Shrinkage of Dental Composite Resin: Contemporary Understanding its Enigmas and How to Solve? A Review

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Abstract

Nowadays dental patients are seeking a restorative material to their teeth that fulfilled most of the ideal requirements for such use especially aesthetic and functional performance needs. Traditionally composite resin can fulfill these requirements but with the major drawback of shrinkage during polymerization. The shrinkage will be manifested as marginal leakage, cuspal deflection, tooth or restoration fracture, postoperative sensitivity that ends ultimately by failed restoration. The aim of the current work was to pay attention of dental workers to the origin of polymerization shrinkage, its consequences, factors affecting, methods used to measure it, and how can they minimize it for promoting longevity of the restoration.

Keywords: *Dental Composite Resin; Polymerization Shrinkage; Shrinkage Stresses; C-Factor; Low Shrinkage Polymer; Bulk Fill; Spherical Glass Mega Fillers*

Introduction

Over the past 50 years, changes have occurred in the development of aesthetic restorative materials. One of these materials is the resin composite but its greatest drawback in this regard seems to be polymerization shrinkage (PS). Resin composites undergo hardening through free radical addition polymerization which inherently is accompanied by shrinkage [1]. This PS results in the development of internal contraction stress which can damage the marginal seal of the bonded restorations, interfacial gap formation, postoperative sensitivity, marginal staining, or recurrent caries, and fracture and crack formation at surrounding walls if cusps are displaced [2].

Factors affecting the stress formation are volumetric polymerization shrinkage, elastic modulus and adherence of the resin composite to the cavity walls. During polymerization the restorative resin shrinks and pulls the opposing walls and floor of the cavity closer together and the magnitude of this pulls depends upon the configuration factor of this cavity [3]. Recently one author attempts to add a new terminology by giving the term "Positive polymerization shrinkage can be defined as the shrinkage that takes place in such a way that the restoration material is being pulled towards the cavity wall, resulting in no gap formation or stress generation between the restoration and the cavity wall during the polymerization sequence. Negative polymerization shrinkage can be defined as the shrinkage that takes place in such a way that the restoration material is being pulled away from the cavity wall, resulting in gap formation or stress generation between the restoration and the cavity wall during the polymerization sequence (Figure 1) [4].
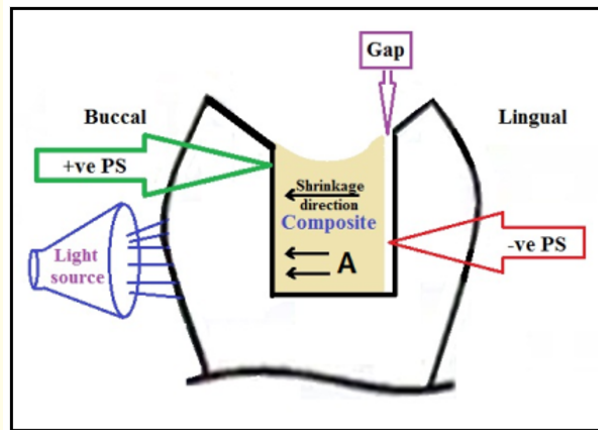
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Figure 1: *Positive PS on the buccal wall of the cavity and negative PS on the lingual wall with gap formation (A is the shrinkage towards the light source).*

Origin of polymerization shrinkage

Blue light activates Camphorquinone photoinitiator (CQ) and transforms it chemically into an excited triplet state which reacts with the amine to produce free radicals [5]. This reaction also stimulates the accelerators to produce larger amounts of free radicals which begin the polymerization process. The generated free radicals react with the monomer molecules in the resin [6], forming active centers for polymerization. Following this, propagation of the polymerization process continues by sequential addition of the monomers to the active centers to produce long cross-linking polymer chains. This reaction brings the individual monomer molecules closer together to form covalent bonds. Monomer molecules are held together by van der Waals forces where the intermolecular distance is 0.3 nm - 0.4 nm. After their polymerization, these molecules are held by covalent bond where the intermolecular distance is reduced to 0.15 nm. This reduction in the intermolecular distance produces volumetric polymerization shrinkage [7].

Polymerization shrinkage of composite resins passes through two phases (Figure 2), the first one the composite resin is transformed from the viscose state to the gel state (pre-gel phase) and the second is the post-gel phase (hard phase), where the gel form is hardened [8]. During the initial stages of the polymerization process, the composite mass is able to undergo plastic deformation. In other words, there is some amount of flow exhibited by the composite which can compensate for the some of the shrinkage. It is believed that in this early plastic stage, only chain formation occurs and cross-linking is not complete, which may allow the molecules to move into new positions and flow (pre-gelation phase). The resin matrix changes from a pre-gel or viscous-plastic paste into a rigid-elastic material as the gel-point (or a range of gelation) is reached. The gel point is defined as the moment at which the material can no longer provide viscous flow to keep up with the curing contraction [9]. During composite resin transformation from the viscose state to the gel state, the volumetric change in the shrinkage is higher than the change that occurs in the second phase. During the first phase of resin polymerization shrinkage is compensated due to resin flowable nature but this is not the case during the second phase because the movement is halted and the stress could not be met [10,11].

Within a filled cavity, the gel-point is a point at which the polymer chains stretch from one side of the cavity preparation to the other. Solidification or post-gel contraction follows, during which the material becomes increasingly stiffer as it loses its potential for plastic deformation. During post-gelation, the elastic modulus or Young's modulus of the material increases dynamically [11].
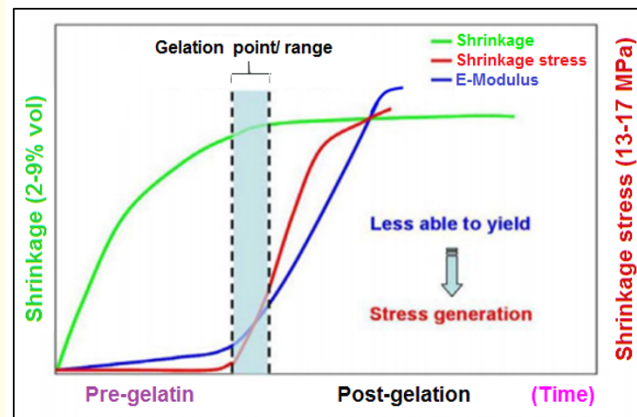
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Figure 2: *Relationship between volumetric shrinkage, elastic modulus and shrinkage stress.*

In a clinical situation where there is an intermediate adhesive/bonding agent layer between the tooth and the composite resin, the ability for plastic deformation of the composite is hindered at the interface. When composite is placed and polymerized in a constrained cavity [12] internal tensile stresses (polymerization shrinkage stress) develop within the composite.

Prior to reaching the gel point, a part of the developing stresses are compensated by flow of the composite from the free or the un-bonded surface [11]. This mode of compensation is not possible after gelation and, subsequently, large stresses are created in the composite which produces strain the tooth-composite interface [13]. The amount of shrinkage stress development is dependent on the rate of modulus development, ability of the material to flow and the extent of the polymerization reaction (Figure 2) [11].

Another explanation to the cause of polymerization stresses is that the exothermic reaction created when the monomer converts to the polymer produces a volume reduction in the polymer with a resulting decrease in molecular vibration and intermolecular distances [14]. As the polymer is formed, the resin matrix changes from a paste or pregel state to a viscous solid [15] and the composite resin contracts by about 1.5% to 5%. When composite resin is a paste, or pregel state, no stress is conducted to surrounding tooth structure, but as the gel point is reached stress appear and as curing begins, the material flows from unbound surfaces to accommodate for shrinkage. Flow stops and the bonded composite resin transmits shrinkage stresses generated to the surrounding tooth. As the composite resin becomes more rigid because of the increasing modulus of the composite. The stress generated at this point (gel point) may exceed the adhesive bond or the cohesive strength of the tooth or the composite, producing a marginal defect [9]. Damage occurs within the composite if this stress is greater than the cohesive strength of the composite, [16]. Enamel fracture occurs if the stress exceeds the tensile strength of enamel [17]. If the cavity walls are primarily enamel, which is brittle and too thin to withstand the forces generated by polymerization shrinkage, cracks or fractures are seen in teeth with wide restorations bucco-lingually [18].

Factors affecting PS are:

1. **Composition of resin matrix:** In case of methacrylate monomers, it is impossible to avoid shrinkage, which ranges up to 10% - 16% by volume [19]. The main part of organic matrix in composite is the high viscosity methacrylate monomer BIS-GMA. It has lower polymerization shrinkage than other monomers because its high viscosity results in less degree of freedom, which in turn, results in kinetically low degree of conversion [20]. Composite resins with silorane monomer have lower polymerization shrinkage than methacrylate-based composites [21].

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2. **Degree of conversion of resin matrix:** The number of C=C double bonds converted to C-C single bonds indicates the degree of conversion of composite. There is directly proportional of volumetric shrinkage and the degree of conversion [22]. Viscoelastic behavior of the composite resin determines its polymerization shrinkage is described by its flow and modulus of elasticity (Figure 3) [23]. Different monomers possess different degrees of conversion depend ending on their molecular weighs and initial concentration of c=c double bonds. TEGDMA, which is used as diluent, has high degree of conversion than BIS-GMA [24].
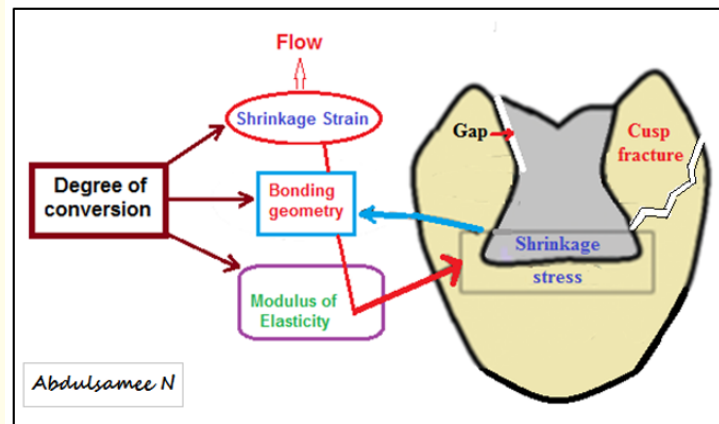

Figure 3: Relationship between degree of conversion and shrinkage stress.

The final degree of conversion ranges between 55% and 75% in commercial composites [24]. The modulus of elasticity of resin increases, as the degree of conversion increases which ultimately increases the shrinkage stress. In some situations, the reduction of contraction stress may be attributed to partial polymerization of the composite resin [25]. The degree of conversion is the major parameter, which influences polymerization shrinkage and stress development [12].

3. Filler volume fraction

Filler volume fraction has an inverse relation to volumetric shrinkage [26]. As the volume of filler content increases, the volume of resin matrix decreases and hence volumetric shrinkage reduces proportionately. The shrinkage values for BIS-GMA and TEGDMA (triethylene glycol dimethacrylate) are 5.2% and 12.5%, respectively [27] but the shrinkage value for composites is only 2% - 3% because of the filler content.

4. Configuration factor (C-Factor)

When a resin composite cures while bonded to the walls of a tooth cavity, stresses develop in the material, at the tooth-restoration interface and in the enamel and dentin of the tooth. The stresses result from volumetric shrinkage of the composite and their developing stiffness (elastic modulus). Constraint from the cavity walls at the bonded interface creates these stress conditions. Without the constraint, fewer stresses occur. These stresses are of clinical relevance because they may create interfacial gaps or, if the bond is sufficiently strong, cause deformation of the tooth. The stresses depend on the anatomy of the tooth and the geometry of the cavity preparation, the quality of the bonded interface [28].

The term "C factor" or "Configuration factor," is defined as the ratio of bonded to unbonded surfaces of the composite restorations (Figure 4) [29]. Shrinkage of the composite resin was determined by the bonding of the composite resin to the tooth structure and by the free

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surfaces rather than by the orientation of direction of the curing light as believed earlier (Figure 5) [30]. If the C-factor is high as the case with class I cavities, the shrinkage stress is high. As the number of unbonded surface increases, there will be lesser stress generation. This is due to the fact that the increased surface area will help to relieve the generated stresses. Cavities with C factor less than one generate least stress and it increases as the C factor increases (Figure 4) [31].

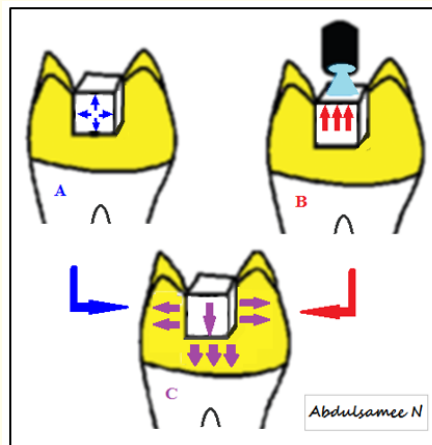*Figure 4: The C-Factor in different class restorations.*

Figure 5: Direction of composite resin shrinkage vector when A) Chemically cured B) Light activated and C) Dual cured.

5. Intensity of curing light

There is direct proportionality between polymerization shrinkage and light intensity, i.e. higher light intensity produced greater polymerization shrinkage [26]. The reason for higher shrinkage with higher intensity is due to greater degree of conversion. The slower polymerization delays the gel point, which provides for stress relaxation in the resin and the interface [32]. Polymerization shrinkage is highest with ramp curing modes and high intensity modes, whereas it is lesser with step-curing and low intensity modes [33].

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6. Thickness of composite resin, shade and opacity of composite

It has been proved that incremental curing induces lesser polymerization shrinkage stress than bulk curing [34].

Consequences of shrinkage

Polymerization shrinkage causes detachment of the enamel margins and/or can form gaps that result in marginal microleakage that allows the passage of bacteria, fluids, molecules, or ions between the cavity surface and composite resin [35]. Microleakage of posterior composite especially at the gingival margins of the proximal box of class II cavities may leads to staining at the margins of restorations, recurrent caries, hypersensitivity and pulp pathology [36].

The volumetric shrinkage during polymerization, inevitably generates stress, if the composite is tenaciously adherent to the walls of a tooth cavity can result in deformation of the cavity walls if the adhesion force is strong enough. This will cause cusps to deflect inward and pressure is transferred to dentinal tubules and pain is elicited. The mechanism of eliciting pain in this case is due to fluid flow through the dentinal tubules "hydrodynamic hypothesis."; this disturbance results in the activation of nociceptors in the inner dentin and peripheral pulp (Figure 6) [37]. If the thickness of the residual dental tissue is thin, it may also cause enamel fracture (Figure 7) when this latter is not sufficiently supported by the dentin [38]. This phenomenon, together with the flow that the composite undergoes, during the setting reaction, at the level of the free surface of the restoration, which is not subject to adhesion, limits the negative effects of stress but does not cancel them completely [39,40]. The ability of the composite to develop stress during its polymerization does depend greatly on the extent of the free surface compared with the adherent one and it's therefore strictly dependent on the cavity configuration. The greater the extension of the adherent surface compared with the free one, the greater the stress that is generated during the composite polymerization [41].
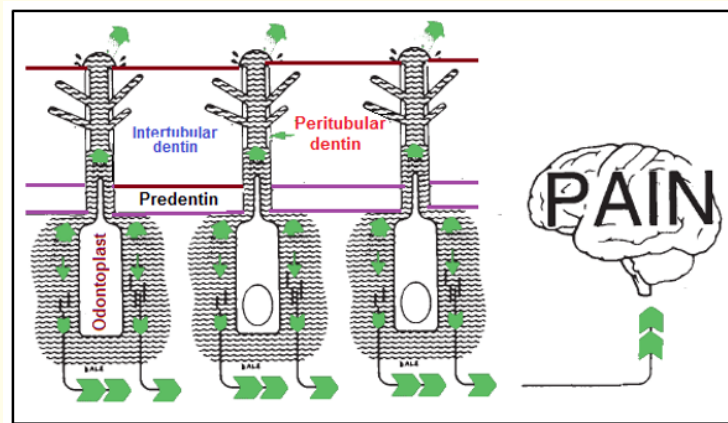

Figure 6: Schematic drawing of theoretic mechanism of dentin sensitivity. Fluid movement as proposed in hydrodynamic theory.
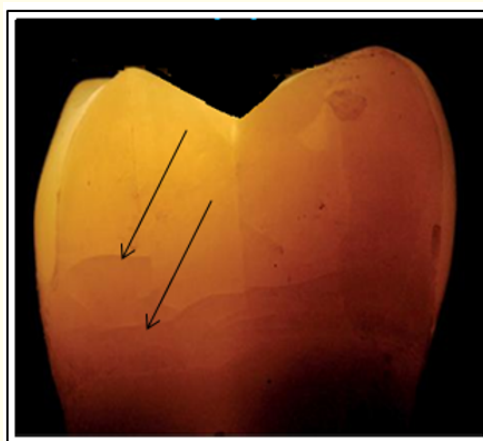

Figure 7: Enamel cracking.

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Methods used to measure polymerization shrinkage and shrinkage stresses

Several methods are described in the literature for measuring the contraction that accompanies the cure of resin composite restorative materials. These methods include mercury dilatometer, bonded disk, acuvol, and managing accurate resin curing test. The *in vitro* polymerization stress test evaluates the stresses at the bonded interface due to resin composite polymerization. These method include tensilometer, tensometer and crack analysis [28].

Methods of minimizing polymerization shrinkage:

I. Use of stress absorbing liners

The application of flowable composite resin ensures a more intimate contact with the cavity's line angles and irregularities [42]. Flowable composite is a low-modulus composite that acts as an elastic buffer that compensates polymerization shrinkage stress by flow, eliminating mastication discomfort and theoretically eliminating cuspal deformation or gap formation and reducing microleakage [43]. When elastic modulus is low, the composite will stretch to accommodate the inherent modulus of the tooth. Therefore, the internal layer may absorb polymerization shrinkage stress of the resin composite by elastic elongation [44]. Flowable resin can be used as an intermediate stress absorbing layer as it has a lower elastic modulus as compared to composite resin, which reduces the stress at the tooth-restoration interface, ultimately reducing the cuspal deflection. This is called the "elastic wall concept" [45].

Resin-modified glass ionomer cements (RMGICs) might be a better material of choice for the liner because of their higher mechanical strength compared to the conventional material and their ability to set on command. They are also known to be less technique sensitive. Furthermore, RMGICs have been recommended as liners under resin composites to reduce the amount of polymerization shrinkage, potential microleakage and secondary caries [46]. In another research it was concluded that: 1) the use of RMGIC liner as the first gingival increment of class II restorations with both silorane- and methacrylate based composite resin restorations resulted in reduced microleakage, 2) the volumetric polymerization shrinkage was least with the silorane-based composite. However, further clinical research is needed to support these findings, as the volumetric polymerization shrinkage of the restorative material was evaluated without cavity factor and bonding influences [47].

II. Placement technique: It includes the following methods:

   A. **The incremental technique:** This technique is based on polymerizing with resin-based composite layers less than 2-millimeters thick [48] and can help achieve good marginal quality, prevent distortion of the cavity wall (thus securing adhesion to dentin) and ensure complete polymerization of the resin-based composite. The various methods of placing composite related to the incremental technique are:

      1. **Horizontal technique:** This technique is an occlusogingival layering generally used for small restorations; this technique increases the C-factor [48].

      2. **Three-site technique:** This is a layering technique that is associated with the use of a clear matrix and reflective wedges. It attempts to guide the polymerization vectors toward the gingival margin thus preventing any gap formation [49].

      3. **Oblique technique:** In this technique, wedge shaped composite increments are placed to further prevent distortion of cavity walls and reduce the C-factor. This technique may be associated with polymerization first through the cavity walls and then from the occlusal surface to direct vectors of polymerization toward the adhesive surface (indirect polymerization technique) [50].

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4. **Successive cusp buildup technique:** In this technique, the first composite increment is applied to a single dentin surface without contacting the opposing cavity walls, and the restoration is built up by placing a series of wedge shaped composite increments (Figure 8) to minimize the C-factor in 3-D cavity preparations. Each cusp then is built up separately [51].
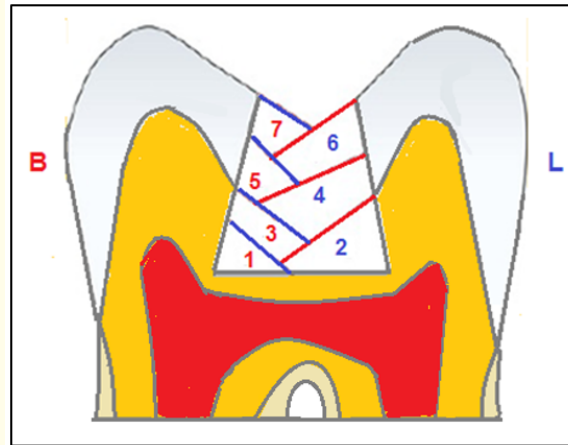

Figure 8: Successive cusp build up technique.

B. **Direct shrinkage**: A chemically cured resin based composite is used on the gingival floor in an attempt to direct the vectors of polymerization toward the warmer cavity walls. This will help to reduce the gap at the cervical margin [52].

C. **Bulk technique:** The bulk technique is recommended by some authors to reduce stress at the cavosurface margins [53]. Some manufacturers recommend using this technique with packable composites even though this is not supported by a recent study [54].

Researches have proved that bulk technique of composite placement results in more polymerization shrinkage than incremental layering technique. Incremental technique reduces the bonded/unbounded ratio, which results in less configuration factor, ultimately lesser shrinkage stress [55]. Horizontal layering technique increases the C-factor and hence the stress is greater. Buccolingual incremental technique induces least strain because cuspal tension is minimized in this technique as composite is applied to a single dentin surface without touching the opposing cavity wall. In centripetal buildup technique, as an initial vertical composite increment is placed in contact with the matrix band, class II cavities are converted to class I cavities [56].

III. Material aspect

A new monomer system named silorane was synthesized by reacting oxirane and siloxane molecules. The novel silorane-based resin is claimed to have the advantages of low polymerization shrinkage due to the ring-opening oxirane monomer which resulted in low shrinkage composite resins [56]. These monomers produce local volumetric expansion because of the opening of ring structure (Figure 9), which compensate for the volumetric shrinkage from C=C polymerization [57].

Modification of photoinitiator and inhibitor system can affect the polymerization reaction and shrinkage. Increasing the concentration of inhibitor reduced the rate of polymerization and shrinkage stress [22]. The rate of polymerization stress is reduced when camphorqui-

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none content was substituted partly by phenylpropanedione [58], the addition of thiourethane oligomers has proven to reduce polymerization stress [59] and addition of up to 20% phene (new monomer) into BIS-GMA/TEGDMA [60]. The development of low shrinkage and bulk fill materials showed promising improvement in the reduction of polymerization shrinkage stress [61].
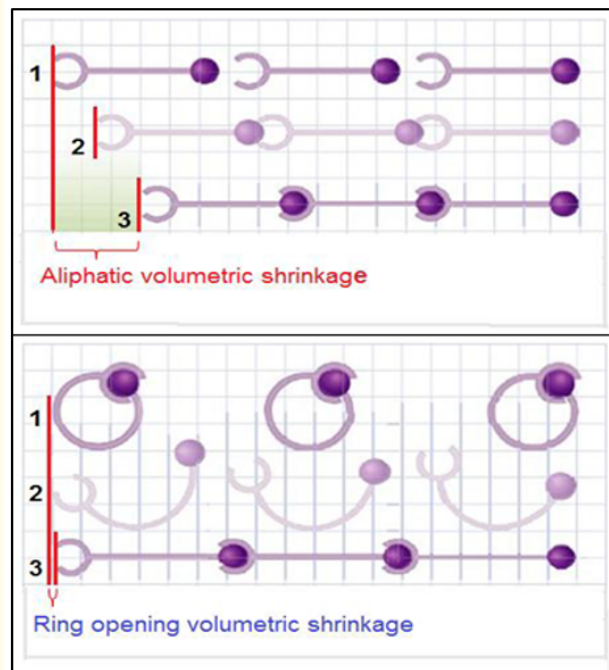

Figure 9: *Volumetric polymerization shrinkage due to opening of ring structure (bottom) compared to aliphatic one (Top).*

IV. Curing technique

Soft start polymerization that cured composite resin at a low intensity and with slow polymerization vs. higher intensity and faster polymerization resulted in improved marginal adaptation and physical properties [62]. Pulse delay technique curing with a delay of 3 - 5 minutes greatly reduced polymerization shrinkage than soft-start technique [63].

V. Preheating

Polymerization shrinkage is reduced if resin composites are preheated because the increased temperature reduces the viscosity of the material and increases radical mobility resulting in increased polymerization and higher degree of conversion. If shrinkage stress in composite resin is minimized, the success and survival rates of the restorations can be improved. So, a prudent practitioner should be aware of all the updates taking place in the field of composite resin to minimize shrinkage stress [64].

VI. Utilization of indirect composite resin restorations (Figure 10)

Figure 10: *Composite inlay.*

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New-generation indirect resins, also known as ceromers (ceramic optimized polymers) maintain a higher density of inorganic ceramic microfillers compared to the earlier-generation direct and indirect systems. Some manufacturers have recommended ceromers to be used for inlays/onlays [65]. Ceromers have been noted for providing the advantages of composite resins and porcelain without being confined by their inherent limitations [66].
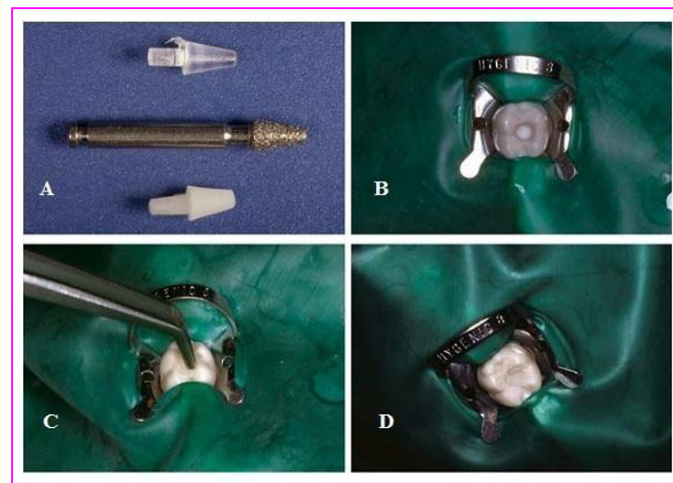
VII. The use of glass inserts (Figure 11)

Figure 11: *Glass inserts kit (A), inserted into composite filled tooth before its curing (B), kept in place during curing (C), and after curing and finishing (D).*

Inserting spherical glass mega fillers (SGMF) into the composite restoration, prior to its polymerization, will decrease the amount of resin matrix used and consequently reducing restoration contraction during its polymerization. Previous works have demonstrated both *in vivo* and *in vitro* the effectiveness of this new restorative technique [67]. The spherical shape of SGMF does not affect the flow ability of the composite during the setting reaction, while minimizing the development of interfacial stress because of its sphere shape that possess the lowest lower surface/volume ration compared with other solid shapes. Another advantage of SGMF is its transparency allowing the diffusion of light through the mass of the composite with the maximum polymerization depth of the selected composite to carry out a bulk polymerization [68]. The effect of SGMF on reducing contraction stress in dental composite resins, was studied by means of a cavity model simulating the cuspal deflection which occurs on filled tooth cavity walls in clinical condition. The SGMFs are reliable in reducing contraction stress in dental composite resins [69].

Recent studies about polymerization shrinkage of composite resins and the resulting stresses

A study compared the microleakage among newer composite materials. ORMOCER - Admira, Tetric N-Ceram and Tetric Ceram concluded that 1) one of the primary variables that determine success in restorative dentistry is choosing the correct restorative material, 2) One of the factors which affects the performance of the material in the oral cavity is its microleakage and 3) ORMOCER - Admira performed better than the other two composite materials with the least microleakage [70].

Newer methods for evaluation of polymerization shrinkage (non-destructive methods) with micro-computed tomography (μ-CT) method. The study group included eight different flowable composites; Surefil SDR Flow (SDR), Charisma Flow (CHF), Clearfil Majesty

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Flow (CMF), Vertise Flow (VF), Grandio Flow (GF), Filtek Supreme Ultimate Flow (3MEFU), Filtek Bulk Flow (3MBF), X-Tra Base Flow (XTB) and concluded that all tested materials were able to achieve acceptable shrinkage at 2 - 4 mm depth [71].

A meta-analysis demonstrated that marginal adaptation after 12 months showed statistically significant outcomes, where methacry-lates-based composites presented significantly better results than resin composites containing modified monomers.

The good level of the scientific evidence as well as the overall low risk of bias of the included studies indicate that composites with silorane, ormocer or bulk-fill type modified monomers have a clinical performance similar to conventional resin composites [72].

Fiber Bragg grating (FBG) sensors used to compare the linear polymerization shrinkage of five resin-based composites (RBCs) Zir-confill® (ZFL); Aura Bulk-Fill (ABF); Tetric® N-Ceram Bulk-Fill (TBF); FiltekTM Bulk-Fill (FBF); and Admira Fusion-Ormocer® (ADF). The linear polymerization shrinkage of RBCs was evaluated in real time using optical fiber Bragg grating sensors embedded in the material evidencing good reliability. Within its limitations, this *in vitro* study showed that Admira Fusion, an Ormocer, presented the lowest linear shrinkage over all other RBCs, while restorative bulk-fill composites exhibited an intermediate behavior and Zirconfill showed the highest shrinkage values [73].

Conclusion

Polymerization shrinkage cannot be completely eliminated but there are numerous methods to reduce it, hence the clinician should implement any of these methods to improve the success rate and longevity of the composite resin restorations [74].

The current article discussed what clinicians and researchers need to know about polymerization shrinkage stress of resin-based materials. Shrinkage stress effects are reviewed and found that it depends upon many complex factors. The current review showed how much progress has been made in the collective development of research techniques to better understand, predict, and develop shrinkage stress mitigation options and strategies that will continue to benefit clinicians and their patients.

Disclosure Statement

The authors have no financial interest in the materials or devices reviewed and declare no conflict of interest.

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