Factors Affecting Resin Polymerization of Bonded All Ceramic Restorations. Review of Literature

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ABSTRACT

Increased conservative and cosmetic dental practice has raised the demand for predictable adhesive all ceramic restorations (Inlay, onlay, crowns and FPD). Many new bonded all ceramic systems have been introduced improving their optical, mechanical, adhesive and working properties. As they are adhesively bonded to tooth substrate (enamel and dentine), the resin luting cements and the adhesive interface are pivotal for their longevity. Light-cured resin cements (LCC) are often preferred due to their controlled polymerization characteristics. As there is no chemical curing for LCC they require sufficient light to initiate and maintain polymerization. However deep preparations and thick restorations may decrease the light intensity resulting in incomplete polymerization. Other factors like ceramic type, shade and translucency; resin cement type, composition and shade; light curing unit and method of testing similarly influence the luting resin polymerization and its investigation. Insufficient polymerization could lead to poor mechanical and biological properties of the luting cement, compromised mechanical characteristics of bonded ceramics and a decrease in the bond strength between tooth and restoration. This literature review will evaluate multiple factors which could potentially influence the resin polymerization of all ceramic bonded restorations.

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INTRODUCTION

With the increasing emphasis of tooth conservation and the high demand on aesthetic restorations, dentists have been dominated by the concepts of adhesive and cosmetic dentistry. The cosmetic material of choice ceramic and the improved resin bonding agents have contributed greatly to the increased demand on cosmetic indirect restorations.

Although, there has been phenomenal development of core ceramic materials in the last decade, resin bonded glass ceramic inlay, onlay, veneers and crowns are still a viable and preferred option for conservative cosmetic dentistry. Adhesive cementation of glass-ceramic restorations with resin cement of good physical properties can allow them to withstand higher masticatory forces and demonstrate improved clinical performance,[1] hence is critical for successful bonding. A recent study evaluating clinical performance of resin-bonded glass ceramic inlays and onlays reported success rate of 92% over 8 years.[2] However, insufficient polymerization of the luting cement could lead to inferior mechanical properties. The degree of polymerization can further affect physico-mechanical properties, solubility, dimension stability, color change and biocompatibility.[3] Thickness and translucency of the ceramic, composition and shade of the luting agent are reported to influence the rate of resin polymerization, which intern effect its mechanical properties. Furthermore the type of light source, their intensity and the exposure time are controversially known to control the degree of resin polymerization.[4,5] It has been shown that ceramics tend to absorb light and ceramic restorations of increased thickness (onlay) require increased curing time.

The development of new ceramics (E-max press-Lithium disilicate glass ceramic), assessment of light absorption on frequently uncontrolled ceramic thickness (onlay) and controversial effect of exposure times needs to be assessed in a controlled environment for developing predictable degree of polymerization. This review of literature aims to evaluate and present in light of evidence the means of assessment of polymerization extent and the factors effecting resin polymerization under all ceramic restorations, mainly, the bonded ceramic materials, the bonding complex, resin luting agents, photo-polymerization units, methods

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of polymerization evaluation and the influence of thickness of ceramic material on polymerization.

Bonded Dental Ceramics

All-ceramic restorations are broadly classified as either resin bonded ceramics supported by the tooth structure itself or all-ceramic restorations, supported by high-strength core such as alumina or ytrria-stabilised zirconia (Table 1). All-ceramic restorations are increasing in popularity as different studies, have shown their good long-term success and in terms of color, surface texture and translucency make them difficult to differentiate from un-restored natural tooth.[6]

Currently on the market there are various types of all-ceramic systems that are used clinically. They can be manufactured by heat pressing, slip-casting, sintering and computer-aided design/computer-aided manufacturing (CAD/ CAM) milling of ceramic blocks or presintered blocks.

Most of the materials available for resin-bonded ceramic restoration are a group of materials known as glass ceramics and according to the composition and physical properties the following classification could be done,

1. Feldesphatic glass ceramic
2. Leucite-reinforced glass ceramics
3. Fluormica glass ceramic
4. Lithium disilicate glass ceramic

Glass ceramics are silica-based, which present predictable bonding procedure with durable results.[7] They posses excellent esthetic properties rendering them material of choice for laminate veneers,[8] for inlays, onlays[9] and crowns. Silica-based ceramics, currently have limited use due to poor mechanical and physical properties, although it still is employed mainly for the fabrication of veneers and veneering ceramic cores and machined ceramics. Leucite- reinforced glass ceramic was previously used for veneering metal frameworks. The leucite ceramic crystals provide increased fracture toughness and flexural strength, enhancing the mechanical properties. It is used for fabrication of resin bonded ceramic inlays, onlays and veneers. The addition of leucite to feldspathic ceramic improves its flexural strength from 40 Mpa upto 120Mpa .Currently on the market, it could be found in the form of; Heraceram Press (Hreraeus Kulzer),a synthetic, low fusing, quartz glass-ceramic and; IPS Empress (Ivoclar-Vivadent), the ceramic is in majority glass with crystalline leucite. Studies have shown some limitations in its use in the posterior region of the mouth in the form of onlays/inlays or crowns due to low strength.[10] However, according to Kramer[2] et al, in a study about the clinical performance of bonded leucite-reinforced glass ceramics inlays and onlays on molars/premolars during a period of eight years has shown a survival rate of 92%. Untill recently it was commercially available however it is now been replaced with lithium disilicate (EMAX) material.

Lithium disilicate is based on silica glass material having lithium disilicate crystals which can be bonded to tooth using adhesive system cementation. Due to its microstructure, the material presents high flexural strength, good optical properties, and excellent translucency. The mechanical properties are much superior,with a flexural strength of 350-450Mpa and the fractures toughness approximately three times than the leucite reinforced glass ceramic.[11] Their production could be done by hot-pressing technique, e.g. IPS Emax (substituing Empress II) or by CAD-CAM system e.g. IPS Emax CAD. E. Max is advocated in the dental literature to be used for inlays, onlays, crowns and anterior FPD.[12-14] According to Kramer[12] et al, in a controlled prospective clinical split-mouth study: totally bonded ceramic inlays and onlays after eight years, had a failure rate of 10%. Valenti[13] et al, in a retrospective study of bonded lithium disilicate ceramic restorations reported a 95.5% survival rate over 120 months. In addition, similar rates by Wolfart[14] et al on a prospective 8 years follow up study made on short span three-unit fixed dental prosthesis showed 93% survival rate.

Thickness, translucency of the ceramic, composition and shade of the cement might have an influence on polymerization on the resin luting cement and therefore on its mechanical properties such as hardness, fracture toughness, wear resistance, elastic modulus, solubility, degradation and bond strength.

Tooth-Ceramic Bonding Complex

The bonding interface: tooth/ luting composite/ ceramic plays a very important role in survival and success of bonded ceramic restorations. The bonding of the ceramic to the tooth structure uses adhesive techniques and luting resin composite cement. Bonding to enamel is considered a long-lasting procedure due to its hydrophilic nature. However dentine bonding is less durable due to its hydrophobic nature and presence of smear layer. Continuous material research has resulted in compatible and highly durable bifunctional molecules (Primers and Bonding agents) for predictable dentin bonding.

The long-term success of the ceramic restoration is determined by the strength and durability of the bond between the three components.[15] As the tooth requires a conditioning regime of etch-prime-bond, the ceramic surface treatment includes etching with hydrofluoric acid for mechanical retention and treatment with silane coupling agents as a bi-functional molecule for chemical adhesion to silica particles in ceramic. The luting resin must provide retention, as its main role and act as a sealing interface and a barrier against microleakage between the tooth and restoration. Different cementation and bonding techniques have been employed in all-ceramic restorations. Dijken[16] et al, demonstrated in a clinical study over a period of 6 years on sintered ceramics, that glass ionomer luting cements exhibited higher failure than resin composite cements. However, it has been demonstrated in some studies that glass ionomers and resin modified glass ionomers behave less favorable than resin composite cements, particulary glass ionomers cements being more suseptible to early water degradation resulting in microcracks facilitating crack propagation within the cement.[17]

Resin based composite luting agents

It has been well proven in the dental literature that breakdown of the cement might result in microleakage, marginal discoloration, pulpal irritation, secondary caries and de-cementation. The ideal requirements of the dental adhesive luting material should be, nonirritant-biocompatible to both hard and soft tissues, provide durable bond between tooth and restoration, low solubility, adequate wet-ability to both tooth and restoration, good tensile and compressive strength, be strong enough to resist fracture when loads are applied to the restoration, adequate film thickness and viscosity, controlled setting and working characteristics.[18]

Resin based composite cements present composition and characteristics similar to conventional restorative composites and can be classified as the restorative composite materials (Table 2). Virtually any restorative composite could be used as a resin-based luting cement.[19]

The high compressive strength of resin cement (320Mpa) increases the fracture resistance of the restoration. The elastic modulus is similar to the dentin, which minimizes stress concentrations at the cement-tooth interface. Resin cements are many times stronger, up to 20x, and tougher, up to 130x, in flexure than the conventional cements.[20] Resin based composite cement are the material of choice for luting all-ceramic restorations.[21] particularly for adhesive luting.[22]

One of the drawbacks of the resin cement is polymerization shrinkage resulting in microgaps and microleakage. Dentin bonding agents (multicoating: etch-primer-adhesive) compensate for the shrinkage due to the use of the adhesive coatings over the primer.[15]

Resin cements with low filler content are more flowable and have an improved bond to tooth. However studies have shown that high filler luting resins show better bond strength. An in vitro study done by Hahn et al,[23] revealed luting spaces greater for inlays cemented with low viscous materials than those luted with high viscous materials at the dentinal margins, using a dye penetration analysis. Acquaviva et al[24] demonstrated in a study done of one hundred and eight onlays of different thickness (2,3,4mm). luted with different cements that preheated light cured hybrid composite enhanced the performance of the composite as luting cement under onlays of great thickness. Depending on their activation mode resin cements could be classified as,

Light cured
Chemical cured
Dual cured (Light and chemical cured)

It has been shown that polymerization performance of dual cure cements was better when dual resin cements were light activated.[25] In a study done by El-Barany et al[26] on chemical versus dual curing of resin inlay composites and ceramic, demonstrated that hardness of chemical phase alone of the dual cure cements was lower than curing with light. It was claimed that chemical curing solely was not sufficient to achieve maximum cement polymerization. Light-curing composites show better performance with relation to working time than dual-cure or chemically curing materials. In addition, their color stability is greater compared with the dual-cured composites particularly when the ceramic thickness is optimum.[27]

Self-etch-self-adhesive luting eliminates the need for pre-treatment of the bondable surfaces and provides easier handling for bonding procedure. Self-adhesive resins are simpler and result in low post-operative sensitivity when compared with the 3 step etch-and-rinse technique.[12] According to Frankenberger et al,[19] resin based self-etch-self-adhesive cements exhibit promising results for dentine bonding but not for enamel bonding as compared to 3 step etch-and-rinse adhesives. Vrochari et al,[28] compared the curing efficiency of four self-etch-self-adhesive dual cure resin cement and a conventional dual cure resin cement in an in vitro setting, demonstrating better performance for dual cure conventional luting cements.

Light Curing Unit

Light activation units must deliver adequate radiation intensity within the correct wavelength to the luting material in order to activate polymerization.

The absorption radiation of the camphorquinone requires a wavelength between 460-480nm. Currently, there exists a wide range of light sources with different output-light intensities (mW cm^2) and wavelength radiance (nm). ISO recommendation regarding intensity for polymerization light is 300mW/cm2.

Halogen lamps (QTH) are conventional type of blue visible light activation system, based on light produced by a quartz tungsten halogen bulb.

They present a wide wavelength spectrum in range of 380 to 550nm, activating camphorquinone, however increases heat during polymerization and provides poor control on radiation dispersion. A study by Rueggeber et al,[29] reported QTH lamp to be less time consuming, furthermore different tip diameters did not show an increase in polymerization.

Plasma arc lamp is another type of light source which uses a xenon bulb. They show high radiance intensity, with extremely high power output, requiring an effective cooling system. They utilize a 2-3 second exposure time compared to 30 seconds for conventional lamps.[30] However, studies have shown that the high light intensity cures the outlayer of the resin early, encouraging poor polymerization of the inner layers. Interestingly enough, an experiment by Usumez et al,[5] revealed greater adhesive failure between the resin (dual cured) and porcelain restoration using plasma arc light and lithium disilicate veneers. Ozturk et al,[31] reported plasma arc lights to be less time consuming however, the extent of polymerization was less than or equal to halogen lamps. Argon laser lamp is more efficient light source with a narrower wavelength. However, it may not be compatible with materials that have a different activator than camphorquinone.

Light emitting diodes (LED) emit blue light in a narrow wavelength band. Some of their advantages include, heatless light emission, narrow wavelength band but compatible with most of the activators, they allow for soft start curing activation to optimize polymerization procedure and minimize the effects of shrinkage,[32] less damaging to the pulp-tooth structure, do not require any cooling device and easier to handle and work with. In a study by Nalcaci et al[33] LED lights were found to result in better shear bond strength of 3mm lithium disilicate ceramics when bonded to resin , they also found that LED units were the preferred option for curing resin due to short polymerization time. Ferracane et al,[34] demonstrated in a clinical study that ensuring optimum light curing enhances the abrasive wear resistance of composites. However it is worth noting that even light or dual activated luting cement beneath glass ceramic have got some limitations, most of them depending on the factors related to properties of ceramic (thickness, shade and translucency) and cement[22] (shade and composition).

Methods to evaluate polymerization efficiency

Insufficient polymerization of the luting cement could lead to inferior mechanical properties of resin cements. The degree of cure affects physico-mechanical properties, solubility, dimension stability, color change and biocompatibility.[35] Ferracane et al[34] showed that wear resistance of hybrid composites are linearly dependent to the timing protocol during the process of polymerization. Insufficient hardening of cement may lead to washout and post-operative sensitivity, subsequent microleakage and recurrent caries.[36,37] There are different methods to evaluate the degree of polymerization of resin composites, these include, evaluation of surface hardness, abrasion resistance and scraping tests, degree of conversion of monomers in polymers which is usually done by conventional infrared spectroscopy, and lastly by magnetic electron resonance. But some of these techniques mentioned are very time consuming, complex and relatively costly, particularly infrared spectroscopy and magnetic electron resonance.[38] However, infrared spectroscopy is very accurate and reproducible.[35]

Hardness is correlated with the extent of degree of conversion[32] and is defined as the resistance to permanent surface indentation or penetration. Many authors describe hardness being same as degree of conversion, however, they are two different units to measure polymerization efficiency and both modes are sensitive to different variables.[35] An absolute hardness number cannot be used to predict a degree of conversion when comparing to different resins.[35]

Hardness test consists of an indentation under load on a workpiece-material for a certain period of time, the indenter will produce an impression. The width, area and depth when measured under microscope give an indication of hardness. Many studies have been done using hardness testers to evaluate the cure efficiency of resin cement material for both dual or light cured.[35,29] Regardless of the type of hardness tester the procedure is generally the same. Newer standards more accurately use the term microindentation tests. Some of the hardness testers used are, Brinell, Rockwell, Knoop and Vickers. Knoop micro-indenter has a rhomboid-base diamond pyramid, however the Vickers micro-indenter is a square-based diamond pyramid where one of the axis of the pyramid is longer than the other. An advantage of this method is that it minimizes the effect of elastic recovery as it has been claimed by some authors. Wassel et al[39] demonstrated that the vickers micro-indenter is a very sensitive method to compare hardness of different resin composites materials and did show clear differentiation between microfilled and hybrid composite resin.

Table 1: Classification of Modern Ceramics

Non-reinforced dental ceramics
A. Conventional feldspathic porcelain
Reinforced dental ceramics
A. Metal ceramic systems
B. Reinforced ceramic core systems
• Alumina reinforced PJC
• Inceram systems
◦ Inceram alumina
◦ Inceram spinel
◦ Inceram zirconia
• Pure alumina cores
◦ Techceram
◦ Procera Allceram
• Pure zirconea cores
◦ Lava
C. Resin bonded systems
• Conventional feldspathic porcelain
• Glass ceramics systems
◦ Leucite reinforced feldpsar glass ceramics
Sintered - fortress
Hot pressed - Heraceram & empress
◦ Lithium disilicate and apatite glass ceramics
EMax
◦ Fluoromica glass ceramics
Dicor

Table 2: The Classification Of Resin Based Luting Composite

Composite Resin Based Luting Agents
By Activation Mode
• Light cure
• Dual cure
• Chemical cure
In Conjunction To Bonding Agents
• Etch and Rinse
• Self Etch
By Composition
• Conventional
• Microfilled & Nanofilled
• Hybrid

Table 3: Factors promoting Ceramic Luting Resin Polymerization

Factors Promoting Ceramic Luting Resin Polymerization
• Ceramic Related Factors
Less thickness
Less opasity
Lighter shade
Greater silica phase
• Resin Cement Related Fators
Dual cured polymerization
Less opasity - high polymerization
< 100 u cement film thickness
Greater filler particle size and concentration
• Light Curing Unit Related Factors
LED light source
Less distance from source of cement
Duration of exposure (Follow manufacturers instructio for cement
Increased ligt intensity
Compatible wavelength

Factors Effecting Luting Resin Polymerization For Ceramics

Several factors have the potential to influence the depth of cure of luting cements: ceramic type, thickness, composition, shade and translucency; the curing light source, wavelength and intensity; the luting resin cement material (activation mode, shade, composition) and the bonding substrate (Table 3).

The thickness of the ceramic interferes with the degree of polymerization of light cure or dual cure cement. It has been well documented that ceramic thickness beyond 2mm compromises the hardness of cement. Blackman et al,[40] in a study done with light and dual cure cements and different thickness of ceramic (up to 4mm) reported a linear reduction in hardness as the thickness of the ceramic increased. Pazin et al,[41] stated that poor hardness values of the resin based dual cured cement were seen with thicker ceramics. The ceramic used was leucite reinforced upto 2mm thick. The hardness measurements differ from most studies already mentioned as both the top and bottom of the cement-sample was evaluated.

It is has been claimed that the thickness of the ceramic will have greater influence than translucency. The ultimate color and translucency of the ceramic system is important for optimal esthetics. Ceramic color and translucency can be affected by many properties, including thickness, crystalline structure, and number of firings. Cardash et al[37] reported low hardness for luting cements when light was transmitted through darker ceramic within the same color-shades of ceramic, therefore less irradiation light reached luting cements. However, they could not make a numeric comparative correlation on hardness values when comparing different color shades (vita guide A1-D4).

Ilea N and Hickel R,[42] in a study on correlation between ceramic translucency and polymerization efficiency through ceramics proved that lesser values of cement hardness with greater opacity of ceramic are seen, therefore for a highly opaque material, a lower thickness of ceramic is required to get similar values on hardness. According to Borges et al,[43] the lowest hardness values were seen in the most opaque ceramic systems. The resin cement used was dual cure and was bonded to different ceramics of 1.2 mm thickness.

Light activated resin cements have the potential for incomplete polymerization due to thicker ceramics.

Dual cure cements were developed with the idea to overcome this problem. The light irradiation transmitted through the ceramic must reach the dual cure cement for the activation of chemical phase. The ratio of photo vs chemical phase of the cement will have an important influence on the extent of polymerization; this might explain why some of these cements have greater hardness values than others. Regarding shade and translucency of the luting cements, Ferracane et al[44] showed that the depth of cure (hardness) of the light cure cements may be less dependent upon the shade than upon the translucency. Blackman et al,[40] revealed a high hardness value for a dual cure translucent cement than for a yellow light cure cement.

Regarding composition of the luting cements, it was shown by Poskus et al[45] that microfilled composite (filtek A110) exhibited less hardness values than the hybrid (filtek Z250) in deeps layers; It also has been shown by Ferracane et al[35,44] that the depth of cure is directly related to the filler particle size of the composite material. Higher particle size and higher filler concentration will show greater hardness values. However, hybrid composite showed more difficulties for reading hardness values (both VH and KH) than microfilled composites according to Shahdad et al.[46]

Exposure times for curing degree of the luting resin cement have been claimed either by authors or manufactures to be dependent not only on all the factors mentioned above but also on the light system radiation intensity of the unit used. In addition, it has been shown that within the same light system increasing time exposure will not always result in higher values of either hardness or degree of conversion.

CONCLUSION

In summary, in light of the discussion and evidence presented above it is apparent that novel ceramic restorations of 2mm thickness when cemented to healthy enamel and dentine using an ideal technique with light or dual cure cement, polymerized with LED curing unit of compatible wavelength and optimum intensity will result in maximum predictability and longevity. Increasing the ceramic and luting resin opacity, increasing ceramic and resin-film thickness, decreasing the curing light intensity and duration, use of only light cure cements and bonding to compromised tooth substrate (carious, sclerotic, bleached dentine) will result in an unpredictable and compromised outcome. An astute clinician must make informed evidence based adjustments appropriate to the clinical scenario to achieve maximum cement polymerization and hence minimising failure and optimising clinical success.

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