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REVIEW

The influence of zirconia veneer thickness on the degree of conversion of resin-matrix cements: an integrative review

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Abstract

Objective The main aim of this study was to conduct an integrative review on the influence of the zirconia veneer thickness on the degree of conversion of resin-matrix cements.

Materials and method An electronic search was performed on PubMed using a combination of the following search items: zirconia, thickness, veneer, degree of conversion, resin cement, light curing, and polymerization. Articles published in the English language, up to July 2020, were included regarding the influence of ceramic veneer thickness on the degree of conversion of resin-matrix cements. Randomized controlled trials and prospective cohort studies were also evaluated.

Results Of the 21 selected studies, 9 investigated the light-curing effect, while five other articles evaluated the ceramic translucency. Three studies evaluated the degree of conversion of the resin-matrix cement while four articles assessed the veneer thickness. Results revealed a significant decrease of light transmission through the zirconia with a thickness ranging from 0.1 up to 1.5 mm. However, the ultra-thin thickness around 0.1 and 0.3 mm allowed a full polymerization of the dual-curing resin-matrix cement resulting in the integrity of the interface properties. The light-curing process of resin-matrix cements is also affected by the shade, chemical composition, and microstructure of zirconia and resin cement. Optimal conditions of light-curing are required to reach the threshold intensity of light and energy for polymerization of resin-matrix cements.

Conclusions The increase in zirconia veneer thickness negatively affects the degree of conversion of resin-matrix cements. Also, shade and microstructure are key factor to improve the light curing of resin cements.

Clinical relevance Clinicians should consider the zirconia thickness on resin-based cementation since a higher veneer thickness can negatively affect the light irradiation intensity towards the dual-curing resin-matrix cement. Thus, the degree of conversion of the resin-matrix cement can decrease leading to a low chemical stability (e.g., color instability) and poor mechanical properties.

Keywords Degree of conversion · Polymerization · Resin cement · Thickness · Translucency · Zirconia veneer

Introduction

Recently, the demand for esthetics has led to the development of high-strength materials such as zirconia-based structures for oral rehabilitation [1–3]. Clinical cases with zirconia-based veneers have been reported in literature although failures can occur by veneer chipping or low adhesion to the teeth structures [4–7]. The ceramic thickness, microstructure, and the resin-matrix cement have an important role on the light curing, translucency, and color of the restoration [8–12]. A low degree of conversion of the resin-matrix cement is dependent on the cement properties itself, ceramic veneer thickness, and polymerization procedure [10, 13–15].

Yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) is a high-strength polycrystalline zirconia developed

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for different industrial applications including biomedical materials such as prosthetics and implants [1, 16]. In dentistry, zirconia-based materials often contain zirconium dioxide named zirconia and 3–7 mol% yttria in the chemical composition to maintain the zirconia tetragonal phase (around 50 vol%) that determine the mechanical properties of the prosthetic structures [1, 2]. The first generation of yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP) with 3–5% yttria has a three-point bending strength of around 1200 ± 130 MPa, fracture toughness at 9 ± 0.34 MPa.m$^{1/2}$, and elastic modulus of around 240 ± 9.5 GPa [1, 3, 17]. Due to its higher opacity, 3Y-TZP has been used as a prosthetic framework material in which veneer glass-ceramics can be applied for esthetic improvements [8, 9, 18–20]. Thus, 3Y-TZP frameworks have the convenient opacity to mask all shades of discolored background which also include metallic abutments. Nevertheless, light transmission is reduced because the opaque tetragonal phase [8, 9, 18–20]. Current changes in the formulation of zirconia resulted in a recent class of monolithic highly translucent zirconia with a different molecular structure and physical properties as well as a quite attractive esthetic appearance [1]. Monolithic translucent zirconia ceramics contain approximately 5–8 mol% yttria and above 50% of cubic crystals, which increase translucency. However, such changes in the chemical composition and microstructure are detrimental to the mechanical properties of the material [1, 2, 16].

Thus, the polycrystalline microstructure of the 3Y-TZP veneer and the increase in thickness negatively affect the light curing ofresin-matrix cements [10, 18, 21, 22]. Indeed, low transmittance is expected through thick layers of Y-TZP, which explains the relatively light irradiation procedures used when cementing light-activated resin-matrix compounds [12, 14]. Over the years, several types of resin-matrix cement materials have been developed for the adhesion of ceramics, and therefore, methacrylate-based cements are the first choice material for joining dental structures and ceramic restorations. The chemical composition of resin-matrix cements involves the presence of Bis-GMA, TEGDMA, and UDMA embedding inorganic fillers such as colloidal silica, ytterbium, or barium glass [6, 10, 22]. The resin-matrix composites possess the following properties which are important for cementing ceramic veneers: low solubility, translucency, flowability, easy handling, and elasticity [4, 6, 10, 23, 24]. Also, the solubility of the resin-matrix cement is lower than those recorded for conventional cements that promote a long-term sealing at the marginal region of the restoration [4, 6, 10, 23, 24]. Regarding the polymerization, there are three types of resin-matrix cements: light-curing, self-curing, and dual-curing [6, 10, 22]. Light-curing and dual-curing methods are used for veneer adhesion with resin-matrix cements, and therefore, the light-curing method has the main advantage on the working time for cementation and removal of remnant cement at the veneer margins [10, 22, 25]. Nevertheless, a solely light-curing procedure cannot guarantee a high degree of conversion of the resin-matrix cement considering other factors such as veneer type and thickness, type of resin-matrix cement, and polymerization pathways [15, 24, 26]. On the other hand, dual-cure resin-matrix cements combine the desirable properties of chemical and light-curing materials to guarantee the degree of conversion of monomers in the case of insufficient light transmission [15, 24, 26]. The major problem of having an inadequate polymerization is the low degree of conversion leading to a decrease in physical properties and color stability [10, 24, 27, 28]. The degree of conversion of the organic matrix of resin-based cements must be enhanced that corresponds to an efficient polymerization of resin-matrix materials. As a result, the strength of the veneer to tooth interface is increased leading to a long-term performance of zirconia-based restorations [10, 24, 27, 28].

The purpose of the present study was to conduct a literature integrative review on the influence of the zirconia veneer on the degree of conversion of resin-matrix cements. It was hypothesized that thick zirconia-based restorations attenuate the light irradiation towards the resin-matrix cements during the light-curing procedure. Also, the microstructure of zirconia can affect the light irradiation, and therefore, the light-curing procedure could be adjusted for different zirconia restorations.

Method

Information sources and search strategy

A literature search was performed on PubMed (via National Library of Medicine) considering such database includes the major articles in the field of dentistry and biomaterials. The present method was performed in accordance with the search strategy applied in previous studies on integrative or systematic reviews [7, 29–31]. The following combination of search terms was applied in this study: “Zirconia” OR “YTZP” AND “Translucency” OR “thickness” AND “resin cement” OR “adhesive” AND “degree of conversion” OR “polymerization” OR “light curing”. The inclusion criteria involved articles published in the English language, up to July 2020, reporting the influence of ceramic veneer thickness on the degree of conversion of resin-matrix cements. The eligibility inclusion criteria used for article searches also involved in vitro studies; meta-analyses; randomized controlled trials; and prospective cohort studies. Ongoing studies were searched in the following clinical trial registries: Current Controlled Trials, International Clinical trials registry platform, ClinicalTrials.gov, ReBEC, and EU Clinical Trials Register. Also, a hand-search was performed on the reference lists of all primary sources and eligible studies of this review for additional relevant publications. The exclusion criteria were the following: papers without abstract; case report with short follow-up period; and articles assessing only the light transmission through other glass-ceramic materials. Studies based on publication date were not restricted during the search process.

Study selection and data collection process

The articles retrieved by the search process were evaluated in three steps. Studies were primarily scanned for relevance by title, and the abstracts of those that were not excluded at this stage were assessed. Two of the authors (JCMS, CMTZ) independently analyzed the titles and abstracts of potentially relevant articles although a third author (BH) performed a final evaluation in case of disagreement. The total of articles was compiled for each combination of key terms, and therefore, the duplicates were removed using Mendeley citation manager (Ed. Elsevier). The second step comprised the evaluation of the abstracts and non-excluded articles, according to the eligibility criteria in the abstract review. A preliminary evaluation of the abstracts was carried out to establish whether the articles met the purpose of the study. Selected articles were individually read and evaluated concerning the purpose of this study. At last, the eligible articles received a study identification label, combining first author and year of publication. The following factors were retrieved for this review: authors' names, journal, publication year, purpose, type of resin-matrix cement, zirconia veneer thickness, light-curing procedures, degree of conversion of the resin-matrix cement, and physical properties. PICO question was adjusted to the issue where "P" was related to the patients or specimens, while "I" referred to the methods of analyses. The major parameters were the thickness and types of zirconia. Also, a correlation of other factors and light-curing parameters was established such as light transmittance, intensity, and exposure time in clinical situations. Data of the reports were harvested directly into a single data collection form to avoid multiple data record in the case of multiple reports in the same study (e.g., reports with different set-ups).

Results

The literature search identified a total of 163 articles in PubMed, as shown in Fig. 1.

Duplicates were removed, and then titles and abstracts of 137 articles were independently evaluated by two authors. A total of 114 articles was excluded because they did not meet the inclusion criteria. The remaining 23 potentially relevant studies were then evaluated (Fig. 1). Of those studies, two were excluded because they did not provide comprehensive data considering the purpose of the present study. Thus, 21 studies were included in this review.

Of the 21 selected studies, nine (42.9%) investigated the light-curing effect, while five articles (23.8%) evaluated the ceramic translucency. Three studies (14.3%) evaluated the degree of conversion of resin-matrix cements, and then four articles (19%) assessed the veneer thickness. The retrieved data on the resin-matrix cement, zirconia veneer thickness, the light curing, degree of conversion, and microhardness are given in Table 1. The major findings are drawn as follow:

- The amount of light that passes through the zirconia structure depends on the translucency, microstructure, zirconia chemical composition, irradiation energy, thickness, porosity, and manufacturing technique. Indeed, fully stabilized zirconia (FSZ) is more translucent than partially stabilized zirconia (PSZ) [9, 20, 21, 32];
- The translucency of the restoration is mainly affected by the zirconia thickness and by the resin-matrix cement. A high translucency is achieved within thin zirconia veneer associated with translucent zirconia and resin-matrix cement. The highest light transmittance was recorded through the zirconia materials with thickness up to 0.3 mm. A lower light irradiance was recorded on zirconia with thickness from 0.5 mm and on colored zirconia veneer when compared to translucent zirconia veneer [18, 19, 34, 35];
- The degree of conversion of resin-matrix cements is strongly affected by the polymerization mode and the zirconia thickness. Thus, an increase in veneer thickness from 0.1 mm (ultra-thin veneer) up to 1.5 mm decreases the light transmission through the zirconia to the resin-matrix cement causing a negative effect on the degree of conversion of the resin-matrix cement [14, 15, 27]. For instance, such degree of conversion ranged from 40 up to 50% after 5 min from light curing and increased gradually from 70 up to 80% within 1 week [14, 15, 27];
- The highest degree of conversion was recorded for dual-curing resin-matrix cements as a function of the polymerization reaction of their organic matrix [14]. An optimal degree of conversion of the resin-matrix cement can be achieved on a proper intensity of the light-curing unit source at 1400 mW/cm^2 and exposure time ranging from 20 up to 120 s. Also, the degree of conversion of the resin-matrix cement can occur through zirconia with 1 mm thickness on 1000 mW/cm^2 irradiation for 60 s [38]. Authors recommend the use of dual-curing resin-matrix cements but with a lower light sensitivity [8]. Also, the wavelength of the light-curing unit should be at the blue light range (360–540 nm) to stimulate all the potential photoinitiators in the resin-matrix phase since current resin-matrix cements can have different photoinitiator molecules;
- The decrease in microhardness values recorded on the resin-matrix cement was resultant from the low degree of conversion due to an increase in veneer thickness [10, 13, 26].

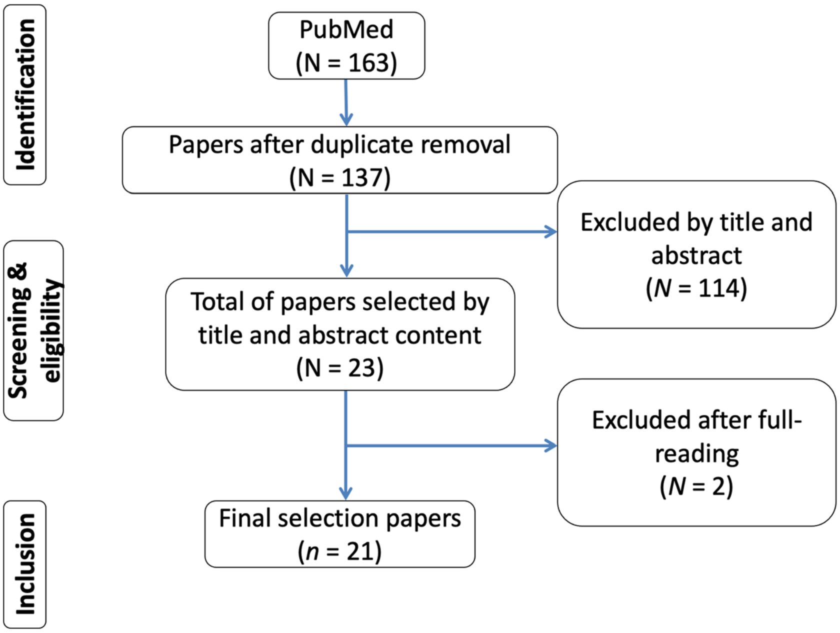

Fig. 1 Flow diagram of the search strategy used in this study

Discussion

The present integrative review reported the major results of relevant previous studies taking into account the effect of the zirconia veneer thickness on the light transmission and degree of conversion of resin-matrix cements during light curing. The microstructure, translucency, and thickness of zirconia veneers do affect the light transmission towards the resin-matrix cement. Also, the type of resin-matrix cement and light-curing method are determinant on the polymerization and properties of resin-matrix cements. Thus, the findings validate the hypothesis of this study. A detailed discussion on the main factors affecting the light curing of resin-matrix cements through zirconia veneer is provided as follow.

Zirconia: microstructure, translucency, and thickness

Y-TZP has been used to manufacture prosthetic structures such as esthetic veneers, single-unit (crown) or multi-unit prostheses due to their physicochemical properties [1, 2]. The facture toughness of YTZP is around 9–10 MPa.m$^{1/2}$, while the 3-point bending strength is ranging from 900 up to 1200 MPa [1, 17]. The first type of ordinary zirconia was stabilized with 3 mol% yttria (3Y-TZP) although its opacity is too high to mimic the teeth enamel structure. Thus, the 3Y-TZP polycrystalline microstructure results in a low translucency restorative material, and therefore, the thickness of the material affects the curing process of resin-matrix cements. Translucent ceramic or glass-ceramics are required to mimic the optical properties of teeth enamel as seen in Fig. 2. Changes in the chemical composition of zirconia resulted in high translucency zirconia that has given the capability to manufacture the entire prosthetic crown structure [8, 13]. In this way, the percentage of yttria has been increased from 5 up to 8% mol Y_2O_3, and the cubic crystals were added ranging from 20 up to 50% in the microstructure that resulted in a high translucency, but some disadvantages are related to the mechanical properties [1, 2]. Therefore, ultra-thin veneers should be produced from 3Y-TZP with high crystalline content to provide translucency and strength. Another way to increase the zirconia translucency was to decrease the amount of alumina (0.05%) and increase the content of lanthanum oxide (0.2%). Also, the size of crystals was decreased below 80 nm to enhance the translucence of the zirconia [1, 2, 17]. Also, a decrease in the size of crystals can control the roughness of the inner surface for cementation, and therefore, a low roughness provides a low light scattering leading to a proper light transmission to the resin-matrix cement [20, 39]. Thus, the surface treatment of the inner surface of the zirconia veneer must consider an adequate roughness avoiding producing an opaque material.

The optical state between complete opacity and transparency named translucency is the essential factor in proper selection of ceramic materials to achieve required esthetic outcomes. The selection of the zirconia type is critical to the recommended translucency for enamel or dentin. Also, porosity, oxide additives, grain size, and thickness can control the dispersion and absorption of light during the polymerization of prosthetic cementation [13, 18, 21]. Absolute translucency can be measured by the percentage of the transmitted light. The “relative translucency” is recorded using either the contrast ratio or the translucency parameter (TP), which is calculated as a difference in luminance and, respectively, color, when the material is assessed upon ideal black in function with

Table 1 Relevant data gathered from the retrieved studies

Author (Year)	Study design/Purpose	Resin-matrix cements (chemical composition)	Zirconia veneer thickness (mm)	Light-curing procedure	Degree of Conversion (%)	Vickers' hardness (HV)
Turp et al. (2010) [10]	In vitro study Investigation of the polymerization efficiency of dual- cured resin cement beneath different shades of zirconia-based feldspathic ceramic restorations	10- MDP, DMA, Bis-MPEPP (22wt%), silanized barium glass fillers (78wt% fillers), (Panavia F 2.0, Kuraray, Japa)	1.2	Quartz tungsten halogen curing (Hilux 200) for 20 s; 600 mW/cm^2	-	1 M2: 65 59 55 53 2 M2: 59 52 44 34 3 M2: 55 43 35 29 4 M2: 44 43 20 17 5 M2: 41 28 25 18
Turp et al. (2014)	In vitro study Evaluation of the effect of thickness of zirconia on curing efficiency of resin cements	10-MDP, DMA, Bis-MPEPP (22wt%); silanized barium glass fillers (78wt% fillers), (Panavia F 2.0, Kuraray)	G: 0.5 G1: 0.5 + 0.5 porcelain G2: 1.0 + 0.5 porcelain G3: 1.5 + 0.5 porcelain	LED (Elipar S10, 3 M, ESPE, Saint Paul, MN, USA) for 20 s, 430–480 nm, 1200 W/cm^2	55-75	G0: 69.95 62.67 53.15 G1: 65.26 58 49 G2: 62.8 54.15 43.64 G3: 52.1 49.33 39.41
		Bis-GMA, UDMA, TEGDMA (38wt%), glass fillers (62wt% fillers), (Duo-Link, Bisco, USA)				G0: 66.05 56.12 48.15 G1: 58.43 48.29 43.47 G2: 55.18 44.78 39.23 G3: 47.78

Table 1 (continued)

Author (Year)	Study design/Purpose	Resin-matrix cements (chemical composition)	Zirconia veneer thickness (mm)	Light-curing procedure	Degree of Conversion (%)	Vickers' hardness (HV)	
						39.37 29.68	
Caprak et al. (2018)	In vitro study Evaluation of the influence of the translucency parameters (TPs) of current monolithic CAD/CAM blocks on the microhardness of light-cured or dual-cured resin cement	Bis-GMA, UDMA, TEGDMA (38wt%), glass fillers (62wt% fillers); (Duo-Link, Bisco, USA)	2.00	LED (HS-LED1500; Henry Schein, Ontario, Canada) for 40s; 1500 mW; 450–470 nm	-	Dual cure G0:59.90 G1: 53.42 G0: 57.9 G1: 52.02 G0: 56.56 G1: 49.73 G0: 56.83 G1: 48.94	Light cure G0: 56.36 G1: 48.01 G0: 54.77 G1: 46.27 G0: 53.19 G1: 45.07 G0: 53.21 G1: 43.32
Bansal et al. (2016) [32] (2016) [22]	In vitro study Evaluation of the effect of ceramic type, thickness, and time of irradiation on degree of polymerization of dual-cure resin cement	UDMA, TEGDMA, 4-META, 2-hydroxyethyl methacrylate, dibenzoyl peroxide; benzoyl peroxide; dental glass; (SoloCEM, Coltène, Switzerland)	2.0 3.0 4.0	Halogen curing light (Spectrum 800, Dentsply, Baar, Switzerland) 40, 60 and 80 s; 600 mW/cm^2	-	-	Bansal et al.,
Shiomuki et al. (2013) [33]	In vitro study. Evaluation of the effects of these factors on the degree of polymerization of dual-cure cement (Panavia F2.0) placed under a restoration: light transmission property of restoratives materials, distance from the directly irradiated surface, and elapsed time after light irradiation	10- MDP, DMA, Bis-MPEPP (22wt%), silanized barium glass fillers (78wt% fillers); (Panavia F 2.0, Kuraray, Japan)	3	LED (G-Light) for 5 s	-	- -	
Lopes et al. (2015) [27]	In vitro study Evaluation of the degree of conversion (DC), Vickers microhardness (VH) and elastic modulus (E) of resin cements cured through different ceramic systems	Bis-GMA, Bis-EMA, TEGDMA (34wt%), Barium alumo-silicate glass, silica fillers (66wt% fillers), (Allcem, FGM, Brazil). Bis-GMA, urethane dimethacrylate, and triethylene glycol dimethacrylate. (28wt%), Barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass, and silica fillers (72wt% fillers), (Variolink II, Ivoclar Vivadent, Liechtenstein).	1.5	Conventional Halogen light curing (Optilux) for 120 s; 501–650 mW/cm^2	-	G0: 74.4 G1: 71.1 G0: 60.7 G1: 67.9 G0: 70 G1: 76.2 G0: 44 G1: 43.7	

Table 1 (continued)

Author (Year)	Study design/Purpose	Resin-matrix cements (chemical composition)	Zirconia veneer thickness (mm)	Light-curing procedure	Degree of Conversion (%)	Vickers' hardness (HV)
		Methacrylate monomers containing phosphoric acid groups, methacrylate monomers (28wt%), silanated fillers, alkaline fillers 0(72wt% fillers), (RelyX U200, 3M, USA). Bis-GMA, UDMA, Bis-EMA, HEMA (43wt%), barium glass, ytterbium trifluoride, silica fillers (57wt% fillers); (Multilink, Ivoclar Vivadent, Liechtenstein).				
Alovisi et al. (2018) [15]	In vitro study Assessment of the conversion degree (DC), micro-hardness (MH), and bond strength of two dual-curing resin cements employed under translucent monolithic zirconia irradiated with different time protocols	Methacrylate monomers containing phosphoric acid groups, methacrylate monomers (28wt%), radiopaque alkaline fillers (72wt% fillers), (RelyX Ultimate, 3M, USA)	1	LED (Valo, Ultradent, South Jordan, UT, USA) for 0 s, 20 s and 120 s; 1400 mW/cm^2		
Sulaiman et al. (2015) [26]	In vitro study Evaluation of the influence of material thickness on light irradiance, radiant exposure, and the degree of monomer conversion (DC) of 2 dual-polymerizing resin cements light-polymerized through different brands of monolithic zirconia	Methacrylate monomers containing phosphoric acid groups, methacrylate monomers (28wt%), silanated fillers (72wt% fillers), (RelyX Ultimate, 3M, USA). Bis-GMA, UDMA, and TEGDMA (28wt%), Barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass, and silica fillers (72 wt% fillers), (Variolink II, Ivoclar Vivadent, Liechtenstein).	0.5 1.0 1.50 2.00	LED (Elipar S10) for 20 s; 1200 mw/cm2; 430–480 nm LED (Elipar S10) for 40 s; 1200 mw/cm^2; 430–480 nm	63.1 66	
Malkondu et al. (2016) [34]	In vitro study Evaluation of the color changes in terms of the perceptibility and acceptability of monolithic zirconia-and cement combinations with 2 monolithic zirconia thicknesses and 3 types of cement. The translucency parameters of these combinations were also compared	Methacrylate monomers containing phosphoric acid groups, methacrylate monomers (28%), silanated fillers, alkaline fillers (72wt% fillers) , (RelyX U200, 3M, USA)	0.6 1.0	LED (Elipar S10, 3 M ESPE) for 20 s; 1200 mW/cm^2; 430–480 nm		
Capa et al. (2017) [19]	In vitro study Evaluation of the effect of the different color of resin cements and zirconia cores on the translucency parameter (TP) of the restoration that simulates the implant-supported fixed prosthesis using titanium base on the bottom	Methacrylate monomers containing phosphoric acid groups, methacrylate monomers (28wt%), silanated fillers Radiopaque alkaline fillers (72wt% fillers), (RelyX Ultimate, 3M, USA). Methacrylate monomers containing phosphoric acid groups, methacrylate monomers (28%), silanated fillers, alkaline fillers (72wt%), (RelyX U200, 3M, USA)	0.5	Halogen curing light (Optilux 501, Kerr Corporation, Orange, CA, USA) for 40 s		
Inokoshi et al. (2016)	In vitro study Assessment of the light irradiance (LI) delivered by two light-curing units and to measure the degree	Bis-GMA, TEG-DMA (30wt%), silanated barium glass filler (70wt% fillers), (Clearfil esthetic cement, Kuraray, Japan). 10- MDP, DMA,	0..5 1.5	LED (G-Light Prima and SmartLite FOCUS) for 40 s		

Table 1 (continued)

Author (Year)	Study design/Purpose	Resin-matrix cements (chemical composition)	Zirconia veneer thickness (mm)	Light-curing procedure	Degree of Conversion (%)	Vickers' hardness (HV)
[35]	of conversion (DC) of three composite cements and one flowable composite when cured through zirconia or ceramic-veneered zirconia plates with different thicknesses	Bis-MPEPP (22wt%); silanized barium glass (78wt%), (Panavia F 2.0, Kuraray, Japan). UDMA, dimethacrylate, phosphonate monomer, γ-methacryloxypropyltrimethoxysilane, α,α-dimethylbenzyl hydroperoxide; fluoro alumino silicate glass, silica fillers, Fluoro alumino silicate glass fillers, (G-CEM LinkAce, GC corp., Japan). Bis-MEPP, TEG-DMA (31wt%), strontium glass (69wt% fillers) (G-aenial Universal Flo,GC corp., Japan).				
Turp et al. (2018) [21]	In vitro study Evaluation of the influence of anterior monolithic zirconia and lithium disilicate thickness on polymerization efficiency of dual-cure resin cements	10- MDP, DMA, Bis-MPEPP (22wt%), silanized barium glass fillers (78wt% fillers), Panavia F 2.0, Kuraray, Japan)	0.5 1.0 1.5 2.0 2.5 3.0	LED (Elipar S10, 3 M, ESPE, Saint Paul, MN, USA) for 20s (Panavia F2.0 and RelyX U200) and 40s (DuoLink Universal)	-	G0: 139 131.3 118.9 98.9 G1: 135.17 127.13 115.39 99.93 G2: 133.67 125.07 114.49 94.03 G3: 130.33 123.98 112.89 90.85 G4: 129.77 122.25 84.26 64.56
Valentino et al. (2010) [36]	In vitro study Study of the influence of ceramic compositions on Knoop hardness number (KHN) immediately and 24 h after polymerization and the effect of activation modes on the KHN of a resin cement	10- MDP, DMA, Bis-MPEPP (22wt%), silanized barium glass fillers (78wt% fillers), (Panavia F 2.0, Kuraray, Japan)	1.2	Quartz-tungsten-halogen light (3 M ESPE) for 40 s; 650 mW/cm2	-	
Gültekin et al.	In vitro study	10- MDP, DMA, Bis-MPEPP	Z: 0.5	LED (Elipar S10, 3 M ESPE, Seefeld, Germany) for 20 s	-	QTH: Z:66.78 LED: Z:69.95

Table 1 (continued)

Author (Year)	Study design/Purpose	Resin-matrix cements (chemical composition)	Zirconia veneer thickness (mm)	Light-curing procedure	Degree of Conversion (%)	Vickers' hardness (HV)	
(2015) [22]	Evaluation of the polymerization efficiency of dual-cure resin cement cured with two different light-curing units under zirconia structures having differing thicknesses	(22wt%), silanized barium glass fillers (78wt% fillers), (Panavia F 2.0, Kuraray, Japan)	Z1: 0.5 +0.5 Porcelain Z2: 1.0 +0.5 Porcelain Z3: 1.5+ 0.5 Porcelain	(5 s rmp, 15 s full cure); 430–480 nm; 1200 mW/cm2 QTH (Hilux 200, Benlioglu, Istanbul, Turkey) for 40 s (time in continuous mode); 410–500 nm; 600 mW/cm2		60.52 48.71 Z1:58.85 54.35 44.15 Z2:52.77 48.29 41.34 Z3:49.37 46.20 37.88	62.67 53.15 Z1:65.26 58 49 Z2:62.80 54.15 43.64 Z3:52.10 49.33 39.41
Gültekin et al. (2015) [22]	In vitro study Evaluation of the polymerization efficiency of dual-cure resin cement cured with two different light-curing units under zirconia structures having differing thicknesses	10- MDP, DMA, Bis-MPEPP (22wt%), silanized barium glass fillers (78wt% fillers), (Panavia F 2.0, Kuraray, Japan)	Z: 0.5 Z1: 0.5 + 0.5 Porcelain Z2: 1.0 + 0.5 Porcelain Z3: 1.5+ 0.5 Porcelain	LED (Elipar S10, 3 M ESPE, Seefeld, Germany) for 20 s (5 s rmp, 15 s full cure); 430–480 nm; 1200 mW/cm2 QTH (Hilux 200, Benlioglu, Istanbul, Turkey) for 40 s (time in continuous mode); 410–500 nm; 600 mW/cm2	-	QTH Z:66.78 60.52 48.71 Z1:58.85 54.35 44.15 Z2:52.77 48.29 41.34 Z3:49.37 46.20 37.88	LED Z:69.95 62.67 53.15 Z1:65.26 58 49 Z2:62.80 54.15 43.64 Z3:52.10 49.33 39.41
Shim et al. (2017) [37]	In vitro study Evaluation of the polymerization mode of self-adhesive, dual-cured resin cements light-cured through overlying materials with different degree of translucency by measuring the degree of conversion (DC)	UDMA, dimethacrylate, phosphonate monomer, γ-methacryloxypropyltrimethoxysilane, α,α-dimethylbenzyl hydroperoxide, fluoro alumino silicate glass, silica fillers, (G-CEM Link ACE, GC corp., Japan) Bis-GMA, glycerol phosphate dimethacryalte (GPDM), co-monomers (33wt%), fluoro aluminio silicate glass, fumed silica, barium glass, ytterbium fluoride fillers (67wt% fillers) (Maxcem Elite, Kerr, USA) Bis-GMA, phosphate acidic monomer, dental glass (BisCem, Bisco, USA)	1	LED (Dr's Light; Good Doctors Co., Incheon, Korea) for 40 s; 718 mW/cm2	50-75	-	

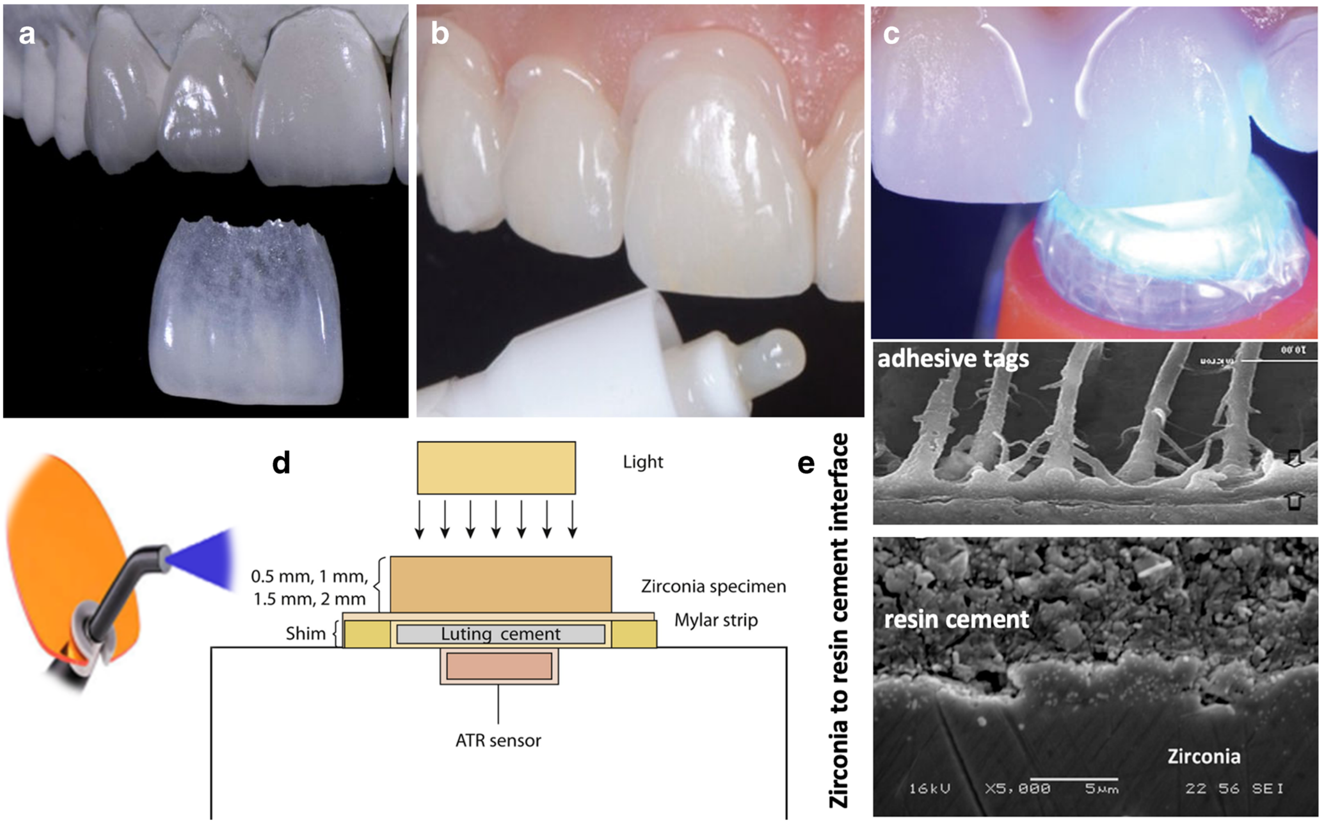

Fig. 2 Schematics of the resin-matrix cement light curing through a zirconia veneer. (**a**) Zirconia veneer and the (**b**) resin-matrix cement application. (**c**) Light curing of the resin-matrix cement. (**d**) Schematics of the tests assessing the effect of different thickness of zirconia veneer (Adapted from Sulaiman et al [26]). (**e**) SEM images of the zirconia to resin-matrix cement interface

the white background [18, 32]. Opaque materials reveal high TP values. However, ideal white and black backgrounds are not commonly used for translucency measurements, due to their availability. A relative translucency parameter (RTP) must be considered when optical measurements are carried out on non-ideal backgrounds and when optical properties of the material are not homogeneous throughout its thickness. The values of this parameter are relative to the color of the white and black backgrounds used for measurements [2, 12, 18, 32].

Prior the cementation, Y-TZP inner surface is often modified by airborne abrasion (grit-blasting process) with alumina (Al_2O_3) particles followed by silica (SiO_2) particles [4–6]. Also, the application of a glass-ceramic thin layer (liner) can be an alternative approach to provide a silica-based coating which can be conditioned by 9% hydrofluoric acid (HF) [40]. However, the increase in roughness can also act as factor of light diffraction depending on roughness magnitude.

Regarding the low translucency and properties of 3Y-TZP, the thickness can play a key role on the clinical success of prosthetic restoration concerning cementation, esthetics, and mechanical performance. The selected studies have shown a significant influence of the veneer thickness on the light transmission through the ceramic leading to an adequate polymerization of the resin-matrix cement, as seen in Table 1. The minimum ceramic thickness for monolithic indirect restorations was recorded at around 0.2–0.3 mm. A previous study reported 46.5% contrast ratio and 8.6% higher translucency for 0.3-mm Y-TZP veneer when compared to 0.5 mm YTZP veneer [41]. The findings were corroborated by another previous study on the measurement of the light irradiance by Raman light spectrometry for 40 s regarding different thickness of zirconia veneers [30]. In fact, there is an inverse relationship between irradiating energy, translucency, and thickness, since a thick or opaque zirconia veneer can decrease the light transmission to the resin-matrix cement. [26].

Resin-matrix cements and light-curing parameters

Considering the chemical similarity to resin-based composite materials, the chemical composition of resin-matrix cements can involve a combination of several monomers and fillers, as shown in Table 1. The polymer-matrix of resin-matrix cements is composed of methacrylate monomers (22–60%wt) like Bis-GMA, UEDMA, and TEGDMA, while the inorganic content is composed of colloidal silica, ytterbium fluoride, zirconium glass, or barium glass fillers [36, 42].

Taking into account the chemical composition, resin-matrix cements have properties quite similar to that of flowable resin composite materials such as low solubility, translucency, and flowability [10, 24, 42]. The viscosity or flowability of the resin-matrix cements provides a mechanical interlocking to the primer-coated enamel and restorative surfaces. Also, the presence of 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) promotes a physicochemical bonding to restorative ceramic surfaces [24]. On the advances in adhesive dentistry, resin-matrix cements have become the first choice materials for the adhesion of ceramics to the teeth surfaces due to their physicochemical properties and clinical procedures [13, 24, 36].

The chemical composition of the resin-matrix cements also varies in the presence or not of photoinitiator compounds. Currently, dual-curing resin-matrix cements are the most commonly materials used in fixed prostheses, since they have a polymerization activated by visible light at around 320–480 nm and by a chemical polymerization activation when two pastes are mixed [14, 15, 27]. The interaction between the benzoyl peroxide and tertiary amines (dimethyl-p-toluidine) is responsible for the chemical activation, while photoinitiator molecules such as canforquinone are stimulated by the light. The adequate properties of the materials are achieved by the accomplishment of the polymerization process that is mainly dependent on the chemical composition and microstructure of the veneer material [26, 27, 37]. Considering the chemical composition of the resin-matrix cements, most of studies have correlate their chemical composition to the light irradiance time and intensity by infrared spectroscopy analyses [26, 27, 37]. Also, the content and optical properties of the fillers can affect the light transmittance. On the other hand, a high filler content provides the required strength to the material [15, 36].

A previous study reported a negative effect of the Y-TZP thickness on the polymerization of resin-matrix cements [21] that was related to an inadequate irradiance of the light source. A decrease of light-curing transmission source was recorded from 900 mW/cm^2 (without veneer) down to 585 mW/cm^2 through 0.2-mm polycrystalline ceramic and to 549 mW/cm^2 through 1.2-mm ceramic polycrystalline ceramic. In fact, dual resin cement showed significant differences in polymerization under polycrystalline ceramic thickness of 1.2 mm when compared to veneer thicknesses ranging from 0.3 to 0.9 mm. The analyses were performed with a spectrophotometer at the middle and cervical regions across the veneer. The values recorded for contrast ratio and translucency were acceptable at the body region although there was a bias of results for the cervical region. On 1.65-mm veneers, the degree of conversion of the resin-matrix cement was significantly low when the light irradiation was below 300 mW.cm^{-2}. However, the threshold thickness of Y-TZP veneer was not determined [21]. Previous studies evaluated the polymerization of the resin-matrix cement through different Y-TZP specimens, as follow: 0.5–3, 0.6–1.0, 1.5, and 0.5–1.5 mm. The highest mean values of microhardness and degree of conversion were recorded for 0.5–1.0 mm Y-TZP thickness, as seen in Table 1 [21, 22, 34, 35]. Kim et al. [14], Gultekim et al. [22], and Inokoshi et al. [35] showed that the transmittance of light decreases as the thickness of the ceramic veneer increases, generating an inadequate light transmission and poor degree of conversion in the inner region of the prosthetic restoration [15]. A thick 3-YTZP veneer negatively affects the light irradiance and polymerization of the resin-matrix cement and then decreases its degree of conversion and color stability [21, 35]. Additionally, monolithic 3Y-TZP provided a lower light transmission value compared to other ceramic materials like lithium disilicate-reinforced glass-ceramic [12].

The light-curing process depends on the irradiance source, exposure time, and distance, and therefore on the resin-matrix cement [47-49]. Thus, the degree of conversion related to the light curing is a key factor when selecting resin-matrix composite materials [24, 25]. A low degree of conversion can promote detrimental effects to the physicochemical properties of the resin-matrix materials such as water sorption, solubility, low strength, lack of hardness, and undesirable optical properties [36]. Also, that compromises the integrity of the tooth-cement-zirconia interface. Resin-matrix cements have been evaluated concerning physical properties like hardness, elastic modulus, and strength, as seen in Table 1 [15, 21]. The depth of the light-curing irradiance can be related to both resin-matrix composite thickness and distance from the light-curing handheld device tip [13, 27]. Previous studies reported an enhancement of the degree of conversion and microhardness of the resin-matrix composite when the irradiance time was increased [10, 15]. High values of degree of conversion and micro-hardness were recorded for resin-matrix cements after LED irradiation time ranging from 20 up to 120 s, as shown in Table 1. According to the results of similar studies, dual-curing resin-matrix cements have revealed greater long term clinical success when compared to self-curing or light-curing cements [15]. The degree of conversion of four brands of resin-matrix cements has been evaluated by ATR/FTIR spectrometry, while their mechanical behavior has been evaluated by dynamic indentation test (e.g., microhardness test) [27]. Lopes et al. [27] showed that the chemical curing provided low microhardness values, and therefore, that finding was also corroborated by another previous study [18]. Groups of resin-matrix cements which were light-cured through zirconia or lithium disilicate glass-ceramic veneers showed a higher degree of conversion than those for self-cured groups [37]. Therefore, a previous study revealed higher values of VHN (Vickers hardness number) for samples light-cured under LED source when compared to QTH source at higher depth of light curing [22].

An important aspect of the polymerization of resin-matrix cements is related to the light-curing parameters. Irradiation power, wavelength, and curing time determine the energy for polymerization of the material. Another key factor to take into account is the photoinitiatior molecules in the material that generate the activation of free radicals [27, 37]. Most of studies carried out the light curing with a wavelength at 430–480 nm [19, 21, 22, 26, 34, 35] while a few studies reported adequate values of degree of conversion and microhardness by using a wavelength at 500 nm (Fig. 2) [14, 22, 26]. One study showed that the highest transmitted irradiance was achieved through a 0.5-mm ceramic thickness regardless of the type of ceramic material, although it decreased as the ceramic thickness increased. That study evaluated 35 zirconia specimens and 7 glass-ceramic (control) specimens, which were then stained with different shades (CL1, CL2, CL3, and CL4), but one specimen remained unstained (CL0) [8].

Among the retrieved articles, the highest light irradiation power values of the light-curing sources recorded as regards the depth of the polymerization were at 1400 and 1500 nW/cm^2 [15, 18]. In fact, previous studies recommended a light intensity higher than 1000 nW/cm^2 for polymerization of resin-matrix cements [19, 21, 22, 26, 34, 35]. However, adequate degree of conversion of dual-curing resin-matrix cements was achieved under LED light curing in a lower power of 718 nW/cm^2 [37]. A previous study showed a higher degree of conversion when groups of specimens were exposed to a longer irradiation time. Nevertheless, there was no significant difference for the irradiated groups with 1000 or 1500 mW/cm^2. On longer exposure time, an increase in temperature can be noted for 1000 mW/cm^2 when compared with an irradiation of 500 mW/cm^2 that can lead to unfavorable damage of the dentin tissue [38]. The increased energy absorbed by the dentin surface can promote the denaturation of proteins and the damage of dentinoblasts leading to a harmful sensitivity to the patients. The damage of the dentin-pulp complex depends on the level and depth of injury. Furthermore, such damage can be irreversible resulting in the retreatment by using invasive procedures and the replacement of the restoration. A previous study assessed the irradiation technique, polymerization time, and storage conditions by measuring the Vickers hardness and the degree of conversion of resin-matrix cement. Findings revealed that proper mechanical properties can also be achieved within a minimum irradiation time in fucntion of a high power irradiation [42].

In fact, dual polymerization of resin-matrix cements is recommended since the light-curing unit and parameters might have limitations regarding thickness and microstructure of different zirconia structures. Knowledge on visible and blue light could help clinicians to individually adapt the light-curing parameters to different ceramic materials. Also, the light-curing unit can have different light wavelength and intensity for several resin-matrix cements regarding the development of several photoinitiators for the polymeric matrix of the resin cement. On the other hand, the technicians must provide the maximum information on the microstructure of the zirconia veneer for adjustment of the light-curing guidelines. Further studies should be carried out concerning the chemical composition, thickness, and microstructure (i.e., crystal size, crystallinity, defects) of zirconia-based materials. Also, surface modifications of the inner surface of zirconia veneer or glass-ceramic coating of the outer region can affect the light transmission through the ceramic material towards the resin-matrix cement, and therefore, those factors should be carefully evaluated in future studies.

Conclusions

This integrative review reported previous findings regarding the effect of the thickness and microstructure of zirconia on the light transmission required for the polymerization of resin-matrix cements. Within the limitations of the selected studies, the following conclusions can be drawn:

- The thickness of the zirconia veneers is determinant for an appropriate esthetic outcome since a thick zirconia-based veneer negatively affected the light transmission to the resin-matrix cement. That results in the decrease of the degree of conversion of resin-matrix monomers leading to a low chemical stability that can be detected by color instability and low microhardness values.
- The zirconia microstructure also plays an important role on the light transmission once the polycrystalline structure can vary depending on the chemical composition and sintering of the zirconia structure by different manufacturers. However, zirconia materials such as Y-TZP containing lower amounts of alumina showed a high transmittance.
- In clinical applications, the light-curing parameters should also be controlled regarding the thickness and microstructure of zirconia structures. For instance, the light-curing intensity and time should be increased for thick and opaque zirconia. On the other hand, thin and ultra-thin zirconia veneers associated with translucent resin-matrix cements have achieved proper optical results for clinical applications as esthetic veneers.

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Declarations

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors

Informed consent For this type of study, formal consent is not required.

Conflict of interest The authors declare no competing interests.

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