Polymerization of Resin-Based Composites Restoration: A Literature Review

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Abstract

An adequately cured/polymerized resin increment(s) is of utmost importance for a successful resin-based composites. During polymerization of the resin-based composites, most of the monomers should be converted into polymers. The conversion of monomers is vital to enhance the physical and mechanical properties, colour stability, and biocompatibility of the resin composite (RC) material. However, some monomers remain unreacted within the polymer matrix. Many factors affect the polymerization of RCs. This paper is aimed to review these factors that may help the clinicians to improve their understanding of the polymerization process of RCs.

Review (J Int Dent Med Res 2019; 12(4): 1618-1625)

Keywords: Polymerization, Conversion of monomer, Resin-based composite.

Received date: 04 May 2019 **Accept date:** 13 July 2019

Introduction

Since it was first introduced as restorative material in early 1960s, resin composite has shown tremendous improvement in both its physical properties and its performance[1,2]. Resin composites (RC) have been used largely as direct restorative materials because of their aesthetic appearance, long working time/command cure, and acceptable clinical behaviour[3,4]. With the development of dentin bonding systems, adhesion of RC to tooth structure is enhanced[1].

An adequately cured/polymerized resin increment(s) is of utmost importance for a successful resin composites. For polymerization of the resin-based composites, most of dimethacrylate monomers should be converted into long, cross-linked polymeric chains[1]. The conversion of monomers is vital to enhance the physical and mechanical properties, colour stability, and biocompatibility of the RC material[5,6,7]. However, some monomers remain unreacted within the polymer matrix that cause volumetric shrinkage and has been identified as a critical limitation of RC[1].

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During polymerization, there is a stage in monomer conversion, referred to as the ‘gel point’, at which an insoluble network is formed within the resin phase (degree of conversion/DC). At this point, the elastic modulus of the composite has increased substantially, and the composite elastic limit has reached a level that does not allow enough plastic deformation (or flow) to compensate for the reduction in volume[1].

Many factors affect the polymerization of RCs including the resin with its shade, its composition, the increment thickness, the light curing unit system used, its duration, and the cavity where the RC is placed[8,9,10,11,12]. This paper is aimed to review these factors; resin composite, light curing unit/photoactivator, and prepared cavity that may help the clinicians to improve their understanding of these factors contributing to the polymerization process of RCs.

Resin Composite

Resin composite is a physical mixture of materials, typically involving a dispersed phase of filler particles distributed within a continuous phase (matrix phase). In most cases, the matrix phase is fluid at some point during the manufacture or fabrication of a composite system. A dental composite is usually a mixture of silicate glass particles within an acrylic monomer that is polymerized during the application[13].

Resin increment thickness

Light curing composites are the most popular aesthetic restorative materials today. However, their success depends on the access of high-intensity light to cure the matrix material. If the composite thickness exceeds 1.5-2 mm, the light intensity can be inadequate to produce complete curing[14]. Restoration with resin composite of the thickness more than 2.5 mm was reported to cause a significant reduction in the material properties that may influence its longevity and serviceability[15]. Tested RCs samples that cured in different thicknesses, and for different exposure times of 20, 40, 60 or 80 seconds. They found the thickness of the resin composite is the most significant factor in RC degree of conversion (DC). A thickness of RC more than 2 mm significantly reduces DC of the composites[16]. A significant effect of resin composite thickness on its hardness after cured with either quartz tungsten halogen or plasma arc light curing unit. The samples of 2 mm thickness showed equivalent hardness values of the top and bottom surfaces at all time intervals using each light curing unit[17]. A reduction of microhardness values of RC at a depth of more than 2 mm. When the thickness of resin composite restoration increases, the absorption and scattering of curing light is higher while light penetration is lower within the layers of the cured material. Overall curing light energy is reduced with increased thickness, and also reduced degree of conversion of the resin composite[18]. Therefore layering technique of 2-mm thickness is recommended for the placement of resin composite. This technique allows sufficient light exposure of the resin composite and lower polymerization shrinkage[19,20,21].

Nowadays, application technique of resin composite restoration has been introduced which allows placement of dental composite materials in a thicker increment of 4 mm thickness. The bulk fill technique of RC placement is considered time-saving compared to the incremental layering technique[22,23]. Evaluated the degree of conversion of five bulk fill RC and one microhybrid RC (Filtek Z250) placed in 4 mm thickness and light-cured for 20 s using LED LCU with light intensity of 1000 mw/cm2. The results showed an adequate degree of conversion of all bulk fill RC while microhybrid resin composite showed inadequate degree of conversion at the bottom surface[24]. Another evaluated the DC of 2 bulk fill flowable composite, one standard flowable composite, and one regular bulk composite that can be made flowable. The results showed higher depth of cure for the bulk fill composite using the scraping test and Knoop hardness test[25]. Evaluates DC and microhardness of two bulk fill composites placed in one increment, 4 mm and 6 mm bulk, then light-cured for 10s, 20s, or 40s. They found a significant difference of microhardness between the RC at all exposure times. In addition, the 4 mm increment also showed significantly higher DC than the 6 mm increment at all exposure times. Therefore, 2 mm increment thickness is still the regular standard for RC placement, while placement bulk fill RC of 4 mm thickness also provide an adequate DC[22].

Resin shade

The superiority of resin composite restoration is on its diverse colours which enable colour matching that provide excellent aesthetic properties[26]. However the colours of RC restoration affect the degree of monomer conversion and also its physical properties. This is supported by several other studies who reported lowest degree of conversion with A3.5 shade of Filtek Z250 RC compared to other shades A3, B3 and C3 Z250[27]. In an in vitro evaluated the effect of different shades (A1, A2, A3, A3.5, A4) of Filtek Z250, they reported lower microhardness of darker shades compared to light shades[28]. The translucency of RC restoration enhances the light penetration capacity and in turn, increases the conversion of monomer and increases its microhardness[29,30]. In addition, different filler composition, size, and loading of resin composite were reported to significantly affect not only the degree of conversion of RC but also the colour values and colour differences between various RC materials with the same shade[31,32,33]. Consequently, higher DC of the enamel opacity of RC than that of dentin opacity within the same shade. This is due to the different translucency between enamel and dentin shades that could affect the light penetration through the RC layers[34]. Therefore some manufacturers recommend increasing the light curing time and curing in increments of 1.5 mm for darker shades in order to get an adequate conversion and therefore physical properties as well[13].

Filler Type

Monomer and filler type, filler content, and filler and polymer matrix refractive index affect the ability of light to be transmitted throughout the resin composite layers[34]. The light penetration capacity through resin composite material is affected by the filler-resin system; higher volume percentages of fillers showed higher DC and microhardness[35]. Therefore, different resin composite compositions, filler size, weight, volume, and filler-to-matrix ratio have a significant effect on the DC and microhardness of resin composite[22,36]. A high DC could be achieved with a lower filler-to-matrix ratio. Lately, bulk fill resin composites are introduced and it is stated that bulk-fill RC materials have a better and greater DC than conventional RCs[37,38]. This was explained by the larger filler size (>20 mm) composition of the bulk-fill materials, which leads to a lower total filler–matrix interface. This enhances the amount of transmitted curing light and reduces the scattered light, resulting in a higher DC of the larger filler containing RCs. The higher DC of bulk fill composites could be accounted for by their translucent matrix and incorporation of a functional photoactive group in the methacrylate matrix[39].

Temperature of the resin composite

The temperature of RCs could also affect its polymerization reaction; the DC and its microhardness. The impact of different pre-curing temperatures of resin composite samples in 2 mm thick on their DC and surface microhardness values. The samples were cured for 20s at 22°C, 26°C, 30°C, or 35°C. They found a significantly higher and faster DC of the RC with increasing temperature[40]. Similar result was compared the effect of 2 different polymerization temperatures of RCs on their DC and microhardness. The samples were procured with 23°C or 33°C. The results showed higher DC and microhardness values in samples with higher procured temperature[41]. When the polymerization temperature increases, the viscosity of RCs decreases which enhances the mobility of monomer molecules within the resin matrix and produces more free radicals that results in a higher value of the DC and hardness of RCs[42]. Therefore, it is recommended to preheat the RCs used with a specific device to enhance the physical properties of RCs[43].

Light curing

Dental light curing unit (LCU) is an essential part of the process of photocuring a resin. Adequate photocuring is required for light-activated RCs restorations to reach their manufacturer's intended properties and is believed to be a basic requirement for predictable long-term clinical success[44].

Light curing system

Dental light curing units (LCUs) were developed in the early of 1970s when UV-curing units were used to polymerize resins[45]. Due to its limited light penetration and potential health risks, UV-light curing was not used anymore[46]. Later, visible light curing units were developed, Quartz Tungsten Halogen (QTH) light curing that has a quartz bulb filled with halogen, iodine, or bromine gas, and contains tungsten filament. The emitted light is powerful with a broad spectrum wavelength of 400-500 nm which is compatible with the most commonly used photoinitiator, camphoroquinone (CQ)[47,48,49]. The disadvantage of QTH light curing unit is its low-energy performance, ineffective light-produced by the bulb that increases the operating temperature which limits the lifetime of the bulb, therefore fans are required to decrease the temperature [50,51]. With the advance of technology, the plasma arc LCU (PAC) was introduced, which delivers light with a narrower range of wavelengths that compatible with CQ[49]. Some studies reported the degree of conversion of light -polymerized of resin composite using PAC for 3 seconds showed similar result when using QTH LCU for 30-40 seconds[52,53,54].

Nowadays, the technology of light-emitting diode (LED) has been also applied to develop light curing unit for dental purposes. LED technology uses doped semi-conductors with a lifespan of about 10 000 hours, has a narrower spectrum within the range of CQ to polymerize the resin, generates less heat, and can be used on battery power (cordless LCU)[48,53,55]. Polywave LED LCUs were introduced that emit lights with two or more different wavelength ranges, a shorter violet wavelength for activating photoinitiators that are sensitive to light within the range of 350-420 nm wavelength, and a longer blue wavelength with maximum light absorbance of 468 nm for activating photoinitiators (mainly CQ). Therefore, these polywave LED LCUs are used to activate a wider range of photoinitiator[56,57].

The effect of light curing unit type on the degree of conversion of resin composite varies among the light curing unit. The better curing efficacy using LED LCU for 20 seconds compared to QTH in curing microhybrid and submicron hybrid resin composite[18]. A higher degree of conversion of tested resin composite when curing for 40 seconds using QTH, 20 seconds using LED and 5 seconds using PAC with similar radiant exposure of 37 J/cm^2 [11]. However, no statistically significant differences in resin composite hardness at 2 mm thickness following light-cured with different curing units, a QTH for 40 seconds, a PAC for 10 seconds, and a laser argon for 5 seconds[58].

Light energy density of different curing profiles of LCUs has an influence on the effectiveness of composite cure. Optimal cure of the top and bottom surface of RCs was achieved after 30 seconds and 20 seconds of irradiation at intensities of 600 mw/cm^2 [59]. Curing profiles of LCUs also have an effect on the cross-link densities of resin composite as polymerization of methacrylate monomers[60]. Composites cured with LED lights were less cross-linked than those cured with conventional halogen lights. Halogen curing lights emit considerable number of other wavelengths beyond the absorption spectrum of the camphoroquinone photoinitiator. These spectral impurities are highly absorbed by dental materials, inducing further heating of the composites during the curing process[61,62] that may be responsible for the greater cross-link density observed with halogen curing light used in that study[63]. Physical properties of the resin composite are affected by the local power, wavelength, tip and beam power profile of the light curing units[64].

Light curing time

Curing time is set depending on the light intensity. The lower the light intensity, the longer the curing time needed. For adequate polymerization of resin composite of 2 mm increment thickness, the energy dose should be within 16-24 J/cm^2 [65]. Energy dose is obtained by multiplying the light intensity (I) from the light curing unit (mw/cm^2) and its duration (T). For example, when QTH LCU with light intensity of 400 mw/cm^2 was used, the time needed was 40 seconds for curing a 2 mm increment of resin composite, leading to a radiant exposure of 16 J/cm^2 [15]. Evaluated the impact of different exposure times on the microhardness of ten resin composites. Using the Knoop microhardness test, they found no significant differences following curing with high power setting QTH for half of the recommended time compared to a medium power setting QTH for the full recommended exposure time[66]. Increasing the curing time beyond the manufacturer’s instruction (+10-20 seconds) has positive effect on the degree of conversion and the microhardness of the resin composite[67].

Currently, the light-emitting diode (LED) LCU is predominantly used by dentists worldwide. New generation of LED LCUs are now available with higher light intensities of more than 5000 mw/cm^2. These enable curing times of 1-3 seconds to achieve adequate polymerization of resin composite[68]. This may mean less time in light curing, resulting in higher clinical productivity. However, the question is what a minimum light curing time necessary to achieve an adequately cured restoration. There is a minimum time exposure to get an acceptable DC. According to their study, exposure times of 10 seconds and above provide 47% DC. These studies indicate that increasing the light curing exposure time results in higher overall radiant exposure reaching the RCs layer, therefore better polymerization can be obtained, in particular in a thick composite layer and/or light curing unit with low irradiance levels[69].

Distance of light curing tip from resin composite surface

The distance of light curing tip from resin composite surface affects the microhardness of resin composite. A significant reduction in the surface microhardness of the tested resin composite when cured with increasing the distance of light curing unit tip from 2-9 mm compared to the distance of 2 mm from the surface[49]. Similar results of lower microhardness of resin composite when cured with 8 mm distance between light curing tip and resin composite surface compared to 2 mm and 4 mm distance[70]. Lower microhardness values of microhybrid and nano-filled resin composite when the distance of light cure unit tip was increased from 0 mm to 6 mm and 12 mm from the surface of resin composite[71]. The increasing distance of the light cure tip from the surface of resin composite is caused by geometric interference such as the cusp height, cuspal steepness, and cavity depth, forcing the curing tip to be a distance from the cured surface. Therefore total energy of light is insufficient to reaching the resin composite surface regardless of the power of the light emitted by different LCUs[49]. Another approach to permit closer approximation of the curing light to the RCs is applying light-transmitting wedges and light-focusing tips for interproximal curing[72]. Extending the curing time or using a higher light intensity of LCU is also recommended to compensate the reduction in irradiance exposure. Light cure tip should be as close as possible, within 2 mm, to the surface of resin composite. However, curing tip could be contaminated with RCs being cured and cause scattering of the light that reducing the effective output. Therefore the tip should be routinely cleaned of cured resin using an appropriate rubber wheel on a slow speed handpiece[13].

Light curing tip

Most of the LCU tip shows non-uniformity in the light output; the centre of the LCU emit high-intensity light, while other areas of the same LCU unit emit a lower irradiances of curing light[73]. For one region of the light tip, the relative contributions of the violet and blue portions of the emitted radiation spectrum to the total radiant exitance at that point can be dramatically different from another, such that some regions across the light tip may only deliver blue light (~450-470 nm), while others only deliver violet light (~ 400-410 nm)[44]. When RCs are photopolymerized using light sources that are highly inhomogeneous, the resin polymerization and microhardness can be adversely affected. Evaluated the effect of irradiance distribution on the local microhardness of RCs and concluded that the irradiance distributions of different LCUs had a significant effect on both DC and the hardness of the RCs' surface[74]. The problem of irradiance inhomogeneity has been compounded by the introduction of polywave blue-violet LED-based LCUs. Examined the impact of localized irradiance and spectral distribution inhomogeneities of a polywave LED LCU on the microhardness of four RCs. They found a significant positive relation between the irradiance beam profile values of the LCUs and the microhardness of all RCs when exposed to the light. They also reported inhomogeneity of local irradiance and spectral emission across the tip of the tested LCU. Different positions of each of the light emitters along the same LCU tip might affect the homogeneity of the light output through the light guide tip[64]. Nowadays, some manufacturers have improved the design of their LCUs to deliver a more homogenous light beam[44].

The temperature changes

Polymerization of light-activated RCs causes both an exothermic polymerization reaction and also a temperature rise from the light energy absorbed during irradiation[75]. The heat generated depends on the LCUs, the bulk of material, the irradiance, and the rate at which the RCs polymerizes. LCUs with an inhomogeneous light output may cause very different temperature changes within different regions of the RCs[44]. Temperature rise can also be due to the small tip of LCUs used. Curing tip of 3-mm diameter has an effect to increase the light output eightfold which increases the chance to produce heat during curing procedure[13,16]. On the other hand, that significantly lower temperature increases and polymerization shrinkage of the LED source compared to a halogen curing units[52,76].

Cavity diameter

The dimensions of molar and premolar teeth are different mesiodistally and buccolingually in both maxillary and mandibular jaws, therefore the diameters of restorations are wider in molar teeth than in premolars. These may affect different degrees of polymerization and DC within the same restoration and in turn the performance of the restoration and its longevity[77].

Cavity location

Location of the cavity in posterior areas, such as on the buccal or lingual surfaces of the second molar, may hamper the accessibility and direction of the curing light, which could limit the DC of the cured RC increment. The LCU tip could not be directly positioned at 90° over the RC restoration surface that may result in a reduction of the light intensity delivered to the RC surface[9,78]. That placement of the LCU at 45° to the surface of the resin composite results in a 56% reduction of light radiant exposure[64,79,80] which is explained that the circular shape of the light beam changes to an ellipse with greater surface area[81]. The consequence of curing the restoration in such areas is the increased distance between the LCU tip and the RC surface, decreases light energy reaching the RC, which leads to a lower value of DC[78,82]. Therefore a 90° angle of the LCU tip to the RC surface is recommended[81].

Conclusions

Basic understandings of the resin composite material, photocuring equipment used, and the prepared cavity are of utmost importance to provide adequately cured resin composite therefore optimal performances of the restorations.

Declaration of Interest

The authors report no conflict of interest and the article is not funded or supported by any research grant.

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