International Journal of Chemical and Biochemical Sciences
(ISSN 2226-9614)

Journal Home page: www.iscientific.org/Journal.html

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A Review of Key Factors Impacting the Polymerization Efficiency of Resin-Based Cements

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Abstract

To attain the correct polymerization of the resin cements, which results in improved physical qualities of the cement, dentists primarily utilize dual-cured or light-cured resin cements. However, a number of factors can influence how resin cements polymerize. A scoping review of the polymerization, degree of conversion (DC), and light transmittance of various resin cements used in dentistry was the primary goal of the current study. Nevertheless, thick restorations and deep preparations may reduce light intensity, leading to insufficient polymerization. The luting resin polymerization and its study are also influenced by other elements such as the kind, composition, and shade of the resin cement; the type, shade, and translucency of the ceramic; the light curing unit (LCU); and the testing technique. The mechanical and biological qualities of the luting cement, the mechanical properties of bound ceramics, and the strength of the bond between the tooth and restoration could all be negatively impacted by inadequate polymerization. Thus, several light-curing characteristics, including sufficient light distance, irradiance, exposure time, equipment, and wavelength, should be taken into consideration when optimizing the polymerization of resin cements. After that, the cemented restorative materials' ideal physical characteristics are attained, resulting in long-term clinical performance.

Keywords: Ceramic thickness, Degree of conversion, Resin cements, Polymerization, FTIR

Full length article **Corresponding Author*, e-mail: fekrialhagpy@gmail.com, Doi # https://doi.org/10.62877/28-IJCBS-25-27-21-28

Submitted:13-08-2025; Accepted: 01-09-2025; Published: 02-09-2025

1. Introduction

The need for ceramic indirect restorations in routine dental treatment has grown significantly over the past 20 years, mostly as a result of patients' increasing emphasis on esthetics, but also because some people have experienced hypersensitivity responses to dental alloys. The effectiveness of esthetic restorations in this situation depends on establishing a strong and long-lasting adhesive bond between the indirect restoration and the tooth structure [1]. Resin cements offer superior mechanical and optical qualities in addition to a robust and long-lasting adhesive contact between the tooth and the restoration. Because of this, resin cements are essential for cementing ceramic restorations [2-3]. Resin cements with superior physical properties are essential for mechanical properties of restorative interface, allowing it to withstand higher masticatory forces and demonstrate improved clinical performance [4]. Restoration debonding could take place due to a number of reasons. One of them is result of inadequate polymerization brought on by resin cement's solubility and matrix degradation, which in increasing the risk of fracture at the restorative interface in addition to dimension instability and color change [5].

The DC of monomers in the organic matrix of resin cements is significantly impacted by transmitted light irradiance [6]. In terms of polymerization, resin cements come in three different types: dual curing, self-curing, and light curing [1]. Clinical professionals frequently utilize self-adhesive dual-cured resin cements, which are the most widely accessible commercial resin cements. In particular, dual-cured resin cements are the most widely used materials as it depends on both chemical polymerization and light curing under light-curing activation [4]. The organic matrix that makes up resin cements aggregates scattered inorganic fillers. Triethylene glycol dimethacrylate (TEGDMA), urethane dimethacrylate (UDMA), and bisphenol A-glycidyl dimethacrylate (Bis-GMA) are frequently found in the organic matrix. Barium fluoroaluminoborosilicate (FAS), strontium calcium aluminosilicate glass, quartz, amorphous silica, ytterbium fluoride, zirconia, and other glass fillers are combinations of inorganic fillers. In commercial resin cements, the percentage of inorganic fillers ranges from 60 to 75 weight percent [6]. The type, thickness, refractive index, and shade of indirect ceramic restorations can all have an impact on resin cement polymerization (Figs. 1-4) [7].

The thickness and translucency of the restorative material affect how much light passes through to the resin cement in an indirect restoration, which in turn affects the DC percentage of resin cements. When the thickness of the ceramic material exceeds 1 mm, the light irradiance during the light curing process decreases [6]. Furthermore, it is debatably known that the degree of resin polymerization can be controlled by the type of light source, its intensity, and exposure duration [8-9]. Since light irradiance drops with increasing restoration thickness and shadow, the light-curing mode and light intensity of light-curing units (LCU) also affect the polymerization process [5]. It has been

demonstrated that ceramics have a propensity to absorb light, and therefore thicker ceramic restorations >2 mm take longer to cure [9]. Hence, one of the most important factors in preventing clinical failures of indirect restorations is proper polymerization of resin cements. A comprehensive evaluation of major variables influencing polymerization efficiency of resin-based cements, such as the degree of monomer conversion, polymerization mechanism, light irradiance, and light transmittance through various resin cements used in dentistry, was the primary goal of this work to enhance its understanding and avoid common complications [12].

2. Resin cements polymerization degree

The majority of polymers exhibit free-radical polymerization. Organic monomers are transformed into a crosslinked polymer structure in resin-luting materials used in dentistry [1]. A number of variables affect resin cement polymerization. The most important of them are the type and proportion of filler particles, the type of organic resin matrix, the kind and concentration of the polymerization initiator, the light intensity released, and the exposure duration [10-11]. The monomer conversion degree, is inversely proportional to the distance from the polymerization light source, and is directly correlated with the exposure duration [12]. Furthermore, special activators or initiators like sodium sulphate because different initiator systems favor different kinds of polymerization reactions and the presence of acid monomers in the composition of self-polymerizing cement lowers the polymerization efficiency [13]. Thus, is crucial to understand oxygen's inhibitory effect because it can also slow down the polymerization reaction [1]. The degree of conversion (DC), is defined in the literature as the proportion of double carbon C=C bonds of the monomer that change into single C=C bonds of the polymer which is determined by dividing the ratio of double C=C bonds in the polymerized and unpolymerized material by the following equation.

$$DC = (R - polymerized/R - unpolymerized)\ X\ 100$$

Where R is ratio of peak areas at 1638 cm^{-1} and 1608 cm^{-1} in polymerized and unpolymerized material, and DC is polymerization efficiency or degree of monomer conversion (in percentage) [14]. The signal at 1638 cm^{-1} is attributed to aliphatic C=C bonds in the polymerized and unpolymerized material, while the peak at 1608 cm^{-1} is attributed to aromatic C=C bonds in the unpolymerized material. The peak at 1608 cm^{-1} is used as an internal standard to determine the degree of monomer conversion because the aromatic C=C bonds do not change during the polymerization procedure [15]. All monomer molecules should theoretically transform into polymers throughout the polymerization process. However, 80.34% has been recorded for self-polymerizing materials, a specific percentage of unreacted double C=C bonds remain in the polymer, similar to dimethacrylate monomers, and the polymerization efficiency varies between 55% and 75% [1]. While, the dual-polymerizing cement's polymerization efficiency is about 73. 58% [15]. The primary factors influencing the monomer's mechanical performance and leaching potential in clinical settings are its chemical structure, the extent of monomer conversion, and the polymerization reaction's kinetics [1]. These factors play a significant role in determining the physicomechanical strength of the resin cements [28].

3. Factors impacting the polymerization efficiency of resin- cements

3.1. Factors related to resin-based cements

3.1.1. Composition of resin cement

Since resin-matrix composites are made of an organic matrix strengthened with silanated inorganic fillers, their chemical composition is fairly similar to that of resin cements [16]. High molecular weight monomers Bis-GMA, UDMA, TEGDMA, & hydroxyl ethyl methacrylate (HEMA) are present in majority of resin-based cements. Aaddition of inorganic particles to resin-based materials is restricted by Bis-GMA's high viscosity and high molecular weight [17]. Resin cements exhibit a significant degree of variation in size (0.5 to 8.1 micrometers), form (spherical and irregularly shaped particles), and content (57 to 78 weight percent) of inorganic filler particles [1-6]. Most common inorganic particles employed as fillers are colloidal silica, ytterbium, or barium glass. Nevertheless, various filler combinations have also employed, including quartz, strontium-calcium-aluminosilicate glass fluoroaluminoborosilicate glass, and other glass fillers [6]. Improved mechanical characteristics are caused by the inorganic filler content, even though resin cements typically contain less filler than resin composites [1]. UDMA and TEGDMA are frequently used as basic monomers in self-adhesive resin-based cements. The amount of TEGDMA determines the degree of conversion of resin-based cements that contain Bis-GMA; higher the proportion of TEGDMA, the better the conversion degree is because of the molecules' increased mobility and reactivity [18].

Acid-functionalized monomers, such as 4-methacryloyloxyethyl trimellitic anhydride (4-META) or phosphoric acid groups, like 10-methacryloyloxydo-decyl dihydrogen phosphate (MDP), 2-methacryloxyethyl phenyl hydrogen phosphate (Phenyl-P), bis(2-methacryloxyethyl) acid phosphate (BMP), and dipentaerythritol pentaacrylate monophosphate (Penta-P), are also found in self-adhesive resin cements [16-19]. However, to create an efficient connection to dentin and enamel surfaces, concentration of the acidic monomers in self-adhesive resin cements needs to be regulated with respect to hydrophilicity and pH [16-17]. Polymerization process continues for the following 24 hours after light activation, reaching maximum degree of monomer conversion, which is another advantage of having TEGDMA present [1]. Photoinitiators such ascamphorquinone (CQ) is linked to a coinitiator like tertiaryamine (TA). Visible light from light-curing stimulates the CQ/TA complex, producing free radicals that start polymerization chain reaction [20-21]. Other photoinitiator systems,such as germanium-based photoinitiators Ivocerin™ (bis 4-methoxybenzoyl) diethylgermanium) and Lucirin™ TPO (2,4,6-trimethylbenzoyldiphenyl phosphine oxide), are found in light-cured resin cements because the low color stability of amines is still a problem [20-22].

3.1.2. Type of resin cement

Three different types of resin-based cements exist according to their activation mode: self-cured, light cured or dual cured. The activation of TA and benzoyl peroxide (BP) is the only way that chemically cured (self-cured) resin cements undergo a polymerization reaction. For thick restorations, luting posts, and crowns that obstruct light

transmission—such as metallic materials or extremely opaque ceramics—self-cured cements utilized. Free radicals are produced within the polymeric chain by the initiator, BP, forming a chemical bond with a co-initiator, TA, in the context of the self-cure reaction [6-23-24]. One paste of resin cements comprises BP as a chemical initiator, and another paste contains the TA. A higher concentration of redox initiators is needed to reach the high DC of monomers, which is necessary for the polymerization process to be successful. However, a short working time and a long setting time are disadvantages of chemically cured resin cements. The luting process may be jeopardized by the chemical reaction, which requires a significant working period [6-25]. Light-curing units are used to activate light-cured cements when they are exposed to a visible light source.

Visible light with wavelengths between 420 and 490 nm can stimulate the CQ/TA complex, however the light absorption peak is observed at 470 nm [20-21]. In terms of the light-curing reaction, the CQ/TA complex absorbs blue visible light (at 470 nm) from an LCU. This process involves three basic steps: (1) unrestricted polymeric chain growth, where the kinetic reactions are determined by monomer concentration and free radicals; (2) rapid viscosity increase with limited free radical mobility and an irreversible increase in resin matrix's elastic modulus (gel point); and (3) vitrification and reaction termination with a high viscosity level. Remaining monomers that are in charge of further polymerization are restricted in their movements by the increase in viscosity [6-11]. However, dual-cured resin cements combine chemical and light activation to guarantee proper polymerization under low light irradiation [25]. Additionally, BP is used as a chemical initiator in one paste of dual-cured resin cements, whereas TA and a photoinitiator are present in a second paste. The tertiary amine and BP undergo a chemical reaction, and visible light also activates photoinitiator system (CQ/TA) [26-27].

In terms of polymerization, the acidic monomer included in self-adhesive resin cements may hinder the resin cements' adequate polymerization, hence reducing their physical qualities [28]. The polymerization chain reaction in the organic matrix is also significantly influenced by the photoinitiator system. When compared to CQ, Lucirin™ TPO, a form of photoinitiator with a lower wavelength of light absorption (380–425 nm), has demonstrated better resistance to hydrolytic degradation, greater DC values, and color stability [6-29]. Nonetheless, a number of studies have documented methods to enhance CQ's photoinitiator performance. Iodonium salt was used as part of the initiator system in a prior study to raise the DC of the resin-based cement in areas with little light exposure. When CQ and iodonium salt were combined, a greater DC % was possible and more free radicals were produced per CQ molecule [6-30]. New photoinitiators that are sensitive to the violet wavelength region and are frequently used in conjunction with CQ can be properly matched thanks to the development of LCU with multiple-emission light-emitted diode (LEDs). To excite the initiator system, the spectral emission of a single- or multiple-emission LCU must be chosen [31].

Dual-cured resin cements have larger DC % (72.8%) than light-cured cements (65.7%) according to previous research [3]. In another research, a light-cured resin cement had a DC percentage of 48.6% however, the dual-cured cement LCU must be chosen [31]. Dual-cured resin cements have larger DC % (72.8%) (58.3%) when use visible light at 800 mW/cm^2 from a quartz halogen (QTH) LCU for 40 seconds, the polymerization was carried out via a ceramic that was 1 mm thick and made of felspar [27]. For dual- and light-cured resin cements, light-curing procedure is still essential to the overall DC efficacy. The DC has a direct impact on the physical characteristics of resin cements. Moreover, when choosing resin cements for clinical use, the DC and shrinkage behavior are crucial considerations [32]. The DC percentage of resin cement used in an indirect restoration range from 5 5 to 75% [6]. Light-curing composites exhibit better performance with regard to working time than dual-cure or chemically curing materials. A prior study on chemical versus dual curing of resin inlay composites and ceramics showed that hardness of chemical phase alone of the dual cure cements was lower than curing with light. However, it was asserted that chemical curing alone was insufficient to achieve maximum cement polymerization [33].

3.2. Factors related to light irradiation

3.2.1. Light-curing unit

To initiate polymerization, light activation units must provide the luting material with sufficient radiation intensity at the right wavelength. The wavelength absorption radiation of the CQ must be between 460 and 480 nm. There are many different types of light sources available today, each with a different wavelength of radiation (nm) and output light intensities (mW cm^2). The ISO recommends 300 mW/cm^2 of light intensity for polymerization [34]. The refraction index of the organic and inorganic components, distance between the LCU and resin-based cement, the organic matrix type, size, and content of inorganic fillers, light irradiance, exposure time, visible light wavelength, and organic matrix type all influence the polymerization's efficiency and high DC [35-36]. The LCU determines how much light the resin cement receives. Indirect restorative debonding, toxicity, increased marginal wear, and bacterial buildup might result from light curing process failures [31]. Halogen lamps which use light from a quartz tungsten halogen bulb, are a common kind of blue visible light activation device. They activate CQ and have a broad wavelength spectrum between 380 and 550 nm, but they also raise polymerization temperatures and offer no control over radiation dispersion [34].

A prior study found that QTH lamps required less time, and that there was no increase in polymerization with varying tip sizes [37]. Blue light produced by LEDs within a specific wavelength range. They have several benefits, such as heatless light emission, a narrow wavelength band that is compatible with the majority of activators, the ability to activate soft start curing to maximize the polymerization process and reduce shrinkage effects, less damage to the pulp-tooth structure, the lack of a cooling device, and ease of handling and manipulation [34]. In a prior study, it was discovered that LED lights improved the shear bond strength of 3mm lithium disilicate ceramics when they were attached to resin. Because of their quick polymerization time, LED units were also the recommended choice for curing resin [38]. Another kind of light source that makes use of a xenon bulb is the plasma arc lamp. They have very high-power output and high radiance intensity, necessitating an efficient cooling system. They use an exposure time of two to three seconds, as opposed to thirty seconds for traditional lamps [39]. Nevertheless, research indicates that the high light intensity

prematurely cures resin's outer layer, which promotes inadequate polymerization of the interior layers.

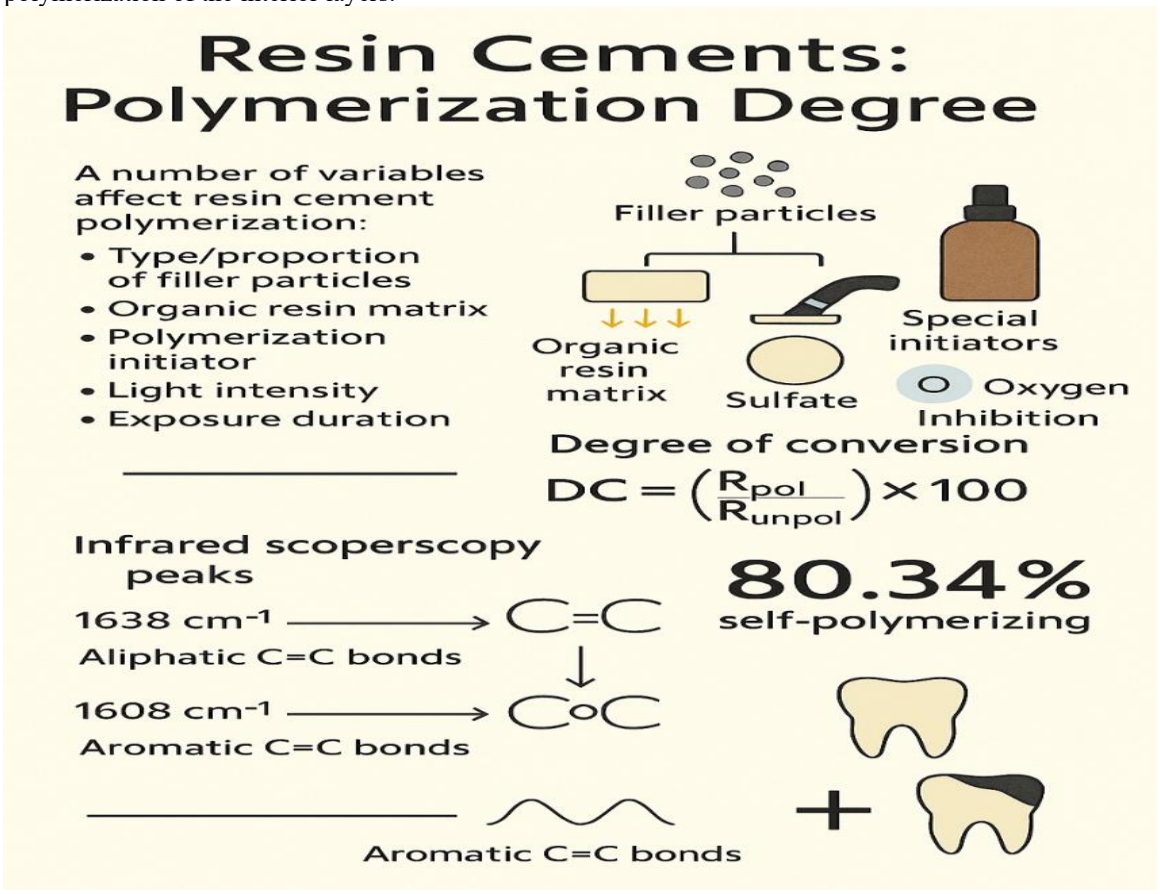

Figure [1]: polymerization degree of resin cements

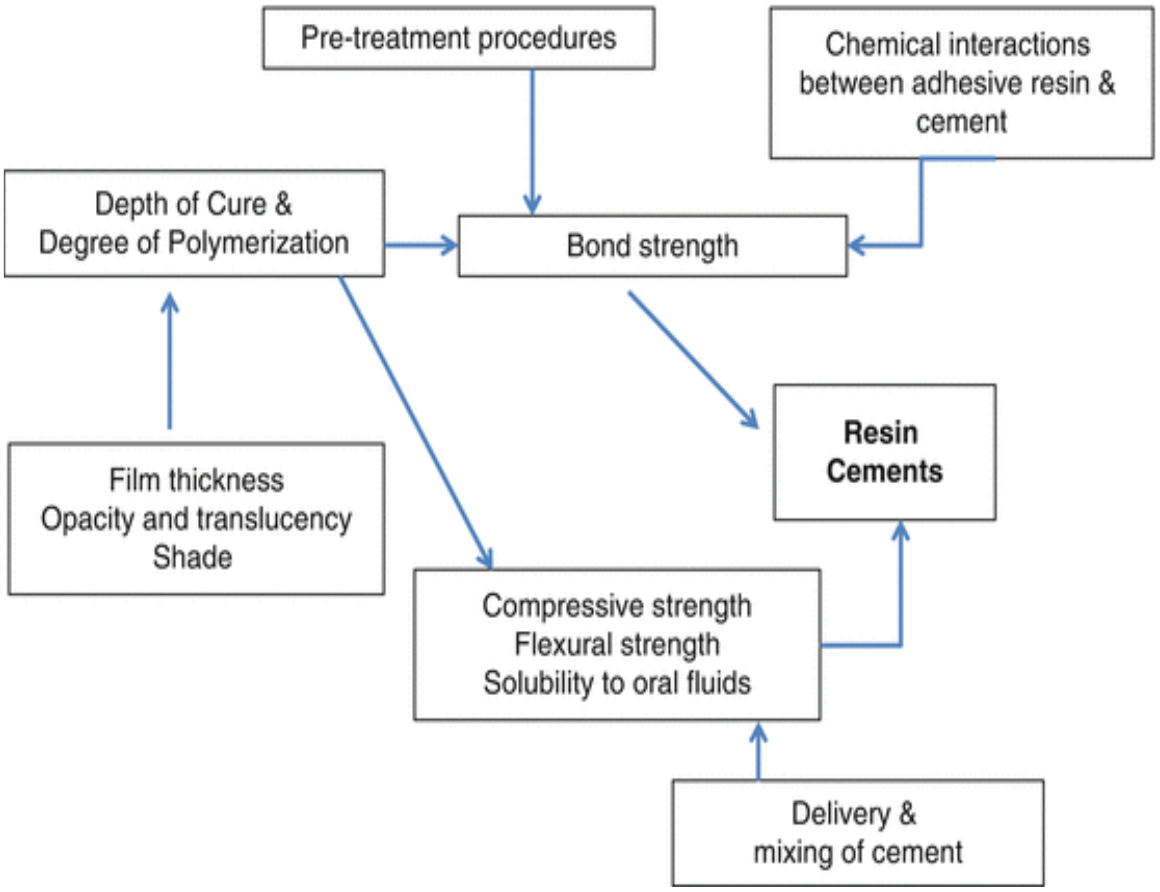

Figure [2]: Diagram show Resin Cement Properties and Influencing Factors.

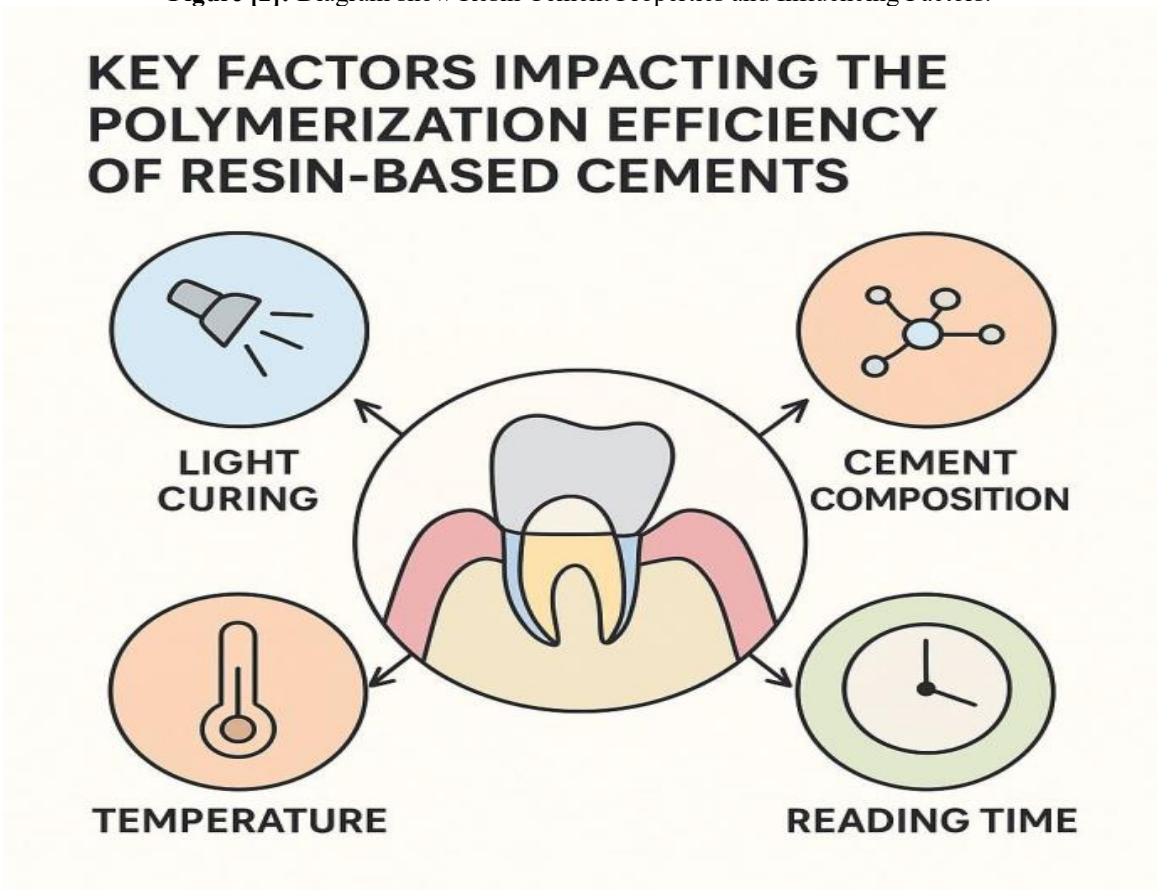

Figure [3]: show key factors impacting the polymerization efficiency of resin-based cements.

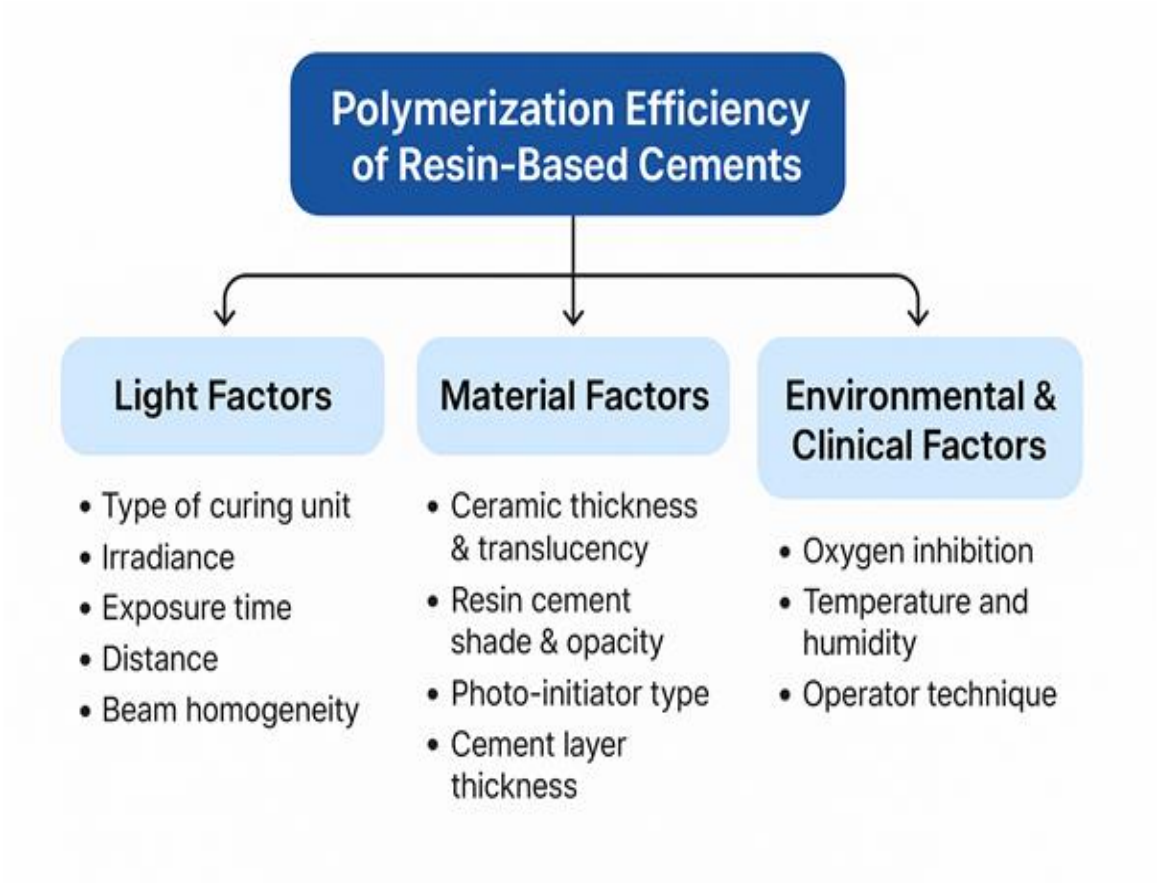

Figure [4]: Diagram related to polymerization efficiency of resin-based cements.

Table [1]: Key Factors Affecting Polymerization Efficiency.

Factor	Illustration	Impact on Polymerization
light Intensity		Higher intensity → better degree of conversion (DC)
Restoration Thickness	thick block reducing light arrows)	Thick ceramics block light → lower DC
Restoration Translucency	HT OR LT	More opaque → less light penetration
Cement Shade	light vs dark color	Darker shade reduces light transmission
Cement Thickness	thin vs thick layers	Optimal thin layer (50–100 µm) = better curing
Cure Mode	dual cure: light + chemical)	Dual-cure = best for deep restorations

Table [2]: Conclusion and clinical implications: Summary Table

🔍 Factor	📌 Key Insights	🎯 Clinical Implication
Curing Mode	- Dual-cure > Light-cure in DC - Soft-start technique yields highest DC	Use dual-cure or soft-start for deep/opaque restorations
Filler Characteristics	- Type, quantity, and size affect light scattering and absorption	Choose cements with optimized filler load for better polymerization
Light Attenuation	- Internal absorption & scattering reduce light transmission - Opaque >1.5 mm → lower DC	Increase exposure time and irradiance for thick/opaque restorations
Organic Matrix Composition	- Photoinitiator system, monomer chemistry, and viscosity directly affect polymerization	Select resin cements with efficient initiator systems and balanced viscosity
Restoration Properties	- Translucent ceramics → better light penetration - Opaque ceramics need higher irradiance & longer curing	Match curing protocol to restoration type and thickness

It's noteworthy that a study using lithium disilicate veneers and plasma arc light revealed greater adhesive failure between dual-cured resin and porcelain reconstruction. Another study discovered that plasma arc lights required less time, even if amount of polymerization was less than or equivalent to that of halogen lamps. A light source with a lower wavelength that is more efficient is an argon laser lamp. Materials that employ an activator other than CQ, however, might not be compatible with it (Tales 1-2) [40-41].

3.2.2. Light transmittance

The filler volume percentage, particle size, filler shape, and the materials' refractive indices all affect light attenuation and scattering phenomena [42]. Light transmittance to the resin cement beneath restorations was decreased as a result of light reflection and dispersion through ceramic restorations [19-35]. Moreover, opaque restorative materials reduce the amount of light that reaches the resin cement, which has a detrimental effect on the organic matrix's degree of conversion [6].

3.2.3. Light-polymerization time

The most reliable factor influencing resin cement's mechanical characteristics was the exposure duration. A 20-second exposure period is advised for light-curing resin cements [43]. A minimum of 40 seconds of light-curing time is advised for indirect restorations that are 2 mm thick or thicker [29]. According to a previous study, the lowest DC and greatest polymerization rate of resin cements in ceramics were obtained by employing a high LED irradiance for shorter light activation durations [35]. A prior study analyzed two resin cements with distinct photoinitiators (AllCem™ and Variolink™), they revealed variations between single- and multi-emission LCUs with respect to light exposure duration. When materials were polymerized separately for 40 s, maximum DC was obtained in both resin-based cements. However, The LCU had no discernible effect on the DC values in either of resin cements with distinct photoinitiators [20]. The impact of single- and multiple-emission peak LCUs on the DC of two resin-matrix cement (Variolink™) shades (A2 and A4) under a 1 mm-thick Empress Aesthetic ceramic A2 was examined in another investigation. The resin cements were polymerized using either a single-emission peak light irradiance or multiple-emission peak light irradiance following 20 seconds of light curing [44]. They found that resin cements were polymerized using either a single-emission peak light irradiance or multiple-emission peak light irradiance following 20 seconds of light curing [44].

3.2.4. Light-polymerization mode

The DC and light irradiance of light-cured and dual-cured cements were studied in a prior work after being light cured for 40 seconds using an LED LCU with two polymerization modes, soft-start and pulse delay, or using a QTH LCU for 20 seconds, the DC of dual-cured and light-cured resin cements (RelyX Ultimate Cliker™) were examined. The dual-cured resin cement polymerized using the LED soft-start mode and subjected to direct light one day after polymerization had a higher DC percentage of 62.9%, according to the results [45].

3.3. Factors related to the indirect restorative materials

A variety of factors, such as the kind, thickness, and shade of the materials can also influence the light transmittance of resin-based cements [6-29].

3.3.1. Material translucency

The translucency characteristics and light transmission towards the resin cement are also influenced by the indirect restoration's thickness and shade [46]. Potentially jeopardizing the indirect restoration prognosis, the restorative material's opacity and chemical makeup attenuate light intensity and decrease the amount of photons that reach the resin cement [11]. In clinical settings, the thickness and microstructure of opaque prosthetic structures should be controlled by the light-curing parameters. For example, for thick and opaque zirconia, the light-curing time and intensity should be increased [5-23]. The light transmittance of two glass-ceramic materials—a low translucency (LT) LDS-reinforced glass ceramic (IPS E.max LT CADTM, Ivoclar Vivadent) and a high translucency (HT) leucite-reinforced glass-ceramic (IPS Empress HTTM, Ivoclar Vivadent)—through varying thicknesses (0.5, 1.0, 2.0, and 4.0 mm) was compared in a prior study. In contrast to the LDS-reinforced glass-ceramic, the HT leucite-reinforced glass-ceramic had greater light transmittance values [5]. Thus, tiny, randomly orientated, interconnecting, plate-like crystals which structure chemical makeup of LDS-reinforced glass-ceramics (70 weight percent LDS crystal) reduces light transmittance. Thus, selecting the ceramic type for deep cavities, where light transmittance is a major concern, it may be necessary to take this discrepancy into account because the ceramic type can result in a substantial difference in light transmittance [6].

3.3.2. Restoration thickness

Light transmittance to the resin cement beneath the restorations affected by light reflection and dispersion through ceramic restorations [6]. For a good aesthetic result, zirconia veneer thickness is crucial since thick zirconia reduces light transmission through the resin cement with low DC values of resin cement [23]. When cementing restorations up to 1.0 mm thick, light- and dual-cured resin cements can be used; however, for restorations exceeding 1.0 mm thick, dual-cured resin-matrix cement is advised [6]. According to results from earlier study light transmission decreases through zirconia at varying thicknesses; however, the greatest drop was observed at a thickness of 1.65 mm, while lowest was observed at a thickness of 0.2 mm [47]. Light-cured resin cements can only be used in specific clinical settings, such as veneer cementation or thin indirect restorations. In order to avoid insufficient polymerization, light-cured resin cements should not be utilized for restorations thicker than 3 mm [6]. The final DC for LDS glass ceramics with thicknesses ranging from 0.6 to 1.5 mm was unaffected by the use of light-cured or dual-cured resin cements. According to findings, a thick layer of LDS-reinforced glass ceramics did not considerably reduce the light transmission from LCU. Conversely, thicker indirect restorations are recommended for dual-cured resin cements [29].

4. Conclusions

The following conclusions can be made while keeping in mind the constraints of the present scoping review. Compared to light-cured resin cements, dual-cured resin cements show higher degrees of conversion. The resin cements' polymerization was influenced by the type, quantity, and size of their inorganic fillers. The primary causes of light attenuation are internal material absorption and scattering. The organic matrix components, such as the photoinitiator systems, chemical composition and viscosity of the methacrylate-based monomers, have a direct effect on the polymerization procedure. High translucency materials permit light to pass through to the resin cement, which results in a high degree of monomer conversion when indirect restorations are taken into account. For restorative opaque materials thicker than 1.5 mm, the degree of monomer conversion decrease. Light transmittance to the resin cement beneath ceramic restorations is decreased as a result of light dispersion across them. For opaque materials like traditional zirconia, a high light irradiance and exposure duration are necessary to obtain the necessary energy for the resin cement's polymerization. When comparing dual-cured cements to light-cured cements, the soft-start polymerization method demonstrated the highest degree of conversion.

References

[1] A. Maletin, M.J. Knežević, D.Đ. Koprivica, T. Veljović, T. Puškar, B. Milekić, I. Ristić. (2023). Dental resin-based luting materials. Polymers. 15(20): 4156.

[2] F. De Angelis, C. D'Arcangelo, M. Buonvivere, G.D. Rondoni, M. Vadini. (2020). Shear bond strength of glass ionomer and resin-based cements to different types of zirconia. Journal of Esthetic and Restorative Dentistry. 32(8): 806–814.

[3] T. Takagaki, A.K. Ko, S. Halabi, T. Sato, M. Ikeda, T. Nikaido, M.F. Burrow, J. Tagami. (2019). Adhesion durability of dual-cure resin cements and acid–base resistant zone formation on human dentin. Dental Materials. 35(7): 945–952.

[4] S.M. Lucey, A. Santini, E.M. Roebuck. (2015). Degree of conversion of resin-based materials cured with dual-peak or single-peak LED light-curing units. International journal of paediatric dentistry. 25(2): 93–102.

[5] S. Oh, S.-M. Shin, H.-J. Kim, J. Paek, S.-J. Kim, T.H. Yoon, S.-Y. Kim. (2018). Influence of glass-based dental ceramic type and thickness with identical shade on the light transmittance and the degree of conversion of resin cement. International journal of oral science. 10(1): 5-7.

[6] R. Fidalgo-Pereira, O. Torres, Ó. Carvalho, F.S. Silva, S.O. Catarino, M. Özcan, J.C. Souza. (2023). A scoping review on the polymerization of resin-matrix cements used in restorative dentistry. Materials. 16(4): 1560.

[7] K. Barutcigil, Ç. Barutcigil, E. Kul, M.M. Özarslan, U.S. Buyukkaplan. (2019). Effect of different surface treatments on bond strength of resin cement to a CAD/CAM restorative material. Journal of Prosthodontics. 28(1): 71–78.

[8] H.-K. Lim, S. Keerthana, S.-Y. Song, C. Li, J.S. Shim, J.J. Ryu. (2024). Effect of Light Irradiance and Curing Duration on Degree of Conversion of Dual-Cure Resin Core in Various Cavities with

Different Depths and Diameters. Materials. 17(17): 4342.

[9] R.C.C. Guimarães, D. de Oliveira, M.G. Rocha, J.-F. Roulet, S. Geraldeli, M.A.C. Sinhoreti. (2025). Effect of glass-ceramic thickness on the degree of conversion, polymerization shrinkage stress, and bond strength of resin cements. International Journal of Adhesion and Adhesives. 136: 871-876.

[10] N.B. Cramer, C.L. Couch, K.M. Schreck, J.A. Carioscia, J.E. Boulden, J.W. Stansbury, C.N. Bowman. (2010). Investigation of thiol-ene and thiol-ene–methacrylate based resins as dental restorative materials. Dental Materials. 26(1): 21–28.

[11] C. Mazzitelli, T. Maravic, E. Mancuso, U. Josic, L. Generali, A. Comba, A. Mazzoni, L. Breschi. (2022). Influence of the activation mode on long-term bond strength and endogenous enzymatic activity of dual-cure resin cements. Clinical Oral Investigations. 26(2): 1683–1694.

[12] P.A. Acquaviva, F. Cerutti, G. Adami, M. Gagliani, M. Ferrari, E. Gherlone, A. Cerutti. (2009). Degree of conversion of three composite materials employed in the adhesive cementation of indirect restorations: a micro-Raman analysis. journal of dentistry. 37(8): 610–615.

[13] V. Miletic, A. Santini, I. Trkulja. (2009). Quantification of monomer elution and carbon–carbon double bonds in dental adhesive systems using HPLC and micro-Raman spectroscopy. journal of dentistry. 37(3): 177–184.

[14] V.J. Miletic, A. Santini. (2008). Remaining unreacted methacrylate groups in resin-based composite with respect to sample preparation and storing conditions using micro-Raman spectroscopy. Journal of Biomedical Materials Research Part B: Applied Biomaterials: An Official Journal of The Society for Biomaterials, The Japanese Society for Biomaterials, and The Australian Society for Biomaterials and the Korean Society for Biomaterials. 87(2): 468–474.

[15] A. Maletin, I. Ristic, T. Veljovic, B. Ramic, T. Puskar, M. Jeremic-Knezevic, D. Djurovic Koprivica, B. Milekic, K. Vukoje. (2022). Influence of dimethacrylate monomer on the polymerization efficacy of resin-based dental cements—FTIR analysis. Polymers. 14(2): 247.

[16] M. Dimitriadi, A. Petropoulou, M. Zafiropoulou, S. Zinelis, G. Eliades. (2021). Degree of conversion and mechanical properties of modern self-adhesive luting agents. Applied Sciences. 11(24): 12065.

[17] Y. Pan, X. Xu, F. Sun, X. Meng. (2018). Surface morphology and mechanical properties of conventional and self-adhesive resin cements after aqueous aging. Journal of Applied Oral Science. 27: e20170449.

[18] A. Kurt, S.H. Altintas, M.V. Kiziltas, S.E. Tekkeli, E.M. Guler, A. Kocyigit, A. Usumez. (2018). Evaluation of residual monomer release and toxicity of self-adhesive resin cements. Dental materials journal. 37(1): 40–48.

[19] J.S. Shim, J.K. Kang, N. Jha, J.J. Ryu. (2017). Polymerization mode of self-adhesive, dual-cured dental resin cements light cured through various restorative materials. Journal of Esthetic and Restorative Dentistry. 29(3): 209–214.

[20] G.F. Bragança, A.S. Vianna, F.D. Neves, R.B. Price, C.J. Soares. (2020). Effect of exposure time and moving the curing light on the degree of conversion and Knoop microhardness of light-cured resin cements. Dental Materials. 36(11): e340–e351.

[21] A. Delgado, E. Castellanos, M.C. Sinhoreti, D. Oliveira, N. Abdulhameed, S. Geraldeli, T. Sulaiman, J. Roulet. (2019). The use of different photoinitiator systems in photopolymerizing resin cements through ceramic veneers. Operative dentistry. 44(4): 396–404.

[22] Y. Chen, C. Yao, C. Huang, Y. Wang. (2019). The effect of monowave and polywave light-polymerization units on the adhesion of resin cements to zirconia. The Journal of prosthetic dentistry. 121(3): 549. e1–549. e7.

[23] C.M. Tafur-Zelada, O. Carvalho, F.S. Silva, B. Henriques, M. Özcan, J.C. Souza. (2021). The influence of zirconia veneer thickness on the degree of conversion of resin-matrix cements: an integrative review. Clinical Oral Investigations. 25(6): 3395–3408.

[24] R. Gheller, A. Burey, B.L.S. Vicentin, P.J. Dos Reis, C.R. Appoloni, C.C.D. Garbelini, M.G. Hoeppner. (2020). Microporosity and polymerization contraction as function of depth in dental resin cements by X-ray computed microtomography. Microscopy Research and Technique. 83(6): 658–666.

[25] A.L. Faria-e-Silva, C.S. Pfeifer. (2020). Development of dual-cured resin cements with long working time, high conversion in absence of light and reduced polymerization stress. Dental Materials. 36(10): e293–e301.

[26] F. Alkhudhairy, F. Vohra, M. Naseem, M.M. Owais, A.H.B. Amer, K.B. Almutairi. (2020). Color stability and degree of conversion of a novel dibenzoyl germanium derivative containing photo-polymerized resin luting cement. Journal of Applied Biomaterials & Functional Materials. 18: 2280800020917326.

[27] V.R. Novais, L.H.A. Raposo, R.R.d. MIRANDA, C.d.C.A. Lopes, P.C. SIMAMOTO, C.J. Soares. (2017). Degree of conversion and bond strength of resin-cements to feldspathic ceramic using different curing modes. Journal of Applied Oral Science. 25(1): 61–68.

[28] N. Turker, U.Ş. Buyukkaplan, E.K. Başar, M.M. Özarslan. (2020). The effects of different surface treatments on the shear bond strengths of two dual-cure resin cements to CAD/CAM restorative materials. The Journal of Advanced Prosthodontics. 12(4): 189-196.

[29] C. Hardy, S. Bebelman, G. Leloup, M.A. Hadis, W. Palin, J. Leprince. (2018). Investigating the limits of resin-based luting composite photopolymerization through various thicknesses of indirect restorative materials. Dental Materials. 34(9): 1278–1288.

[30] A.R. Palialol, C.P. Martins, D. Dressano, F.H. Aguiar, L.S. Goncalves, G.M. Marchi, C.S. Pfeifer,

A.F. Lima. (2021). Improvement on properties of experimental resin cements containing an iodonium salt cured under challenging polymerization conditions. Dental Materials. 37(10): 1569–1575.

[31] M. Butterhof, N. Ilie. (2021). Predicting transmitted irradiance through CAD/CAM resin composite crowns in a simulated clinical model. Dental Materials. 37(6): 998–1008.

[32] L.N. Khanlar, A. Abdou, T. Takagaki, S. Mori, M. Ikeda, T. Nikaido, A. Zandinejad, J. Tagami. (2022). The effects of different silicatization and silanization protocols on the bond durability of resin cements to new high-translucent zirconia. Clinical Oral Investigations. 26(4): 3547–3561.

[33] W.A. El-Badrawy, O.M. El-Mowafy. (1995). Chemical versus dual curing of resin inlay cements. The Journal of prosthetic dentistry. 73(6): 515–524.

[34] F. Vohra, M. Al-Rafaiy, M. Al Qahtani. (2013). Factors affecting resin polymerization of bonded all ceramic restorations. Review of literature. Journal of the Dow University of Health Sciences (JDUHS). 7(2): 80-86.

[35] A.L. Faria-e-Silva, C.S. Pfeifer. (2017). Effectiveness of high-power LEDs to polymerize resin cements through ceramics: An in vitro study. The Journal of prosthetic dentistry. 118(5): 631–636.

[36] R. Fidalgo-Pereira, D. Carpio, O. Torres, O. Carvalho, F. Silva, B. Henriques, M. Özcan, J.C. Souza. (2022). The influence of inorganic fillers on the light transmission through resin-matrix composites during the light-curing procedure: an integrative review. Clinical Oral Investigations. 26(9): 5575–5594.

[37] F.A. Rueggeberg, J.W. Ergle, D.J. Mettenburg. (2000). Polymerization depths of contemporary light-curing units using microhardness. Journal of Esthetic and Restorative Dentistry. 12(6): 340–349.

[38] A. Nalcaci, C. Kucukesmen, B. Uludag. (2005). Effect of high-powered LED polymerization on the shear bond strength of a light-polymerized resin luting agent to ceramic and dentin. The Journal of prosthetic dentistry. 94(2): 140–145.

[39] A.G. Ozyesil, A. Usumez, B. Gunduz. (2004). The efficiency of different light sources to polymerize composite beneath a simulated ceramic restoration. The Journal of prosthetic dentistry. 91(2): 151–157.

[40] A. Usumez, A. Ozturk, S. Usumez, B. Ozturk. (2004). The efficiency of different light sources to polymerize resin cement beneath porcelain laminate veneers. Journal of Oral Rehabilitation. 31(2): 160–165.

[41] A. Ozturk, A. Usumez. (2004). Influence of different light sources on microtensile bond strength and gap formation of resin cement under porcelain inlay restorations. Journal of Oral Rehabilitation. 31(9): 905–910.

[42] D.P. Lise, A. Van Ende, J. De Munck, K. Yoshihara, N. Nagaoka, L.C.C. Vieira, B. Van Meerbeek. (2018). Light irradiance through novel CAD–CAM block materials and degree of conversion of composite cements. Dental Materials. 34(2): 296–305.

[43] N. Ilie. (2017). Transmitted irradiance through ceramics: effect on the mechanical properties of a luting resin cement. Clinical Oral Investigations. 21(4): 1183–1190.

[44] M.Q. AlQahtani, M.M. AlShaafi, R.B. Price. (2013). Effects of single-peak vs polywave light-emitting diode curing lights on the polymerization of resin cement. Journal of Adhesive Dentistry. 15(6): 547-551.

[45] M.M. AlShaafi, M.Q. AlQahtani, R.B. Price. (2014). Effect of exposure time on the polymerization of resin cement through ceramic. Journal of Adhesive Dentistry. 16(2): 129–135.

[46] N. Supornpun, M. Oster, K. Phasuk, T.-M.G. Chu. (2023). Effects of shade and thickness on the translucency parameter of anatomic-contour zirconia, transmitted light intensity, and degree of conversion of the resin cement. The Journal of prosthetic dentistry. 129(1): 213–219.

[47] V. Turp, P. Turkoglu, D. Sen. (2018). Influence of monolithic lithium disilicate and zirconia thickness on polymerization efficiency of dual-cure resin cements. Journal of Esthetic and Restorative Dentistry. 30(4): 360–368.