the cements may be associated with the chemical composition of the materials. The higher ΔEab values for the dual-cured cements can be attributed to the presence of tertiary aromatic amines and benzoyl peroxide as an initiator system. The degradation of the residual amines and the oxidation of unreacted carbon double bonds in the polymerization reaction tend to darken the cements over time. The light-cured cements have aliphatic amines in their chemical composition, which makes them less susceptible to color change.

Haralur *et al.*[16] and **Almeida *et al.***[17] concluded that the dual cure resins have more ageing induced colour changes in comparison to light cure resins. The increased colour changes can be attributed to multiple factors like degradation of residual amines, and oxidation of remaining unreacted carbon double bonds. These structural changes in the cement lead to the formation of yellow compound.

Turgut *et al.*[19] and **kilinc *et al*.**[20] stated that dual cured luting agent have more colour changes in compared to light cured luting agents. The reason behind these color changes have been listed as: 1) composition of luting agents 2) thickness of ceramic veneers. Despite the composition of the luting cements they stated that thinner ceramic veneer have more color changes.

Ghavam *et al.*[22] concluded that light cured luting agent have more color stability than the dual cured resin & reason for more color changes in dual cured luting cement was same as described by **Pissaia *et al***.[14]

In contrast to above results **Elgergawi *et al.***[13]**&** ***Tabatabaei et al.*** [15]stated that there is no significant difference in light & dual cured luting agents. Elgergawi said that ceramic is color stable but can't mask the color changes behind the thin translucent ceramic veneers.

Magalhaes *et al.*[18] concluded that there were no differences in any coordinates between the curing modes of the cement tested, except from the a* coordinate: the light-cured mode showed a tendency to red shades, with a higher a* value. A probable explanation for this is the more efficient polymerization reaction in the dual cured cement, as it relies on two processes: the dual-cured and the light-cured. That might enhance the degree of cure in these cements when compared to the light-cured ones, with fewer unreacted components and a more steady color.

Turgut *et al.*[21] stated that resin cements and ageing process influence the color of porcelain laminate veneers. Cementation of laminates with either dual or light-cure resin cements does not effect the long term color stability differently.

So, as the majority of studies suggest the light cured luting agent is more color stable compared to dual cured luting agent. The reason behind these is composition of light cured luting agent. The light-cured luting agents have aliphatic amines in their chemical composition, which makes them less susceptible to color change.

Effect of accelerated aging

The resulting color of CLVs after cementation is important for shade matching whereas color stability is more important for the long-term aesthetic results. Among the included studies, six have investigated discoloration of the luting agents caused by aging, using thermal cycling and/or weathering simulation, exposing the samples to temperature, humidity and light . These studies showed discoloration after accelerated aging for all materials evaluated. The magnitude of color changes was significantly different amongst the studies.

Four studies [16, 20-22] detected discoloration within the AT (acceptability threshold $\Delta E<2.7$)[25] or even below PT (perceptibility threshold $\Delta E<1.2$)[25] , in contrast to that two studies [17&18 that] detected discoloration above AT.

The discoloration of resin-based materials has been associated with the hydrolytic degradation of organic components, as well as oxidation of unreacted polymerization promoters. In addition, the elution of unreacted and oxidized components should be taken into account as cause of changes in the optical properties with time. Therefore, the surface area of luting agent exposed to the aging conditions can affect the dynamics of elution and degradation of components, consequently affecting the magnitude of color change. For these reasons, only a thin luting agent line sandwiched between veneer and substrate should be exposed to aging, in order to better simulate the clinical exposure of CLVs in the mouth.

Ceramic system

The ceramic systems used to fabricate the CLVs in the included studies are listed in Table 3. The materials can be grouped in four main composition classes: leucite-based glass ceramics, lithium disilicate glass-ceramics, fluorapatite glass-ceramics and finally, a broader class of materials commonly called 'dental porcelains'. Three processing techniques have been applied to obtain the CLVs: slip casting, heat pressing, and CAD/CAM. Both the ceramic composition and the processing technique have influences in the material microstructure and its properties.[26]

The esthetic appearance of CLVs is greatly influenced by the ceramic translucency, which is associated with its composition, microstructure, and thickness.

Here from the included studies, two studies by **Turgut** [19&21]investigated CLVs produced with different ceramic shades. The first study [21] indicated that the shade of the ceramic seems to play a role on the magnitude of the discoloration measured for cemented CLVs after aging. When a translucent ceramic (HT) or a light chroma ceramic (A1) were used, greater discoloration of the cement was observed with time in comparison to opaque (HO) and dark chroma (A3) ceramics. The following study[19] confirmed that the ceramic chroma, hue, and value have significant influences on the final color of the CLVs.

Distinct processing techniques can yield microstructural differences within the same ceramic composition. A classic example is lithium disilicate processed by heat-pressing or CAD/CAM techniques, the latter resulting in smaller crystals randomly oriented.

Conclusions

Within the limitation of this systematic review, following conclusions were drawn:

1) The dual polymerizing cements have higher color variation than light polymerizing cement.

2) Effect of accelerated aging on laminate veneer is within the Acceptability threshold.

3) When a translucent ceramic or a light chromatic ceramic are used, great discoloration of the cement observed with time in comparison to opaque and dark chroma ceramics.

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