

Review Article**Polymerization Shrinkage Of Resin Based Composites :An Overview****Sandhya Kapoor Punia¹, Vikas Punia², Vivek Sharma³, Meenakshi Khandelwal⁴**¹ Ph.D. Scholar, Faculty of Dental Sciences, Pacific Academy of Higher Education and Research University, Udaipur Udaipur (Raj.)² Reader, Department of Prosthodontics, Darshan Dental College & Hospital, Loyara, Udaipur (Raj.)³ Professor & Head, Department of Prosthodontics, Darshan Dental College & Hospital, Loyara, Udaipur (Raj.)⁴ Professor, Department of Prosthodontics, Darshan Dental College & Hospital, Loyara, Udaipur (Raj.)

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ABSTRACT

Stress generation at tissue/resin composite interfaces is one of the important factors for failure of resin-based composite (RBC) restorations owing to the inherent property of polymerization shrinkage (PS). Polymerization shrinkage of resin composites invariably generates a degree of stress at the tooth/restoration interface. The magnitude of the stresses so produced depends on resin composite composition and its ability to flow before solidification, which is, in turn related to cavity configuration and curing characteristics of the composite. These unrelieved stresses can weaken the bond between the tooth structure and the restoration, eventually producing a gap at the restoration margins. This can lead to postoperative sensitivity, secondary caries, fracture of the restorations, marginal deterioration and discoloration. The objectives of this article are to review the mechanism of polymerization shrinkage, the clinical factors affecting polymerization stress, and methods advocated to reduce shrinkage stress. This article emphasize on minimizing the shrinkage stresses in RBC restorations to improvement in the success rate and survival of restorations. Thus, it is important for dental practitioners to be aware of various techniques and materials available to reduce these shrinkage stresses and be updated with the current knowledge available to deal with this issue.

Introduction

Dentistry had always thrived to achieve biocompatible restorations that do not compromise the pulp and also maintain the dental seal.¹ Dental amalgam and gold alloys, which have a long record of clinical success, have been used as dental restorative materials for more than 100 years, especially in posterior teeth, because their mechanical properties match those of natural teeth; however, these metallic materials are not esthetic.²

One of the significant contributions has been the development of resin-based composite technology.¹ The demand of posterior composite restorations has

increased over the past decades due to some advantages like esthetics, no use of mercury, the ability to strengthen the remaining tooth structure, the increase of the fracture resistance of the restored teeth and conservative tooth preparation.³

Although composites are now the material of choice for most restorations,⁴ the greatest limitation in the use of composite resin as a posterior restorative material seems to be shrinkage during polymerization.^{5,6} The contraction stress associated with this shrinkage can cause debonding at the composite/tooth interface and can contribute to microleakage resulting in postoperative sensitivity, enamel fracture, recurrent

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caries, marginal staining and eventual failure of the restoration.⁶

Because no method guarantees a perfectly sealed restoration for adhesive restorative materials, clinicians must address problems of polymerization shrinkage and resulting destructive shrinkage stress. Only a thorough understanding of the mechanisms that cause shrinkage stress and the techniques that may reduce its effect will allow clinicians to gain a better use of resin composites. The objectives of this article are to review the mechanism of polymerization shrinkage, the clinical factors affecting polymerization stress, and methods advocated to reduce shrinkage stress.

POLYMERIZATION SHRINKAGE MECHANISM

Composite resins have four primary components: an organic matrix, inorganic fillers, a coupling agent that binds the filler to the matrix, and the initiator/accelerator system. In most composites, the organic matrix is a dimethacrylate, generally bisphenol-A glycidyl dimethacrylate (bis-GMA) or urethane dimethacrylate (UDMA) blended with triethylene glycol dimethacrylate (TEGDMA). The matrix contains reactive carbon-carbon double bonds, which crosslink to form a polymer network. Composite resin polymerizes by free radical polymerization generated when a photo-initiator, such as camphoroquinone, absorbs light energy (photons) emitted from the curing light and initiates polymerization by reacting with a photoreducer, a tertiary amine forming free radicals and initiating crosslinking.⁷

Complete polymerization of the material is determined by the degree of conversion of monomers into polymers indicating the number of methacrylate groups that have reacted with each other during

conversion process.⁸ As the polymer is formed, the resin matrix changes from a paste or pregel state to a viscous solid³ and the composite resin contracts by about 1.5% to 5%.⁹ When composite resin is a paste, or pregel state, no stress is conducted to surrounding tooth structure. As curing begins, the material flows from unbound surfaces to accommodate for shrinkage. As the composite resin becomes more rigid because of the increasing modulus of the composite, flow stops and the bonded composite resin transmits shrinkage stresses generated to the surrounding tooth. This point is called the gel point. When the gel point is reached, stress is transmitted from the composite resin to the surrounding tooth structures, the stress generated may exceed the adhesive bond or the cohesive strength of the tooth or the composite, producing a marginal defect.¹⁰

FACTORS AFFECTING POLYMERIZATION OF RESIN BASED COMPOSITE

Polymerization shrinkage is dependent on the conversion of the monomer to the polymer. The stress development due to polymerization shrinkage is affected by the geometry of preparation and RBC compliance. It was best explained by the C-factor which is the ratio of bonded and unbonded surfaces in the restored tooth.¹¹ Feilzer and colleagues used C-factor to describe the stress generated during polymerization shrinkage of composite resin.¹² When the ratio of bonded to unbonded surfaces increases, the stress placed on the tooth increases because the composite resin cannot flow to relieve the shrinkage.¹³ Many factors affect the degree of polymerization of RBCs, including the shade, light curing duration, increment thickness, light unit system used, cavity diameter, cavity location, light curing tip distance from

the curing RBC surface, substrate through which the light is cured (e.g., curing through ceramic, enamel, or dentin), filler type, and temperature.¹⁴⁻¹⁷

1. **Effect of resin shade:** Different shades of Resin Based Composite(RBC) are available with different translucencies, to provide better shade matching with surrounding tooth structures, thus enhancing the esthetic of the restoration. Ferracane et al. (1986) evaluated the effect of four different shades of three types of RBC (Macrofill (Prisma-fil), Microfill (Prisma-fine), and conventionally filled (Aurafill)) on their monomer degree of conversion. The translucency of each shade was measured with a spectrophotometer and it was concluded that the degree of conversion (DC) of resin composites depends significantly on the light penetration capacity through RBC material, which is determined by its translucency and the filler-resin system.¹⁸ A variety of studies, concluded that RBC translucency and not the shade has a significant effect on light transmission through the RBCs' thickness. Thus confirming that more translucent composites will have more DC and thus lower Polymerization shrinkage.
2. **Effect of filler type:** RBC materials may be classified according to their consistency into packable and flowable RBCs.¹⁹⁻²⁰ Flowable RBC has low viscosity, owing to its low filler level while packable composites have high viscosity. Monomer and filler type, filler content, and filler and polymer matrix refractive index have an impact on the ability for light to be transmitted throughout the RBC layers. Therefore, it is reported that different RBC compositions, filler size, weight, volume, and

filler-to-matrix ratio have a significant effect on the RBCs' DC.²¹ Ilie et al. and Moszner et al. stated that bulk-fill RBC materials have a better and greater DC than conventional RBCs. 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 RBCs.²²⁻²³ Although the literature supports the use of bulk-fill RBCs over conventional types (in both flowable and packable consistencies), further investigations are required to confirm this conclusion, especially when using them in thicker increments (>2 mm) in clinical procedures.

3. **Effect of resin increment thickness:** Previously, restoration of a deep cavity with a single RBC layer (more than 2.5 mm thickness) was reported to cause a significant reduction in the material properties that may affect its longevity.²⁴ In 1994, Rueggeberg et al. evaluated the effect of filler type, shade, exposure time, and curing radiant exposure on the DC of RBCs . The authors tested RBC samples cured through different thicknesses of already polymerized RBCs for different exposure times (20, 40, 60, or 80 s) with an irradiance level of 800 mW/cm² . They concluded that the most significant factor in RBCs' DC is the thickness. A thickness of the RBC of more than 2 mm results in significant DC reduction. In addition, Rueggeberg et al., in another study, concluded that, to provide an adequately polymerized RBC, it has to have a 2

mm increment cured for 60 s with irradiance levels of at least 400 mW/cm².²⁵ Thus, although 2 mm incremental thickness is still the regular standard for RBC increment placement, using bulk-fill allows placement of RBCs in more than 2 mm increments (up to 4 mm) while maintaining an adequate DC. This is due to higher light transmission through the more translucent bulk-fill RBC thickness when compared to conventional RBCs.

- Effect of light curing system:** The development of dental light curing units (LCUs) began in the early 1970s when UV-curing units were introduced to polymerize resins.²⁶ However, the search was soon on for a better device, because of its limited light resin penetration and potential health risks (Rueggeberg, 2011).²⁷ Later, visible light curing units were developed, setting the stage for the well-known conventional QTH. The QTH was the unit of choice until the early 2000s. During the era in which QTH was the standard choice, the plasma arc (PAC) LCU was introduced.²⁸ The light-emitting diode (LED) is the newest light source introduced to the dental market and was first developed by Mills and colleagues in 1995. The narrow range of light wavelengths emitted by a LED LCU makes it more effective, with less heat generation than a QTH LCU.²⁹ Magalhaes Filho et al. (2016), stated that physical properties of the RBC are affected mainly by the local power, wavelength, and beam power profile of the LCU used, and concluded that, with the current advanced development of the new LED units and the declining usage of QTH units, the LED unit,

preferably its polywave system, is the method of choice to cover a broader range and activate more photoinitiators.³⁰

- Effect of light curing duration:** Many in vitro studies have been done to determine the effect of light curing duration on RBCs' mechanical properties. For a 2 mm increment in the thickness of the RBC to have adequate polymerization, it should receive a radiant exposure within the 16–24 J/cm² range.²⁵ It has been concluded by various studies that increasing the light curing exposure time results in higher overall radiant exposure reaching the RBC layer. Thus, better polymerization can be obtained, especially with a thick composite layer and/or LCU with low irradiance levels.
- Effect of cavity diameter:** Most of the LCU tip shows non-uniformity in light output; some regions of the LCU emit high intensity light, while other areas of the same LCU unit emit a lower irradiances of curing light.³¹ The irradiance distributions of different LCUs had a significant effect on both DC and the hardness of the RBCs' surface.³² Therefore, as the cavity diameter increases, the chance of different degrees of polymerization and DC within the same restoration also increases. This could affect the performance of the restoration and limit its longevity. However, Erickson and Barkmeier concluded that less mold dimension results in lower DC, explaining that a narrower mold allows more light absorption by its walls. Thus, it prevents curing light from reaching the RBC surface, resulting in a lower DC than wider diameter molds.³³ This also means that, with conservative cavity preparation (small

diameters), exposure time may need to be increased to adequately cure the RBC increment.

7. **Effect of cavity location:** A 90° angle of the LCU to the RBC surface is recommended. However, in some clinical situations, such as in posterior areas, it is impossible to position the LCU tip directly and at 90° over the RBC restoration surface. The location of the RBC restoration, such as on the buccal or lingual surfaces of the second molar, can affect the accessibility and direction of the curing light, which could limit the DC of the cured RBC increment.³⁴⁻³⁵ Curing of the restoration in such areas is more difficult and may be done with the LCU tip several millimeters away from the surface of the RBC or at more or less than a 90° angle. With increasing distance between the LCU tip and the RBC surface, light energy reaching the RBC decreases, which leads to a lower value of DC. An improper position of the LCU in relation to the surface of the RBC restoration affects the light radiant exposure delivered to the restoration. Placement of the LCU at 45° to the surface of the RBC results in a 56% reduction of light radiant exposure.²⁸
8. **Effect of light curing tip distance from RBC surface:** Many studies have reported a reduction in radiant exposure of the light from increasing the curing distance between the composite surface and the light cure tip.³⁶ Increase distance will result in insufficient total energy of light reaching the RBC surface, regardless of the power of the light emitted by different LCUs.²⁸ So, it is recommended to minimize the distance between the LCU tip and

the RBC surface as much as possible, and if such distance cannot be avoided, to consider either extending the curing time or using a higher irradiance level LCU to compensate for the expected reduction in irradiance exposure.

METHODS OF MEASURING POLYMERIZATION SHRINKAGE

Two Methods can be used to measure the volumetric changes during polymerization: (a) those measuring total shrinkage, and (b) those measuring post-gel shrinkage.

During polymerization, there is transition of resin from a viscous liquid state to a viscoelastic solid. Depending on the restraints placed on shrinkage movements, stress can develop at any time during the polymerization reaction, but residual stresses only develop after development of elastic properties. Thus, the portion of the total shrinkage that causes residual stresses is defined as the post-gel shrinkage. Many methods have been developed to measure polymerization shrinkage of composites. These include water and mercury dilatometers, transducer methods, and optical methods.³⁷⁻³⁹

METHODS TO MANAGE THE STRESS GENERATED BY POLYMERIZATION SHRINKAGE OF RESIN COMPOSITE RESTORATIONS

Various compensatory mechanisms aimed at minimizing the effects of polymerization shrinkage stresses at the resin composite/tooth interface to reduce the risks of marginal gap formation, can be broadly classified into three categories:

1. Manufacturer controlled factors.
2. Clinician controlled factors.
3. Miscellaneous factors.

Manufacturer controlled factors

- 1.1 **Monomer system:** Polymerization with expansion in volume can be achieved with 2,3-bis (methylene) spiro-orthocarbonate monomers through a double ring-opening process in which two bonds are cleaved for each new bond formed. The resulting expansion can be applied to counter the PS associated with the conventional methacrylate monomers used in dental composites.⁴⁰
- 1.2 **Amount of filler:** Increasing the amount of filler in the composite results in decreasing polymerization shrinkage, but also increases the modulus of elasticity. For example, micro-filled composites, which are less filled than hybrid composites, have higher PS, and tend to develop lower contraction stresses than hybrids. This has been attributed to their lower modulus of elasticity. Similarly, nano-filled and highly filled hybrid composites have been shown to exhibit greater deformation stresses than a hybrid composite with a lower filler content.⁴¹
- 1.3 **Concentration of initiators and inhibitors:** increasing the inhibitor concentration reduces curing rate and contraction stresses in resin composites, without compromising the final degree of conversion.⁴¹

Clinician controlled factors:

2.1 **Shape of the cavity:** The shape of the cavity determines its configuration, or C-factor (the ratio of the restoration's bonded to un-bonded surfaces). Generally, the lower the number of free, un-bonded surfaces in the cavity, the less the ability of the resin to flow, and therefore the greater the contraction stress at the bonded surfaces. Incremental placement of a resin

composite restoration and the use of a base material, such as glass ionomer cement, decreases the volume of the resin composite placed, thus generating more free surface (low C-factor) relative to the amount of resin. Clinically, conservative cavity preparation with rounded internal line angles is recommended because it will have less surface area than a box shaped cavity and therefore the C-factor will be reduced.¹¹⁻¹³

2.2 **Size and position of resin increments placed in the cavity:** The polymerization shrinkage stress is directly related to the volume of composite resin material. The layers should not exceed 2mm thickness, with 1mm being the ideal. Moreover, horizontal increments exhibit the least stresses compared to the vertical increments.⁴²⁻⁴⁴

2.3 **Light- or chemically-cured composite:** Chemically-cured composites produce the lowest polymerization contraction stresses. The reduced stresses in self-cured composites may be due to two factors: the delay in stress build-up within the composite due to a slower setting rate and a resultant extended flow, and a lower degree of conversion which results in a reduction in both the volumetric shrinkage and the elastic modulus. For the light-cured type, micro-filled composite is intermediate (due to their lower modulus of elasticity) and the hybrid composite produces the highest stresses.⁴¹

2.4 **The use of bases and liners:** Using a liner of low elastic modulus, for example resin-modified glass-ionomer, flowable composite, or filled adhesive system has been found to reduce the polymerization shrinkage stresses. The use of a glass-ionomer liner will solve the problem of adhesive and cohesive failures of the bonding agents, mainly at the floor of the cavity where strain is maximally concentrated. Ikemi and Nemoto demonstrated that a thicker lining

application decreases shrinkage stresses. This can be due to the fact that these materials have higher linear polymerization displacement and polymerization stresses.⁴⁵⁻⁴⁶

2.5 Modifying the curing light intensity: The minimum intensity of the conventional halogen curing light should be 400mW/cm² and the curing time 60 seconds for each 2mm increment. Increasing light intensity will increase the polymerization shrinkage and thus the level of stress. The use of soft-start polymerization (i.e. initially curing the composite at low light intensity, followed by full intensity light) to permit greater flow and stress relief in the composite has been suggested.⁴⁷

2.6 Sealing the margins of the restoration with unfilled resin: After finishing the restoration, it has been suggested that the margins be re-bonded with a low-viscosity resin to reduce micro-leakage and reseal the marginal gap resulting from PS as it is assumed to eliminate some of the negative effects of polymerization shrinkage and improve the restoration longevity.⁴¹

Miscellaneous factors:

3.1 Hygroscopic expansion: Resin composites absorb fluids from the oral cavity and swell with time. This hygroscopic expansion occurs days and weeks following placement of the resin composite restoration, after the negative effects of polymerization shrinkage might already have been occurred.⁴⁸

3.2 Clinical considerations: Sound knowledge of the available products would be the basis of making this choice, with good physical properties, and especially a low polymerization shrinkage being central to it. In areas where no or only low occlusal forces apply,

micro-filled composites can be used because they have better polishability and at the same time produce lower polymerization shrinkage stresses. In areas of high occlusal load, the physical properties of the material become crucial, and hybrid composites should be used. However, manipulative techniques should aim to reduce the polymerization shrinkage stresses.⁴¹

CONCLUSIONS

Polymerization shrinkage produces some well-recognised, undesirable effects on the resin composite/tooth interface. Nevertheless, several aspects regarding this extremely complex phenomenon remain unclear. Reduction of polymerization shrinkage has been an important issue. Although these cannot be completely eliminated, it is within the dentist's ambit to utilise certain techniques, based on current best practice recommendations, which can reduce the extent, and consequently the effects of polymerization shrinkage. Despite considerable efforts, none of the newer developed resins are successful enough to tackle this problem. Thus, further investigations on visco elastic behavior and reaction kinetics of these materials are necessary.

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