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College of Dentistry

Techniques to reduce polymerization shrinkage of resin-based composite

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in Partial Fulfillment for the Bachelor of Esthetic and Restorative Dentistry

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بسم الله الرحمن الرحيم

صدق الله العظيم

المجادلة الآية ١١

Certification of the Supervisor

I certify that this project entitled " **Techniques to reduce polymerization shrinkage of resin-based composite** " was prepared by the fifth-year student "…………………." under my supervision at the University of Baghdad, College of Dentistry in partial fulfillment of the graduation requirements for the Bachelor Degree in Esthetic and Restorative Dentistry.

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Date: / / 2023

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I would like to thank God Almighty, for without the power he gave me to move on through many hard times, I would’ve given up a long time ago.

I would like to thank (**Dr. Samar Abdul Hamed**) for supervising my project, for her directives and guidance to accomplish this work.

Dedication

TO

My Mother

A strong and gentle soul who taught me to trust in Allah, believe in hard work and that so much could be done with little

My Father

For earning an honest living for us and for supporting and encouraging me to believe in myself

My sisters

Who supported me all the way through my pursue to higher education

To all my friends who cared for me

Aim of Study

The purpose of this study is to know how polymerization shrinkage of resin-based composite occur and how to reduce this shrinkage by using different placement techniques (incremental technique, bulkfill, snowplow technique, and injection molding technique)

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Introduction

Composite resin has been introduced since the late 1950s and is widely used as a restorative material in dentistry (Schneider et al., 2010). It has several advantages over amalgam such as better aesthetic properties, ability to bond to the tooth structure, and allowing for better conservation of tooth structure (Kaisarly and Gezawi., 2016). Due to all these advantages, the use of composite resin has increased drastically in modern preventive and restorative dentistry.

Despite the continuous advancements in composite resins, it still suffers from polymerization shrinkage that ranges from 2 to 5% (Braga et al., 2005). Polymerization shrinkage of composite resins occurs mostly due to the conversion of monomer into polymer chain in which the van der Waals forces are replaced by covalent bonds that pull the particles closer (Kaisarly and Gezawi., 2016). This leads to interfacial polymerization stresses, causing gap formation at the dentine-bond interface, increasing the risk of recurrent caries and consequently restoration failures (Al Sunbul et al., 2016).

Possible causes of marginal gap development are polymerization shrinkage, effect of configuration factor (C-factor), differences in coefficients of thermal expansion between the tooth and restorative materials, and water sorption,(Subbiya, Venkatesh et al. 2020)

Many techniques were suggested to reduce the adverse effects of shrinkage stress, among these suggestions are: altered light curing cycles (intensity and time curing), thiol-ene photo polymerization, preheating , vibration, stress absorbing layers with low elastic modulus liners and diverse composite layering techniques (Deliperi and Bardwell 2002)

Different placement techniques of posterior composite were adopted to reduce polymerization shrinkage. Among these techniques, a widely used method named Incremental Technique which rely on applying composite in 2mm increment in different suggested ways such as: horizontal technique, oblique successive cusp build-up technique, centripetal incremental technique, split horizontal technique and three-site technique. (Chandrasekhar, Rudrapati et al. 2017).

Although polymerization shrinkage has been reduced by incremental technique, researches documented some drawback such as voids, cuspal deflection and time consuming. Bulkfill composite which allow 4-5mm bulk placement, has been developed to overcome some of these shortenings (Boaro, Lopes et al. 2019) . Some authers advocated the use of flowable composite underneath the bulkfill to improve the adaptation of composite and help in increase relaxation stress (Kaisarly, Meierhofer et al. 2021).

In addition to traditional technique in the application of composite, two advanced methods has been suggested. A snowplow technique is one of these techniques, which involves the placement of a layer of flowable composite on the pulpal floor and the gingival margin of the proximal box of a posterior composite resin restoration. However, the layer of flowable composite is not cured, followed by application of packable composite and curing the 2 layers simultaneously (Doustfateme, Khosravi et al. 2018) While another technique was suggested by David Clark named injection molding technique, which proposed the use of one layer of adhesive followed by flowable composite then finally injecting the paste composite. The resin-flowable-paste mass is polymerized together in a single (Clark 2010).

The development of new resinous materials and the inevitable clinical signs and symptoms associated with polymerization shrinkage make this topic an important issue for clinicians and researchers. Therefore, this review article will focus on polymerization shrinkage, polymerization stress, their consequences and strategies used by companies and clinicians to minimize the effects.

1- Polymerization Shrinkage and Stress

A polymer occupies less volume than the monomers, the effect of which is well known as polymerization shrinkage (Kim et al., 2015). During the process of polymerization, the weak physical van der waals attraction between the monomer molecules are replaced by a stronger covalent bond and thus development of shrinkage (Pratap et al., 2019).

Unfortunately, almost all composite resins currently available in the dental market exhibit shrinkage during transforming monomers into polymers, ranging from 2 to 7% volumetrically (Hassan and Khier 2019). Composite polymerization could well be split into two phases: the pre gel phase and the post gel phase. Prior to gelation, the reactive species exhibit sufficient mobility to reorganize and adjust for volumetric shrinkage without producing substantial quantities of internal and interfacial stresses (Perdigão et al., 2012; Sezinando, 2014). Polymerization shrinkage occurs after the gel point, causing strain on the network and the attachment region to the bonding system after the gel point. This stress condition is known as polymerization shrinkage stress (Hilton, 2002a, 2002b).

2- Polymerization mechanism

A dental composite comprises a system of mono-, di- or trifunctional monomers. BIS-GMA (bisphenol A–diglycidyl ether methacrylate) and urethane dimethacrylate are the most popular and widely used dimethacrylates (Rueggeberg, 2011).

Blue light activates Camphorquinone photoinitiator (CQ) and transforms it chemically into an excited triplet state which reacts with the amine to produce free radicals (Stansbury JW. 2000). 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 (Braem M., et al., 1989), 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 (Peutzfeldt A.,1997).

3- Factors involved in the development of polymerization shrinkage stress in dental composite

3.1 Volumetric Shrinkage

When the monomers react to form a covalent link, the distance and the free volume between the two groups of atoms are reduced, both of which result in volumetric shrinkage of the polymer structure. The amount of volumetric shrinkage experienced by a composite is governed by the volume fraction of filler used, the composition of the resin matrix, and the degree of conversion experienced by the resin matrix (Braga et al., 2005)

3.2 Configuration factor (C factor):

The C-factor is the ratio of bonded surfaces to the un-bonded, or free surfaces in a tooth preparation.

The higher the C-factor, the greater is the potential for bond disruption from polymerization effects (Ikemi and Nemoto., 1994).

Class I and class V cavity exhibit greatest stress because the restoration is bonded to five walls of the cavity. High C – factor results in de bonding of the restoration. Lowest stress is seen in class IV cavity because it has enough un bonded surfaces providing stress relief. Hence it is important to have lower configuration cavity (Combe et al., 1999).

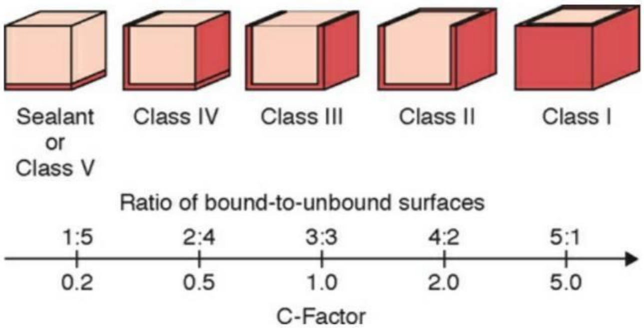

Figure 1 Configuration factors (C-factors) associated with polymerization shrinkage for different situations using dental restorative materials.

3.3 Composition of resin matrix:

In case of methacrylate monomers, it is impossible to avoid shrinkage, which ranges up to 10% 16% by volume (Jakubiak J and Linden LA., 2001). 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 (Kilambi H., et al., 2009). Composite resins with silorane monomer have lower polymerization shrinkage than methacrylate-based composites (Son SA., et al.,2014).

3.4 Degree of conversion:

The degree of conversion (DC) can be defined as the extent to which monomers react to form polymers or as the ratio of C=C double bonds that are converted into C-C single bonds (Iile and Hickel., 2011).

There is a direct relationship between degree of conversion and shrinkage (Silikas et al., 2000). For a given composite, a reduction in the final degree of conversion will lead to lower shrinkage and lower contraction stress. However, a low degree of conversion might compromise some of the materials mechanical properties. In contrast, small increases in the degree of conversion will produce substantial increases in stress but will improve the mechanical properties of the material (Braga and Ferracane., 2002).

3.5 Filler volume fraction

Filler volume fraction has an inverse relation to volumetric shrinkage (Wang Zand Chiang MY., 2016). 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 (Gonçalves F., et al. , 2011), but the shrinkage value for composites is only 2% -3% because of the filler content.

3.6 Water sorption

The quantity of water absorbed by a material via the exposed surface and into the substance's body is referred to as water absorption by the material. Two opposing processes occur as a result of the diffusion of water into the matrix. In certain composites, water will leak away free unreacted monomers and ions that have not yet been reacted. This outward migration of ions leads to additional shrinkage and weight loss of the material as a result of the process. Hygroscopic absorption of water, on the other hand, results in a swelling of the material as well as an increase in weight. This process may allow for a degree of relaxation of the tensions that are created inside the matrix during polymerization shrinkage if the matrix is sufficiently flexible (Shalan and Yasin, 2011).

3.7 Intensity of curing light

There exists a linear relationship between polymerization shrinkage and light intensity, which means that higher light intensity produced greater polymerization shrinkage when exposure time is constant.(Sakaguchi RL, 1998). 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. (Giachetti L, Scaminaci Russo D, Bambi C, Grandini R, 2006) Polymerization shrinkage is highest with ramp curing modes and high intensity modes, whereas it is lesser with step-curing and low intensity modes . (Watts DC, Silikas N, 2005).

3.8 Thickness of composite resin:

Incremental curing produces lesser polymerization shrinkage stress than bulk curing (Giachetti et al., 2006).

4- Techniques to reduce shrinkage stress

4.1 Intensity of curing light

There exists a linear relationship between polymerization shrinkage and light intensity, which means that higher light intensity produced greater polymerization shrinkage when exposure time is constant. (Sakaguchi RL, 1998) 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. (Giachetti L, Scaminaci Russo D, Bambi C, Grandini R, 2006) Polymerization shrinkage is highest with ramp curing modes and high intensity modes, whereas it is lesser with step-curing and low intensity modes. (Watts DC, Silikas N, 2005).

There are many types of alternative light-curing methods:

4.1.1 Pulse delay:

In this method, each exposure is separated by a dark interval. During this phase the polymerization reaction takes place at a slow rate. The greatest reduction in the shrinkage is accomplished with the delay of 3 to 5 minutes.

Curing done for 10 seconds at 1-cm distance with a time gap of 10 seconds followed by 20 seconds curing in contact with the tooth surface proves to be a suitable technique to reduce the polymerization shrinkage without compromising the degree of conversion (Subbiya et al., 2015).

4.1.2 Ramped curing:

The intensity is gradually increased during the polymerization process. It is achieved by increasing the intensity with every 30 seconds either by bringing the light closer to the tooth or using a curing light designed to change its intensity. This allows the light curing material to have a prolonged gel phase during which the polymerization stresses are distributed readily (Schneider et al., 2008).

4.1.3 Staged curing / delayed curing:

The restoration is initially cured at lower intensity until the contour and shape of the restoration is achieved. The second exposure with high intensity is applied to cure the final restoration. This provides substantial stress relaxation period. The longer the relaxation period, lower the stress generated (Bassi et al., 2016).

4.2 Incremental Curing of Composites-Layering Techniques

The reason for using multilayer methods is to decrease overall polymerization stress by increasing the number of increments and providing them an optimum shape to increase the total free surface area of the polymerization product (Park et al., 2008)**.**

4.3 Stress Absorbing Layers with Low Elastic Modulus Liners

In the case of resin-based composites, liners such as flowable composite and resin-modified glass ionomer cement are used (Kwon et al, 2010) .The lower filler content and lower elastic modulus of these materials suggest that they may be used as a "stress breaker," absorbing the forces of shrinkage during polymerization and loading under cyclic conditions. Using a flowable resin composite as an intermediary thin layer to overcome polymerization shrinkage stress has been proposed as a means of overcoming polymerization shrinkage stress. This is based on the idea of an "elastic cavity wall" previously proposed for filled adhesives (Braga et al., 2005).

Under the "elastic cavity wall concept," the shrinkage stress produced by the following layer of greater modulus resin composite may be absorbed by an elastic intermediate layer, decreasing the tension at the tooth-restoration interface (Unterbrink & Liebenberg, 1999). Restorative materials, on the other hand, come in a broad range of shrinkage and elastic modulus values.

As a result, certain combinations may have worse overall effectiveness when compared to the typical restorative substance used alone. Some author stateded that the shrinkage stress of flowable resin composites was found to be comparable to that of conventional resin composites, confirming the hypothesis that the use of flowable materials does not result in a significant stress reduction and that the risk of debonding at the adhesive interface as a result of polymerization contraction is the same for both types of material. (Cadenaro et al., 2009).

4.4 Preheating

Preheating resin composites have found to reduce the polymerization shrinkage because the increased temperature reduces the viscosity of the material and increases radical mobility. This would result in increased polymerization and higher degree of conversion. (Baroudi K, Mahmoud S, 2015)

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 the shrinkage stress.

4.5 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 shrink- age composite resins (Moosavi H., et al., 2012). These monomers produce local volumetric expansion because of the opening of ring structure (Figure 2). which compensate for the volumetric shrinkage from CaC polymerization (Weinmann W., et al., 2005).

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 (Braga RR and Ferracane JL., 2002). The rate of polymerization stress is reduced when camphorqui - none content was substituted partly by phenylpropanedione (Schneider LF., et al., 2008), the addition of thiourethane oligomers has proven to reduce polymer- ization stress (Bacchi A., et al., 2018) and addition of up to 20% phene (new monomer) into BIS-GMA/TEGDMA (He J., et al., 2016). The development of low shrinkage and bulk fill materials showed promising improvement in the reduction of polymerization shrinkage stress (Meereis CTW., et al., 2018).

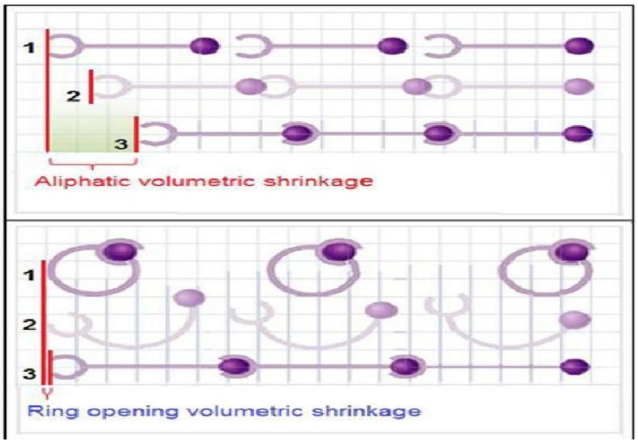

Figure 2: Volumetric polymerization shrinkage due to opening of ring structure (bottom) compared to aliphatic one (Top).

4.6 Vibration

Based on the premise that vibration reduces the viscosity of the composite, enabling the material to flow and readily adapt to the cavity walls without voids, this method is comparable to flowable composites in its performance characteristics. So instead of having to deal with the drawbacks of large polymerization shrinkage and poor mechanical characteristics of a flowable composite, a condensable material with a higher viscosity may be utilized in a similar manner two examples are Sonicfill composite and Compothixo instrument (Iovan et al., 2011).

Figure 3 Sonicfill composite and Compothixo instrument

5- Composite Placement Techniques

5.1 Incremental Technique

The incremental technique has been widely accepted as a standard method for resin composites placement because it depends on layering thickness of 2mm or less than allows enough light penetration for adequate polymerization. This will enhance the physical properties, marginal adaptation, reduce cytotoxicity, and minimized polymerization shrinkage of composite restoration by reducing the volume of material and C-factor (Costa et al., 2017).

When the incremental technique was used for insertion of the composite, there was a reduction in microleakage, which could be due to the reduced volume of the resin and the stress generated on the cavity walls, as well as to more uniform and efficient polymerization of the resin composite throughout its entire thickness (Pfeifer et al., 2006). The followings are some examples of variations associated with different stratifications (Nadig et al, 2011).

5.1.1 Horizontal Technique

This is an occlusogingival layering technique that is usually utilized less than 2 mm thickness of composite restorative material against the prepared cavity surface is done and cured. But the primary disadvantage is that there is an increase of the C-factor, which in turn increase the shrinkage (Reis et al., 2003) (Figure 4)

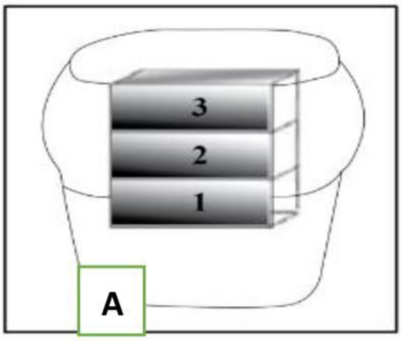

Figure 4 A: Horizontal Technique (Reis et al., 2003)

5.1.2 Oblique technique

The concept of the oblique technique was first introduced by Lutz et al., (1986) to improve resin flow and therefore reduce polymerization shrinkage stress by increasing adhesive-free surface area. In this method, wedge-shaped composite increments are inserted and polymerized just from the occlusal surface, rather than the whole surface. Because the form of the increment in the oblique method covers less cavity wall surface than the horizontal technique does, it may have resulted in less stress being applied to the wall (Mereuţă et al., 2012). (Figure 5)

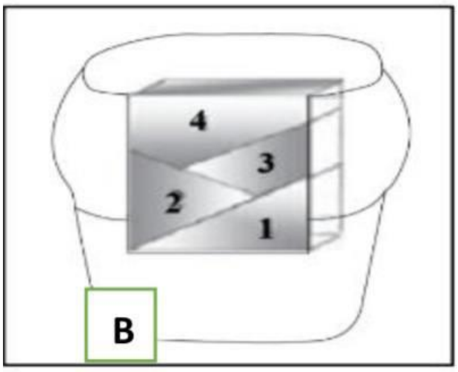

Figure 5 B: Oblique Method (Reis et al., 2003)

5.1.3 Centripetal Incremental Technique:

was developed by Bicho in 1994. It included the creation of a thin composite proximal wall before filling the whole preparation with horizontal increments, resulting in greater adaptability of the composite to cavity walls (Nadig et al., 2011). (Figure 6)

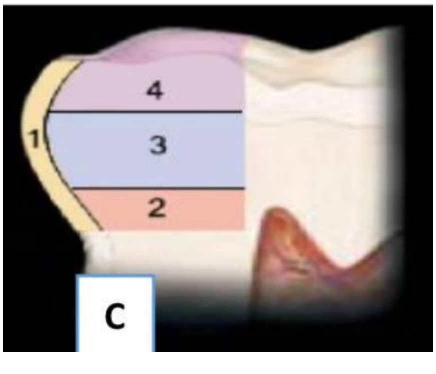

Figure 6 C: Centripetal Incremental Technique (Szep et al., 2001)

5.1.4 Split Horizontal Technique:

A variation of the centripetal and horizontal incremental methods, the split horizontal incremental approach has been suggested, in which, after constructing the proximal wall, the horizontal increments put to fill the class I cavity thus created are divided to further decrease the C factor (Iovan et al., 2011). (Figure 7)

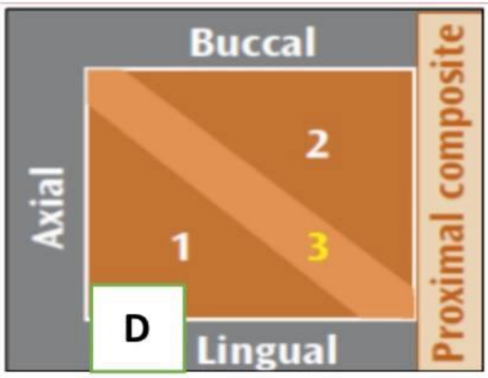

Figure 7 D: Split Horizontal Technique (Nadig et al., 2011)

5.1.5 Three-Site Technique:

For many years, it was thought that contraction in light-curing resin composites always occurred toward the light source. However, this was shown incorrect (Lutz et al., 1986). This method is linked with the employment of a reflecting wedge and a modified transparent matrix, among other components. To begin, the curing light is directed through the matrix and wedges in an attempt to guide the polymerization vectors toward the gingival margin. This has resulted in a reduction in the intensity of the light, a reduction in contraction stresses, and an improvement in the adaptation ((Lindberg et al., 2007); Karthick et al,. 2011) (Figure 8) .

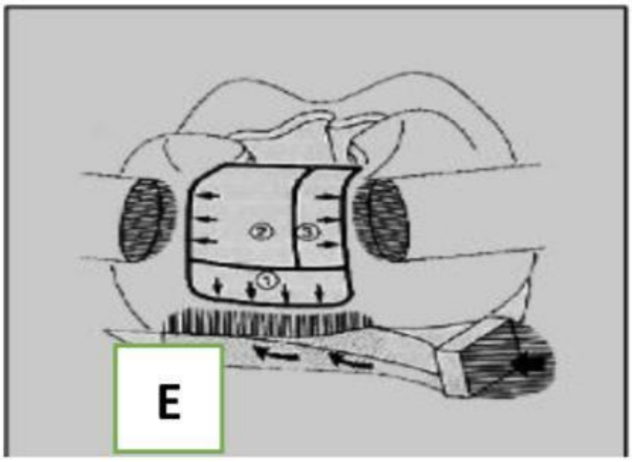

Figure 8 E: Three-Site Technique (Karthick et al., 2011)

5.1.6 Successive cusp build-up Technique:

In this method, the initial composite increment is placed to a single dentin surface without coming into touch with the opposing cavity walls, and then the restoration is built up by putting a succession of wedge-shaped composite increments to reduce the C-factor. (Giachetti et al. (2006)) describe the process of building up each cusp one at a time (Figure 9).

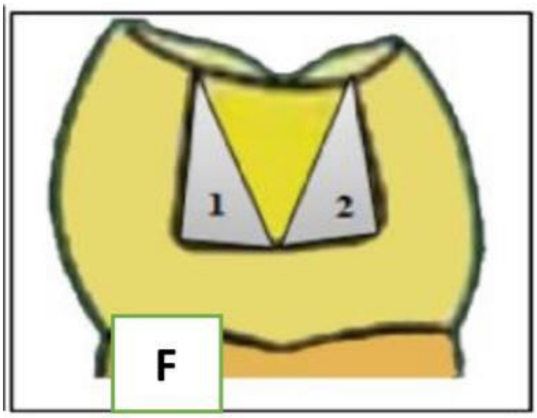

Figure 9 F: Successive cusp build-up Technique (Giachetti et al., 2006)

5.2 Bulk Technique

This technique refers to the use of a regular consistency bulk-fill composite in one increment up to 4-5mm without an additional capping layer as shown in Figure (10) (Hirata et al., 2015). This helps to decrease curing time and controlled polymerization shrinkage that leads to time-saving for the dentist and patient and produces more comfortable restoration (Ilie et al,. 2013)

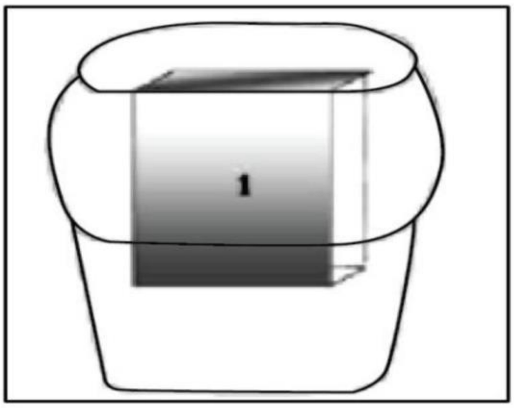

Figure 10; Bulkfill Technique

Bulk fill receives Innovative modifications in monomer chemistry, initiation system, and filler content, as well as developing novel polymerization strategies (Elshazly et al., 2020).

5.3 Snow plow technique

The snowplow technique involves the placement of a layer of flowable composite on the pulpal floor and the gingival margin of the proximal box of a posterior composite resin restoration. However, the layer of flowable composite is not cured before the placement of a denser-filled composite resin restorative material. In this way, the flowable is pushed into a very thin layer, and the excess is pushed out of the preparation. Reportedly, this will leave a very thin film of the high-shrinking flowable composite (Opdam et al., 2003). The flowable and the initial heavier-filled composite layer are light-cured as one increment. In contrast, a flowable composite cured in the traditional manner prior to subsequent incremental placement has been shown to increase the polymerization stress at the adhesive interface leading to a possible adhesive failure (Oliveira et al., 2010).(Figure 11).

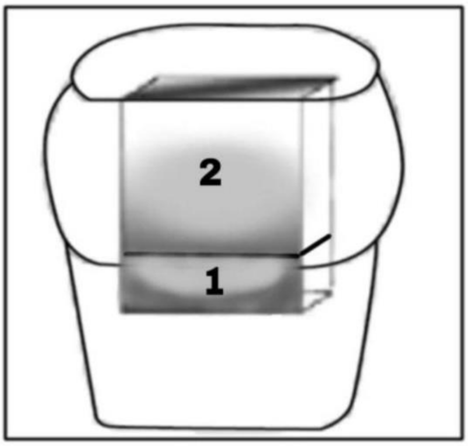

Figure 11: Snowplow technique 1:uncured flowable composite ,2: packable composite ,the two layers cured simultaneously.

5.4 Injection molding technique

The injection-molded composite technique was firstly suggested by David J. Clark in 2010, who proposed using one layer of adhesive followed by flowable composite then finally injecting the paste composite. The resinflowable paste mass is polymerized together in a single light cure. The concept of injection-molded composite dentistry can be compared to impressioning, in which the low-viscosity, light-body material is syringed into subgingival areas, and then followed and partially displaced by a heavier, high-viscosity impression material that has appropriate physical characteristics. In this technique, successively higher-viscosity materials are applied in sequence, and the bonding resin and flowable composite act as wetting agents, which are subsequently displaced by the heavier pastecomposite material. (Clark, 2010) (Figure 12).

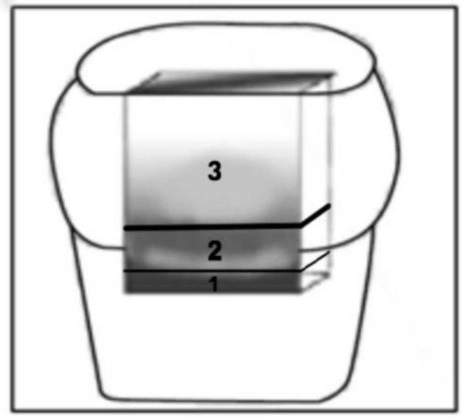

Figure 12: Injection molding technique 1:uncured adhesive ,2:uncured flowable, 3:packable composite ,the three layers cured simultaneously.

Conclusion

The use of composite restorations is increasing because of the benefits accrued from adhesive bonding to tooth structure, esthetic qualities, and almost universal clinical use. When done properly, a composite restoration can provide excellent service for many years.

Though shrinkage cannot be eliminated completely, there are numerous methods to reduce it. Therefore, the clinician should implement any of these methods to improve the success rate and longevity of the composite resin restorations.

Reference

A

- Al Sunbul H, Silikas N, Watts DC. Polymerization shrinkage kinetics and shrinkage-stress in dental resin-composites. Dent Mater 2016;32(8):998–1006.

B

- Bacchi A., et al. "Shrinkage/stress reduction and mechanical properties improvement in restorative composites formulated with thio- urethane oligomers". The Journal of the Mechanical Behavior of Biomedical Materials 78 (2018): 235-420.
- Baroudi K, Mahmoud S Improving composite resin performance through decreasing its viscosity by different methods. Open Dent J 2015;9:235-42
- Bassi MA, Serra S, Andrisani C, Lico S, Baggi L, Lauritano D. Polymerization shrinkage and spherical glass mega fillers: Effects on cuspal deflection. Oral Implantol. 2016 Oct;9(Suppl 1):71.
- Boaro, L. C. C., D. P. Lopes, A. S. C. de Souza, E. L. Nakano, M. D. A. Perez, C. S. Pfeifer and F. Gonçalves (2019). "Clinical performance and chemical-physical properties of bulk fill composites resin—a systematic review and meta-analysis." Dental Materials 35(10): e249-e264.
- Braem M., et al. "Mechanical properties and filler fraction of dental composites". Dental Materials 5 (1989): 346-349.
- Braga RR and Ferracane JL. "Contraction stress related to degree of conversion and reaction kinetics". Journal of Dental Research 81 (2002): 114-118.
- Braga RR, Ballester RY, Ferracane JL. Factors involved in the de-velopment of polymerization shrinkage stress in resin-composites: a systematic review. Dent Mater 2005;21:962-970.

- Braga RR, Ferracane JL. Contraction stress related to degree of conversion and reaction kinetics. J Dent Res 2002;81:114-8.

C

- Cadenaro, M., Marchesi, G., Antoniolli, F., Davidson, C., Dorigo, E. D. S., & Breschi, L. (2009). Flowability of composites is no guarantee for contraction stress reduction. Dental Materials, 25(5), 649-654.
- Chandrasekhar, V., L. Rudrapati, V. Badami and M. Tummala (2017). "Incremental techniques in direct composite restoration." Journal of conservative dentistry: JCD 20(6): 386.
- Clark, D. J. (2010). "The injection-molded technique for strong, esthetic Class II restorations." Inside Dentistry 6(1): 68-76.
- Combe EC, Burke FJT, Douglas WH, eds. Dental Biomaterials. Boston: Kluwer Academic Publishers, 1999.
- Costa, M. B., Tomisaki, E. T., dos Santos, D. C. M., Hoeppner, M. G., & de Almeida Cardoso, S. (2021). Clinical Evaluation of Composite Resin Restorations in Posterior Teeth. Journal of Health Sciences, 23(1), 39-43.

D

- Deliperi, S. and D. N. Bardwell (2002). "An alternative method to reduce polymerization shrinkage in direct posterior composite restorations." The Journal of the American Dental Association 133(10): 1387-1398.
- Doustfateme, S., K. Khosravi and S. Hosseini (2018). "Comparative evaluation of microleakage of bulk-fill and posterior composite resins using the incremental technique and a liner in Cl II restorations." Journal of Islamic Dental Association of Iran 30(1): 1-8.

E

- Elshazly, T. M., Bourauel, C., Aboushelib, M. N., Sherief, D. I., & El-Korashy, D. I. (2020). The polymerization efficiency of a bulk-fill composite based on matrix-modification technology. Restorative Dentistry & Endodontics, 45(3).

G

- Giachetti L, Scaminaci Russo D, Bambi C, Grandini R A review of polymerization shrinkage stress: Current techniques for posterior direct resin restorations. J Contemp Dent Pract 2006;7:79-88.
- Giachetti L, Scaminaci Russo D, Bambi C, Grandini R. A review of polymerization shrinkage stress: current techniques for posterior direct resin restorations. J Contemp Dent Pract. 2006 Sep 1;7(4):79-88.
- Gonçalves F., et al. "BISGMA/TEGDMA ratio and filler content effects on shrinkage stress". Dental Materials 27 (2011): 520-526.

H

- Hassan, K. and S. Khier (2019). "A review on incremental techniques for placing direct occlusal and proximal composite restorations." Dental & Oral Health Int J 1(1): 1-11.
- He J., et al. “The effect of adding a new monomer “phene” on the polymerization shrinkage reduction of a dental resin composite”. Dental Materials 35 (2019): 627-635.
- Hilton, T. J. (2002a). Can modern restorative procedures and materials reliably seal cavities? In vitro investigations. Part 1. American Journal of Dentistry, 15(3), 198-210.

- Hilton, T. J. (2002b). Can modern restorative procedures and materials reliably seal cavities? In vitro investigations. Part 2. American Journal of Dentistry, 15(4), 279-289.
- Hirata, R., Kabbach, W., De Andrade, O. S., Bonfante, E. A., Giannini, M., & Coelho, P. G. (2015). Bulk fill composites: an anatomic sculpting technique. Journal of Esthetic and Restorative Dentistry, 27(6), 335-343.

I

- Ikemi, T, Nemoto, K. Effects of lining materials on the composite resin's shrinkage stresses.Mater. 1994; 13:1–8.
- Ilie N, Hickel R. Resin composite restorative materials. Aust Dent J. 2011;56(Suppl 1):59–66. Implantol. 2016 Oct;9(Suppl 1):71.
- Ilie, N., Bucuta, S., & Draenert, M. (2013). Bulk-fill resin-based composites: an in vitro assessment of their mechanical performance. Operative Dentistry, 38(6), 618-625.
- Iovan, G., Stoleriu, S., Moldovanu, A., Morogai, S., & Andrian, S. (2011). SEM study of the interface between the cavity wall and composite resin in cavities filled using vibration. Int J Med Dent, 1(3), 254-258.

J

- Jakubiak J and Linden LA. "Contraction in polymerization. Part 1. Fundamentals and measurements". Polimery 46 (2001): 7-8.

K

- Kaisarly D, Gezawi ME. Polymerization shrinkage assessment of dental resin composites: a literature review. Odontology 2016;104(3):257–270.

- Kaisarly, D., D. Meierhofer, M. El Gezawi, P. Rösch and K. Kunzelmann (2021). "Effects of flowable liners on the shrinkage vectors of bulk-fill composites." Clinical Oral Investigations: 1-14.
- Kilambi H., et al. “Evaluation of highly reactive mono-methacrylates as reactive diluents for BISGMA-based dental composites”. Dental Materials 25 (2009): 33-38.
- Kim RJ, Kim YJ, Choi NS, Lee IB. Polymerization shrinkage, modulus, and shrinkage stress related to tooth-restoration interfacial debonding in bulk-fill composites. J Dent. 2015;43(4):430-9.
- Kwon, O.-H., Kim, D.-H., & Park, S.-H. (2010). The influence of elastic modulus of base material on the marginal adaptation of direct composite restoration. Operative Dentistry, 35(4), 441-447.

L

- Lindberg, A., van Dijken, J. W., & Lindberg, M. (2007). Nine-year evaluation of a polyacid-modified resin composite/resin composite open sandwich technique in Class II cavities. Journal of dentistry, 35(2), 124-129.
- Lutz, E., Krejci, I., & Oldenburg, T. (1986). Elimination of polymerization stresses at the margins of posterior composite resin restorations: a new restorative technique. Quintessence international (Berlin, Germany: 1985), 17(12), 777-784.

M

- Meereis CTW., et al. “Polymerization shrinkage stress of resin-based dental materials: A systematic review and meta-analyses of composition strategies”. Journal of the Mechanical Behavior of Biomedical Materials 82 (2018): 268-281.

- Mereuţă, V.-D., Andrian, S., Iovan, G., Topoliceanu, C., Sălceanu, M., Hamburda, T., & Lăcătuşu, Ș. (2012). CLINICAL PERFORMANCE OF CLASS II COMPOSITE RESINS DIRECT RESTORATIONS RELATED TO RESTORATIVE TECHNIQUE: 12 MONTHS LONGITUDINAL STUDY. Romanian Journal of Oral Rehabilitation, 4(1), 44.
- Moosavi H., et al. “Fracture resistance of premolars restored by various types and placement techniques of resin composites”. Inter- national Journal of Dentistry (2012): 5. Article ID 973641, doi:10.1155/2012/973641.

N

- Nadig RR, Bugalia A, Usha G, Karthik J, Rao R, Vedhavathi B. Effect of four different placement techniques on marginal microleakage in class II composite restorations: An in vitro study. World J Dent. 2011; 2(2): 111-

O

- Oliveira, L. C., Duarte Jr, S., Araujo, C. A., & Abrahão, A. (2010). Effect of low-elastic modulus liner and base as a stress-absorbing layer in composite resin restorations. Dental Materials, 26(3), e159-e169.
- Opdam, N., Roeters, J., de Boer, T., Pesschier, D., & Bronkhorst, E. (2003). Voids and porosities in class I micropreparations filled with various resin composites. Operative Dentistry, 28(1), 9-14.

P

- Park, J., Chang, J., Ferracane, J., & Lee, I. B. (2008). How should composite be layered to reduce shrinkage stress: incremental or bulk filling? Dental Materials, 24(11), 1501-1505.

- Perdigão, J., Sezinando, A., & Monteiro, P. C. (2012). Laboratory bonding ability of a multi-purpose dentin adhesive. American Journal of Dentistry, 25(3), 153.
- Pereira RD, Valdívia AD, Bicalho AA, Franco SD, Tantbirojn D, Versluis A et al. Effect of photoactivation timing on the mechanical properties of resin cements and bond strength of fiberglass post to root dentin. Oper Dent.2015;40(5):E206-21.
- Peutzfeldt A. "Resin composites in dentistry: the monomer systems". European Journal of Oral Sciences 105.2 (1997): 97-116.
- Pfeifer, C. S. C., Braga, R. R., & Cardoso, P. E. C. (2006). Influence of cavity dimensions, insertion technique and adhesive system on microleakage of Class V restorations. The Journal of the American Dental Association, 137(2), 197-202.
- Pratap B, Gupta RK, Denis L, Goswami D. Evaluation of polymerization shrinkage and Vickers hardness for restorative dental composites. Mater. Today Proc., vol. 21, 2020, p. 1563–5. doi:10.1016/j.matpr.2019.11.090.

R

- Reis, A. F., Giannini, M., Ambrosano, G. M. B., & Chan, D. C. (2003). The effects of filling techniques and a low-viscosity composite liner on bond strength to class II cavities. Journal of dentistry, 31(1), 59-66.
- Rueggeberg FA State-of-the-art: Dental photocuring—A review. Dent Mater 2011;27:39-52. Back to cited text no.

S

- Sakaguchi RL, Berge HX Reduced light energy density decreases post-gel contraction while maintaining degree of conversion in composites. J Dent 1998;26:695-700.

- Schneider LF, Cavalcante LM, Silikas N. Shrinkage stresses gen- erated during resin-composite applications: a review. J Dent Biomech 2010;2010. Doi: 10.4061/2010/131630.
- Schneider LF, Pfeifer CS, Consani S, Prahl SA, Ferracane JL. Influence of photoinitiator type on the rate of polymerization, degree of conversion, hardness and yellowing of dental resin composites. Dent Mater. 2008 Sep 1;24(9):1169-77.
- Schneider LF., et al. "Influence of photoinitiator type on the rate of polymerization, degree of conversion, hardness and yellowing of dental resin composites". Dental Materials 24 (2008): 1169-1177.
- Shalan LA, Yasin SH. Water sorption of three types of composite resins. J Medical Dent. 2011; 8(3): 242-7.
- Silikas N, Eliades G, Watts DC. Light intensity effects on resin-composite degree of conversion and shrinkage strain. Dent Mater 2000;16(4):292–6.
- Son SA., et al. "The effect of resin thickness on polymerization characteristics of silorane-based composite resin". Restorative Dentistry and Endodontics 39 (2014): 310-318.
- Stansbury JW. "Curing dental resins and composites by photopolymerization". International Journal of Esthetic Dentistry 12.6 (2000): 300-308.
- Subbiya A, Mary NS, Suresh M, Vivekanandhan P, Dhakshinamoorthy M, Sukumaran VG. Comparison of variation in the light curing cycle with a time gap and its effect on polymerization shrinkage, degree of conversion and microhardness of a nanohybrid composite. J ConservDent: JCD. 2015 Mar;18(2):154.

- Subbiya, A., Venkatesh, A., Saatwika, L., & Karthick, A. (2020). A Review On Polymerization Shrinkage Of Resin Composites. European Journal of Molecular & Clinical Medicine, 7(5), 1245-1250.

U

- Unterbrink, G. L., & Liebenberg, W. H. (1999). Flowable resin composites as" filled adhesives": literature review and clinical recommendations. Quintessence international, 30(4).

V

- Versluis A, Tantbirojn D. Relationship between shrinkage and stress. In: Daskalaki A, editor. Dental computing and applications: advanced techniques for clinical dentistry. Hershey, PA: IGI Global; 2009. p. 45-64.

W

- Wang Zand Chiang MY. "System compliance dictates the effect of composite filler content on polymerization shrinkage stress". Dental Materials 32 (2016): 551-560.
- Watts DC, Silikas N In situ photo-polymerisation and polymerisation-shrinkage phenomena. In: Eliades G, Watts DC, Eliades T, editors. Dental Hard Tissues and Bonding Interfacial Phenomena and Related Properties. Berlin, Germany: Springer; 2005. p. 123-54.
- Weinmann W., et al. “Siloranes in dental composites”. Dental Materials 21 (2005): 68-74.