



Polymerization Shrinkage of Composite Resins: A Review

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ABSTRACT:- The greatest limitation in the use of composite resins as a posterior restorative material seems to be shrinkage during polymerization, which often leads to marginal fracture, subsequent secondary caries, marginal staining, restoration displacement, tooth fracture and, or post operative sensitivity⁽¹⁾. The objectives of this article are to throw light on the origin of polymerization shrinkage, the clinical factors affecting polymerization stress, and methods advocated to reduce shrinkage stress and the effectiveness of these methods.

Keywords:- composite resin, inorganic filler, organic matrix, polymerization shrinkage, contraction stress, degree of conversion.

I. INTRODUCTION

Visible light polymerizing composite resins have been the material of choice for esthetic restorations. In the last few decades, adhesive dentistry has evolved remarkably, greatly due to the development and incorporation of new monomers, new initiation systems and filler technologies which improve the physical properties of these materials.[1] Composite resins, however, have one deficiency: they all contract, causing dimensional changes, during photopolymerization. Such contraction is termed polymerization shrinkage. Contraction shrinkage of composite resin is important because of its effect on cavosurface margins.[2]

Polymerization shrinkage causes separation between a composite resin mass and adjacent tooth structure. Marginal adaptation of composite resin is dependent on several factors, such as polymerization shrinkage, hygroscopic properties, bonding between restorative material and the cavity walls, coefficient of thermal expansion of the material, and composite resin finishing methods. It has been demonstrated that, despite acid etching of enamel walls, hygroscopic expansion of composite resin, careful finishing procedures and use of materials with thermal expansion-contraction properties similar to that of enamel, marginal gaps still result from polymerization shrinkage.[3]

II. POLYMERIZATION REACTION : PROCESS AND IMPORTANCE :

Full 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.

The shrinkage suffered by the composite during curing ranges from 1.35% to 7.1%. This, together with curing stress leads to cohesion and adhesion failures, which are joined by the degree of monomer to polymer conversion as the main causes of composite resin restoration failures. Most materials shrink about 2-3%. Macro filled composite resins exhibit less polymerization shrinkage and hygroscopic expansion than do composite with lower filler contents,[4] but resin contraction of any extent is of concern to the clinician. The purpose of this review is to discuss the various factors that influence the development of contraction stresses in dental composites and methods to overcome them. These causative factors include:

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1. VOLUMETRIC SHRINKAGE:

Contraction stress in composite restorations is the result of polymerization shrinkage taking place under confinement, due to bonding to cavity walls.[5]

When monomers in proximity react to establish a covalent bond, the distance between the two groups of atoms is reduced and there is a reduction in free volume, both of which translate into volumetric shrinkage experienced by a composite and is determined by its filler volume fraction, the composition and degree of conversion of resin matrix.

- **FILLER CONTENT :**

Shrinkage values reported for Bis GMA and TEGDMA are substantially higher than those displayed by typical composites, which range between 2 and 3%. This difference is due to the fact that in hybrid composites, approximately 60% of the volume is occupied by filler particles. Microfilled composites, though their inorganic content is typically about 40 vol%, have shrinkage values similar to hybrids, due to the presence of pre-polymerised composite particles, sometimes referred to as “organic fillers”, which render them similar to hybrid composites, in terms of the actual volume fraction of polymerizing resin. Low-viscosity (flowable) composites present volumetric shrinkages upto 5%, in large part due to their reduced inorganic content, which is typically below 50 vol%.[6]

- **DEGREE OF CONVERSION :**

In the photoactivated materials, degree of conversion is determined by the product of light irradiance and exposure time (radiant exposure, J/cm²).[7] As curing rate is proportional to the square root of the light intensity applied to the composite,[8] it has been proposed that the method by which light energy is delivered to the composite is capable of delaying the acquisition of elastic modulus, allowing polymeric chains to re-arrange and microscopically and macroscopically accommodate the reduction in volume by plastic deformation. It is the so called ‘rigid contraction’ (sometimes previously referred to as ‘post-gel contraction’) that is the fraction of the total volumetric shrinkage responsible for stress development.[8]

In the photoactivated composites, the fast reaction rate virtually eliminates the time allowed for viscous flow, and it is estimated that the polymer matrix becomes ‘rigid’ within seconds after a relatively low degree of conversion. As a result, stress begins to build-up almost immediately after polymerization is triggered, and nearly all of the shrinkage occurs after the polymer matrix has reached a significant level of rigidity, the magnitude of which continues to increase with time. Selfcured composites, on the other hand, develop lower contraction stress values than light-cured materials, in part due to their slower reaction rate, but also because the self-initiated reaction generates a smaller number of free-radicals than photoactivation, often resulting in lower degrees of conversion.[10]

- **PHOTOACTIVATION METHODS :**

Several photoactivation methods have been proposed as alternatives for continuous high intensity irradiation. These curing routines, generically referred to as “soft start”, use of reduced light irradiance during the first few seconds of light activation, switching to high irradiance for the remaining curing time in order to provide the material with sufficient radiant exposure.[10]

It has been reported that these curing methods effectively reduce the shrinkage strain when compared to continuous high intensity photo activation. However, significant reduction in reaction rate do not necessarily correspond to significant reductions in contraction stress. It has been suggested that this discrepancy is due to the fact that dimethacrylate composites develop elastic modulus at very low conversions.[11] Therefore, even at relatively low reaction rates, the stage in the conversion where the composite ceases to allow significant plastic deformation is reached rapidly.

This technique of changing polymerization rate has limitations. Its efficacy varies according to composite formulation. It may alter the nature of the polymer network formed.[12,13,14]

- **CONCENTRATION OF DILUENTS IN THE RESIN MATRIX :**

Higher TEGDMA/BisGMA ratios in experimental composites resulted in higher contraction stress values due to increased volumetric shrinkage, as a result of enhanced conversion. Diluents monomers have lower molecular weight than the host monomers and they increase the density of polymerizable carbon double bonds, which may lead to more shrinkage.[15,16]

III. VISCOELASTIC BEHAVIOUR

Early in the polymerization reaction, composites present a predominantly viscous behaviour and gradually, they become elastic. Viscous flow accommodates a significant fraction of the total volumetric

shrinkage and stress build up occurs at a faster rate at high conversions. Faster curing rates do not allow enough time for viscous flow.[17] Moreover, elastic modulus acquisition in composites occurs rapidly which further shortens the time available for stress relaxation. Thus, rate of conversion is a significant factor affecting the generation of contraction stress in dental composites.[18]

IV. EFFECT OF CONFINEMENT AND CONFIGURATION FACTOR

The c-factor (configuration factor) is a term used for the ratio of the number of walls bonded to unbonded surfaces.

During polymerization the restorative resin shrinks and pulls the opposing walls and floor of the cavity closer together. The magnitude of this phenomenon depends upon the configuration of the cavity.[19]

The greatest stress occurs when composite is bonded to five walls of a prepared cavity ($C = 5$) as in Class 1 or Class 5 restorations. The lowest C-factor values are obtained with class IV cavities because the material has enough unbonded surfaces to flow, providing stress relief. A high C-factor creates a risk for debonding of the restoration. Therefore, it is important to have a lower configuration cavity.[20]

V. METHODS TO REDUCE POLYMERIZATION SHRINKAGE:

1. MATERIAL ASPECT

There has been a general consensus about the addition of reinforcing filler to a resin matrix in a composite resins . This is because these inorganic fillers do not undergo any contraction during the setting reaction. The increase in filler content decreases the polymerization shrinkage.

Recently, novel monomer combinations and alterations of the resin-composite formulation have been developed and evaluated with the goal of decreasing polymerization shrinkage stress.[21] Nanocomposites contain a combination of non-agglomerated 20-nm-size nano silica filler and aggregated zirconia/silica nanocluster (primarily 5- to 20-nm size) filler.[22,23] The combination of nanomer-sized particles and the nanocluster formulations reduces the interstitial spacing of the filler particles. This reportedly provides increased filler loading ,thus, reduced polymerization stress.

The most recent modification on the polymer matrix is based on using ring opening polymerization of the silorane molecules. These monomers “open” their molecular structures with local volumetric expansion and this may partly or totally compensate for volumetric shrinkage from $C=C$ or similar polymerization.5 As silorane-based composite polymerizes, “ring opening” monomers connect by opening, flattening and extending towards each other. The molecules of these “linear monomers” connect by actually shifting closer together in a linear response.[3]

SILORANE system has been developed to minimize polymerization shrinkage and polymerization stress, while providing a high performance bond to the tooth.

2. INCREMENTAL LAYERING TECHNIQUE

Many researchers have suggested the use of “incremental layering techniques” for resin-composite restoration to reduce the polymerization shrinkage stress and cusp deflection . By using an incremental technique, the bonded/unbonded ratio would be reduced and, consequently, the stress level within the cavity might be lower, preserving the bonded area. Cuspal tension from polymerization shrinkage is common. Research shows this tension can be minimized if the composite is placed in at least three increments and each increment is sloped up one cavity wall at a time.[24]

Various techniques include the horizontal occluso-gingival layering, the wedge-shaped oblique layering, the successive cusp buildup technique, and the split-increment, horizontal placement technique.

3. EFFECTS OF CURING TECHNIQUE

When composite resins are cured, light passes through the composite attenuates, which means that deeper layers of composite resin are less cured. Any factor that decreases the light intensity passing through the composite will lower the conversion rates of the composite resin. If inadequate levels of conversion are achieved during polymerization, polymerization shrinkage would result and wear resistance is reduced. Curing composite in 2-mm increments is recommended.

Even though different curing units have different curing modes, the composite selected affects shrinkage more than the method of curing. The clinical effectiveness of the soft-, ramp-, or pulse-delay cure is questionable. Continued development of composite resins with reduced shrinkage is critically needed.[25]

4. STRESS ABSORBING LAYERS WITH LOW ELASTIC MODULUS LINERS

The use of a flowable resin composite as an intermediate thin layer has been suggested as a mean of overcoming polymerization shrinkage stress based on the concept of an “elastic cavity wall” suggested for filled adhesives. According to the “elastic cavity wall concept” the shrinkage stress generated by a subsequent layer of higher modulus resin composite can be absorbed by an elastic intermediary layer, thereby reducing the stress at the tooth-restoration interface manifested clinically as a reduction in cuspal deflection.[26] However, actual implementation of such a “stress absorbing” material is problematic.

5. PREHEATING

Recently, preheating resin composites have been advocated as a method to increase composite flow, improve marginal adaptation and monomer conversion. The benefits of preheating composites may have an impact on daily restorative procedures as well, with the application of shorter light exposure to provide conversion values similar to those seen in unheated conditions.[27]

The reasons for increased conversion are based on many factors. Increased temperature decreases system viscosity and enhances radical mobility, resulting in additional polymerization and higher conversion. The collision frequency of unreacted active groups and radicals could increase with elevated curing temperature when below the glass transition temperature. Therefore, at raised temperatures, in theory, it would be possible to obtain higher degree of conversion before the vitrification point, decreasing the magnitude of stress. However, real benefits were not fully demonstrated and, until now, there are no published studies showing stress reduction by warming resin composites.

VI. CONCLUSION

An intense research in the last few years brought many contributions to the knowledge on polymerization contraction stress of resin composites. Nevertheless, several aspects regarding this extremely complex phenomenon remain unclear. Reduction of polymerization shrinkage has been an important issue. 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. Continued development of composite resins with reduced shrinkage is critically needed. However, judicious selection of composite resins and effective methods to reduce polymerization shrinkage can be used to create more predictable esthetics in resin based composites.

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