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# Marginal and Internal Adaptation of Different Flowable Composite Restorative Systems in Class V Cavities after Thermomechanical Cyclic Loading: Review article

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Flowable restorative systems are crucial for restoring Class V cavities, where it is essential to achieve optimal marginal and internal adaptation to prevent microleakage and secondary caries. conventional flowable composites are versatile and commonly used, they typically exhibit higher levels of polymerization shrinkage and marginal gaps after being subjected to loading. Bulk-fill flowable composites offer superior internal adaptation because they have reduced polymerization shrinkage and improved flowability, which allows for better contact with cavity walls. These materials are especially effective in dynamic conditions and perform well in deeper cavities. Additionally, ORMOCER-based flowable materials demonstrate enhanced marginal adaptation, likely due to their lower polymerization stress properties. This quality helps achieve good adaptation at the tooth-restoration interface, reducing the incidence of microleakage and improving long-term marginal integrity.
Thermomechanical cyclic loading, designed to simulate oral conditions, often poses challenges to the adhesive bond and overall adaptation of these materials. Thermomechanical cyclic loading adversely affects all restorative systems by creating stress at the adhesive interface. This stress leads to compromised adaptation between the restorative material and the tooth structure. The degree of this impact differs based on the material composition, filler content, and flowability properties. Bulk-fill flowable materials and ORMOCER-based

materials are more effective than conventional flowable composites in reducing these negative effects, demonstrating promising results for clinical applications. Investigate the long-term performance, material enhancements, and innovative formulations that improve marginal and internal adaptation in clinical conditions. Selecting the appropriate restorative material is crucial for ensuring durable and reliable restorations in Class V cavities that face mechanical and thermal challenges.

## 1. Introduction

Since the late 1990s, there has been a significant expansion in the clinical applications of resin composite materials, driven by their enhanced durability and stability. This continuous evolution has led to a growing adoption of these materials in dental practice.1 Today, resin composite materials are the primary choice for direct restorations in dental practice.1 Unlike amalgams and glass ionomers, resin composites offer unlimited working time for placing restorations and superior esthetics. They also allow for extended manipulation, which is made possible by photoinitiators.2

Clinical research has indicated favorable results for resin composites, which have shown greater durability, establishing them as the benchmark in restorative dentistry.3 Notable progress in particle filler systems has occurred during the initial phases of utilizing resin composites. As a result, materials with improved mechanical properties and more excellent wear resistance have been created.4 The physical attributes and handling characteristics of resin composites are determined by the viscosity of the resin matrix and the reinforcing filler particles.5

These materials may fail mostly because of the development of secondary caries caused by microleakage, which may offer a loss of marginal integrity.6 The most critical issue in resin composites is polymerization shrinkage (PS) and the resulting microleakage, especially when the gingival margins extend below the cemnto-enamel junction (CEJ). Understanding and implementing techniques to mitigate these effects is crucial for successful restorations.7,8

PS decreases the adhesive bond, which leads to adverse clinical effects such as post-operative sensitivity, enamel cracks, and the creation of marginal gaps and microleakage. Failures of resin composite restorations with marginal leakage can reach over 50%.9 The formation of gaps might be linked to changes in volume within resin composites, which result from shrinkage stress during polymerization at the bonded interface.10

These gaps result from insufficient compensation for initial PS stresses occurring before the first occlusal loading or repeated stresses below the maximum stress the adhesive restoration can resist.11,12

## 2. Marginal and Internal Adaptation

Marginal adaptation refers to how closely and effectively the filling material interlocks with the cavity wall. Both their internal and external marginal integrity can be crucial when assessing the long-term performance of restorative materials.13 Marginal discoloration, secondary caries, and pulp damage are all linked to micro-leakage, which occurs when acids, enzymes, ions, bacteria, and their products penetrate the margins of the restoration.14 The micro-gap (5 and 20 μm) dimension is observed and considered a parameter for restoration survival. It is one of the most critical factors in the long-term evaluation, as it is the most predictive.14

Loss of internal adaptation is caused by gap formation at the edges of the enamel and dentin and along the resin-dentin interface.11 According to a widely accepted principle in restorative dentistry, the connection between the restorative material and the dental hard tissue must be continuous to improve the restoration's likelihood of long-term survival.15 The way the material acts during polymerization and its effectiveness in adhering to dental structures are the key factors that influence how well resin composites fit against the cavity walls.16 Bonding resin composites to enamel is a widely accepted clinical practice, whereas achieving a bond to dentin presents greater difficulties.17

### 2.1- Causes of Inappropriate Marginal Adaptation

Resin composites experience dimensional changes during the curing process as the components undergo polymerization via a free-radical mechanism.18 These alterations happen as the monomer molecules convert into a polymer configuration, decreasing free volume by substituting van der Waals spaces with covalent bonds.19 The visco-elastic characteristics of the material significantly influence the extent of contraction stresses.20

When the contraction is resistant, and the material is hard to withstand, the loss of volume PS occurs.21 Clinically, PS strains may extend to the restoration's edges, reducing marginal quality.22 These include fatigue from the aging process. Differences in thermal expansion coefficients between the tooth substrate and resin composite, polishing techniques, and improper placement of the restorative material can also cause issues.23 Occlusal loads significantly contribute to the formation of gaps as resin composite restorations undergo mechanical changes in the oral environment.17

### 2.2- Techniques Modifications

To enhance the marginal integrity of resin composite restorations, consider techniques such as indirect placement, applying a flowable resin liner, hybrid polymerization reactions, preheating, and stress absorption,24

#### 2.2.1- Incremental Placement Technique

When using polymerizing resins, it is important to take care during placement to reduce shrinkage and maximize the amount of polymerization that can occur.25 It has been proven that restoration placement techniques play a significant role in reducing shrinking stress.26 A small amount of material, a smaller cavity configuration factor, and less contact with the opposing cavity walls during polymerization all work together to reduce shrinkage stress.25 Since less material is used in the polymerization process, incremental filling has been proven to reduce shrinkage stress.27

Since the bond surface can only be impaired by the volume reduction of the final layer, the effects of PS are less harmful because each subsequent increment offsets the previous one.28Although the technique used to place the resin increments varies, dentists generally agree that an incremental filling approach helps achieve both criteria.

2.2.2- Soft Start Curing Techniques

Numerous clinical techniques have been developed to limit shrinkage stress and prevent gap development.5 These strategies include modulating the intensity of the curing light. To enhance both the functional and esthetic outcomes of resin composite materials, manufacturers strive to create light sources that achieve optimal conversion while minimizing curing stress. A useful method for decreasing resin composite shrinkage is the application of "soft-start" lamps, which slowly escalate the intensity of the light.5 This technique aims to enhance the marginal fit of resin composite restorations..29 In addition, elevated polymerization temperatures enhance the conversion of monomers, which in turn boosts the physical properties.30

2.2.3- Preheating Technique

Preheating the resin composite before applying it in the cavity decreases its viscosity and temporarily alters its handling characteristics to flowable resin composite while maintaining improved mechanical properties.31 This method aimed to enhance the marginal fit of resin composite restorations.29 In addition, elevated polymerization temperatures enhance the conversion of monomers, leading to better physical properties.30 Moreover, preheating resin composites could reduce shrinkage stresses, improving the fit at the margins.29

2.2.4- Sonic Activation Technique

Nevertheless, using sonic activation during application facilitates quicker placement and better adaptation to the cavity walls, and is another way to lower the viscosity of resin composites.32 The resin composite regains viscous consistency after the sonic activation stops.33 It should be mentioned that not all resin composite materials and brands respond well to sonic activation.32

2.3- Materials Modification

To attain the essential characteristics for long-term durability, resin composites need to reduce the polymerization shrinkage (PS) rate and enhance the bond strength of dental hard tissues.34,35 The volume and composition of the material determine the amount of PS used.36 Although significant long-term studies have been carried out to create low-shrinkage resin composites, the intricacies of the polymerization process necessitate ongoing evaluations of new resin composite formulations and application methods in laboratory and clinical environments.37

2.3.1- Resin Modifications

Some high-molecular-weight monomers are added to certain resin composite materials, typically using bisphenol A diglycidyl methacrylate ethoxylated (Bis-EMA), triethylene glycol dimethacrylate (TEGDMA), ethoxylated bisphenol Adimethacrylate (EBPDMA), and Urethane dimethacrylate (UDMA) monomers.38 Furthermore, specific stress-relieving monomers, like Addition-Fragmentation Monomer (AFM) and Aromatic Urethane Dimethacrylate (AUDMA), can act as chemical regulators of the polymerization reaction.39 Along with 1,12-Dodecanediol Dimethacrylate (DoDDMA).40 New resin modification enhances the adhesive and bonding capabilities of dental restorations. Its strong wetting ability ensures a tight seal between the restoration and the tooth while improved thermal and mechanical properties align with the tooth’s expansion, minimizing gaps from temperature changes. Enhanced resin flow fills micro spaces, ensuring better marginal sealing and reducing gap risks. Modern resin formulations also provide superior wear resistance and maintain structural integrity, reducing marginal breakdown and keeping restoration margins intact.41

2.3.2- ORMOCER

A recently introduced packable material is Ormocer.42 ORMOCER stands for "organically modified ceramic technology."42 These substances consist of inorganic-organic co-polymers along with inorganic silanated filler particles. The ormocer matrix, before light curing, is essentially a polymer.

It is made up of ceramic polysiloxane, which exhibits minimal shrinkage compared to the organic di-methacrylate monomer matrix found in resin composites.43 The inorganic molecules in ORMOCER are longer than those in Bis-GMA, so they have lower volumetric shrinkage than conventional materials.42 ORMOCER was developed to address the challenges associated with traditional resin composite polymerization shrinkage and offer features such as low shrinkage, high resistance to abrasion, biocompatibility, and caries protection.44

2.3.4- Filler Modifications

Increasing the filler load enhances the material's ability to withstand physical wear and tear; higher filler content leads to greater viscosity.45 Most direct restorative resin composites have a putty-like consistency, making them ideal for clinical use.46 However, this can make achieving a perfect seal and fit within the cavity challenging. Therefore, a less viscous resin composite resin is required for better adaptation to the cavity wall.47 As a result, a new class of "flowable resin composite " was developed in late 1996.47

### 2.3.5- Nano Technology

Lately, the advancement of nanotechnology has resulted in the creation of a new composite resin containing nanoparticles.20 This resin reduces the possibility of the material biodegrading over time and gives the restoration a superior finish.48 Additionally, This method offered mechanical characteristics appropriate for application in both the anterior and posterior regions.49 Likewise, smaller particles result in less curing shrinkage and less cusp wall deflection.50

### 2.3.6- Flowable Resin Composite

Conventional resin composites with a filler loading of 37%–53% (volume), known as flowable resin-based composites(F RBCs), have modified viscosity compared to traditional mini-filled hybrids, which typically have a filler loading of 50%–70% (volume).47 F RBCs are among modern dentistry's most widely used restorative materials.47 These materials are suitable for single applications or combined with conventional resin composites in various cavity preparations.47 Their high fluidity allows for successful application in microinvasive preparations, and their high flexibility ensures penetration into every irregularity.45

The changing filler loading modifies the viscosity of these materials.31 The low-viscosity materials help the plastic flow during the initial stages of polymerization, this could account for the improved adaptation shown by these restorative materials.1 The initial flowable resin composites were unsuitable for filling deep cavities at the back of the mouth because they had lower mechanical properties and higher shrinkage than standard high-viscosity resin composites.22 This was mainly due to the lower filler content.51

However, traditional F RBCs have little filler content, more shrinkage upon curing, weak wear resistance, and poor mechanical qualities, which are clinical disadvantages. These drawbacks depend on the type of flowable resin composite material used. Therefore, despite these restrictions, dentists should still be able to use flowable composites in acceptable clinical procedures.52 A new category of F RBCs were introduced based on their distinct applications, including self-adhering, bulk-fill, ormocer-based, conventional, and fiber-reinforced flowable types. 31

### 2.3.7- Bulk-fill Resin Composites

In contrast to the traditional incremental restoration method, a new kind of resin composite has been developed that simplifies and accelerates the bulk-filling of deep and extensive dental cavities.53 Bulk-fill resin composites (BF-RBC) are a new generation with a unique monomer concentration and improved curing properties.36 They have been introduced to reduce microleakage and minimize working time.54 Clinicians have succeeded with BF-RBCs because it is easy to apply, particularly in posterior restorations.55

In its experimental version BF-RBCs exhibited the lowest values for shrinkage stress and shrinkage rate when compared to both regular flowable and non-flowable nanohybrid and micro-hybrid resin composites, as well as a siloxane micro-hybrid resin composite.56They can fill the cavity in a single phase because BF-RBCs can cure with minimal shrinkage at maximum increment thicknesses of 4 mm.31

Decreasing the amount of filler while expanding its size in RBC decreases the scattering at the interface between the resin and the filler, thus enhancing the quantity of light absorbed that can trigger the photo-initiator.31 This explains why they are created to achieve a greater depth of cure by increasing translucency or by adjusting the photo-polymerization process, which is enhanced not only by camphorquinone and tertiary amines but also by unique modulators, specifically a dibenzoyl germanium derivative.57 Unlike conventional light-cured RBCs, the photo-initiator system in BF-RBCs was still based on camphor quinone (CQ) and included Ivocerin as an extra initiator.58

Because of its enhanced ability to absorb visible light, this germanium-based initiator system was found to have a higher photo-curing activity than CQ. Its absorption spectra are quite similar to CQ's.59 In several bulk-fill resin composites, the shade and layer thickness, the filler's and matrix's chemical makeup, and the variations in their refractive indices raised the filler's dimension.60

The bulk-fill technique made the process easier, ensuring acceptable physical qualities and satisfactory cavity adaption. Thus, the chair time required to complete the restoration is decreased.61 Despite the strong clinical and scientific proof of BF-RBCs' beneficial characteristics, further research into their mechanical and clinical efficacy is necessary, especially concerning PS and the internal adaptation of the restoration.62

BF-RBC materials have demonstrated improved physical properties to address this issue during placement. An ideal BF-RBC would be one that can be inserted into preparation with a high C-factor design and still demonstrate minimal PS while maintaining a high depth of cure (DC).1 In addition, reducing filler size and altering monomers leads to decreased shrinkage.53 Considering the materials' chemical composition and the images from the scanning electron microscope, manufacturers have adopted various approaches to enhance the depth of the cure. Several manufacturers decreased the quantity of filler used while increasing the size of the filler particles.58 As a result, the interface between the fillers and the organic matrix is minimized, which decrease light scattering.58

BF-RBCs are usually divided into high-viscosity (sculptable, full-body) and low-viscosity (flowable, base) materials. High-viscosity BF materials are more resistant to slumping and contain more inorganic fillers. 63

### 2.3.8- Bulk-fill Flowable Composite

Recent developments have resulted in bulk-fill flowable resin-based composites (BFF-RBCs) that feature enhanced filler content and mechanical characteristics, they made them appropriate for larger restorations in the posterior region.64 Initially, flowable composites were proposed to serve as filling materials or to substitute dentin since they can more effectively adapt to the contours of cavities, particularly on irregular surfaces.65 The latest BFF-RBCs effectively utilize 4-mm layers while enhancing their surface hardness in a single process, eliminating the need for a layer of high-viscosity resin composite.65

Furthermore, it was demonstrated that BFF-RBCs notably decreased cuspal deflection in cavities compared to traditional resin composite restored using an oblique incremental filling method.66 It aims to tooth-colored restorations that are more effective, less time-consuming, and less technique-sensitive than traditional flowables.36,67 Flowable resin composite material in cavity preparations can minimize the risk of marginal failure caused by microleakage.64

The characteristics of low-viscosity and high-viscosity materials are particular to each material, making it challenging to apply them broadly in clinical settings.64 Additionally, new BFF-RBCs are typically nano-filled, which improves optical translucency and provides a smooth surface texture.68 BFF-RBCs have shown superior internal adaptation to conventional composites in cavities with high C-factors.69 This improved performance is attributed to the low viscosity of BFF-RBCs, which enables better plastic flow during the early polymerization stages.22

This is due to their pseudoplastic and thixotropic behavior (decrease in viscosity over time for a given shear rate), which helps them flow easily and adapt well to the cavity floor.70 This may be the reason for the improved adaptation these restorative materials show.31 Manufacturers claimed that the PS of those materials is even lower than that of commonly used flowable and conventional RBCs. Thus, problems related to PS stresses could be minimized.71

### 2.3.9- Core Build-up Flowable Resin Composite

These materials can be applied to badly broken vital or non-vital teeth and to restore and fortify weak spots.72 The practitioner can create a form to improve the underlying prosthesis' resistance and retention by doing this. Core build-up resin composite has low, medium, and high viscosities.72 Severely fractured teeth requiring endodontic treatment, flowable or injectable core build-up materials.73 These supplies ensure a sufficient seal and flow into any preparation irregularities while reducing off-chairside time.73

### 2.3.10- Self-Adhering Bulk-fil Flowable Resin Composite

Developing a self-adhering BFF-RBC, which contains functional monomers that promote attachment to tooth structures without etching, washing, or drying, has made a breakthrough in the field.74 Self-adhesive resin composite decreases the space between the restoration and the tooth by thinning the adhesive hybrid layer, preventing microleakage development. Recent studies on self-adhering BFF-RBC highlight their utility and performance in Class V cavity restorations.75,76 These materials simplify application by integrating adhesive properties. This consequently simplifies the restoration procedure in difficult regions such as the gingival third of the tooth.75

### 2.3.11- ORMOCER-based Bulk-fill Flowable Resin Composite

ORMOCER technology is a light-cured restorative substance with excellent flow characteristics and significant material elasticity, making it an effective stress-absorbing agent.77 ORMOCER-based BFF-RBC possess a higher elastic modulus, providing better deformation resistance under masticatory forces. This property is particularly beneficial in BFF RBC, as it allows for better adaptation to the cavity walls without requiring multiple increments. Improved elastic properties help the material withstand stress during setting, promoting a more durable marginal seal.43

### 2.3.12- Fiber-reinforced Bulk Fill Flowable Resin Composite

The need for strengthened resin composite materials has resulted in an ongoing research effort concerning reinforcement approaches. Many earlier methods focused on incorporating fibers (continuous or discontinuous fibers in different orientations), whiskers (single or multi-layer), or ceramic particles (random orientation).78 Fiber-reinforced BFF-RBC has improved performance for Class V cavities, where effective adaptation and stress resistance are vital. Integrating fibers into the composite matrix offers better structural support, less PS, and improved fit. The fibers also help distribute stress evenly, reducing the risk of marginal gaps or microleakage, which is especially important for Class V cavities under flexural stress near the gingival margin.79

The microstructural features, such as fiber diameter, length, orientation, loading, and the bond between the fibers and the polymer matrix, greatly affect numerous properties of fiber-reinforced composites.80 Due to the release of more recent materials.80 Regarding mechanical performance, fiber-reinforced and bulk-fill materials demonstrated greater rigidity (elevated modulus of elasticity) and increased plasticity (higher values of plastic deformation and creep) compared to standard flowable resin composites.56

## 3. Class V Cavity preparation

RBCs are frequently utilized to restore Class V cavities. However, restoring Class V cavities is difficult due to various unique factors that complicate long-term success esthetically and functionally.43 Primarily because of their location near the gingival margin and the high dentin-to-enamel ratio. Unlike other cavities, the gingival third of the tooth is exposed to flexural stress, particularly in regions with high occlusal forces. This stress may cause micro-cracks, marginal gaps, and restoration debonding.43 If the seal is inadequate, plaque can accumulate on the gingival margin, increasing the likelihood of recurrent decay. Compared to traditional nanohybrid resin composites, BFF-RBCs applied in Class V restorations, have enhanced the marginal seal at dentin margins.81 Overall, these challenges necessitate that clinicians employ particular materials to effectively manage issues related to moisture control, flexural forces, and adhesion to dentin for a successful Class V restoration.82

## 4. How to Evaluate Marginal Integrity

The interface quality between a tooth and filling can be evaluated using direct or indirect techniques. Destructive techniques involve using a tracer or dye and compromising the sample's integrity by slicing it into sections to examine the degree of staining along the tooth–filling interface through scanning electron microscopy (SEM) or optical microscopy.90Outstanding non-destructive techniques include the replica approach used alongside scanning electron microscopy (SEM) for assessing external marginal adaptation or employing X-ray micro-computed tomography (μCT) for analysis.91 This three-dimensional (3D) technique facilitates the identification of all internal gaps and irregularities and their evolution over time. Additionally, it provides a means to examine the internal composition of restorative materials or tooth structures with high precision and spatial resolution.90

### 4.1- In Vivo Assessment

This system examines restorations using direct or indirect methods.92 One method is to examine the margin using a mirror and probe directly on the patient's mouth regarding occlusal shape, cavosurface marginal discoloration, and marginal adaption.92 The smallest ledge that could be clinically detected was 0.1 mm, indicating the limitations of human abilities to detect marginal ledges using a probe.93An intraoral camera with Polarization mode calibrated images helps assess the marginal adaptation.92

The camera serves as a practical and reliable diagnostic tool.92 The edges and uneven restorations create perfect situations for food and plaque build-up, making it challenging to maintain proper oral hygiene.94 However, the accuracy of these examinations heavily depends on clinicians' experiences. For example, differences less than 80 μm on X-ray are challenging to observe.95

Additionally, if only tactile and visual inspection had been conducted, gaps of less than 0.1 mm at the restoration's edges could have developed.67 The other method indirectly evaluates the margin's quality through scan electron microscope (SEM) analysis of replicas. 93 SEM study of marginal adaptation using replicas is a reliable assessment technique.93 "Scavenging" impressions were used. Polyvinylsiloxane imprint materials are highly recommended due to their excellent dimensional stability. Epoxy replicas are formed using different resins and have other application in SEM.93 Researchers appear to be particularly interested in Stycast Resin.96 Despite this, selecting a resin appears to depend on individual preferences.97

This approach has several disadvantages, such as a prolonged sample preparation procedure, the potential for cavities or an excess of epoxy resin in the samples, and the formation of uneven edges caused by a chemical reaction between water and the impression material.98 Furthermore, air is frequently enclosed within the epoxy replicas as bubbles, which can disrupt measurements of the overall marginal gap length by concealing an existing gap.99

4.2- In Vitro Assessment

The procedure can be conducted on extracted teeth, either by direct examination or indirectly using a replication technique, such as developing study models, capturing images, or producing replicas for analysis under an electron microscope.93

4.3- Evaluation Device for Marginal Integrity

4.3.1- Micro Computed Tomography Imaging

Micro-computed tomography (µCT) is a high-resolution imaging technique developed by Lee Feldkamp in the early 1980s to examine defects in ceramics. Initially, these scanners were not widely available, but compact commercial systems quickly became essential in research labs, offering a viable alternative to histological sectioning.90 Micro-CT is a non-destructive imaging technique that can identify the most profound levels of adhesion failure and gap formation. These benefits lead to a more precise assessment of the bonding between restorative materials and tooth structures.90

Micro-CT has several advantages over other methods but also some limitations. Its narrow, high-flux monochromatic X-rays enable detailed exploration, it is non-destructive, allowing for multiple assessments of the same sample without damage. Additionally, it supports multiple scans and specialized image processing software. Sample preparation is straightforward, unlike destructive methods, contributing to more accurate measurements.90 However, micro-CT involves longer scanning and reconstruction times, high costs, and requires computer expertise.100 The large image files (around 3 GB) can complicate data storage and retrieval.91

4.3.2- Profilometry

Profilometry has been documented in research conducted both in vivo and in vitro.101 These involve moving a stylus across the surface of a restoration. Stylus profilometry can result in slight damage to materials because of the contact between the stylus and the surface. Additionally, optical profilometry techniques may struggle to accurately measure surfaces made up of different materials, which could cause inconsistencies in measurements across various areas of the surface.102

4.3.4- Optical Microscopy

Optical microscopes have existed for centuries, but the introduction of digital optical microscopes has enormously boosted the quality of imaging, especially the depth of field.103 Digital optical microscopy (DOM) can be considered a promising, reliable, and repeatable method for performing marginal analysis of adhesive dental restorations using the replica technique.103 This time and cost-effective method can be beneficial in assessing newer generations of adhesive systems and techniques.103 Even though new users of the DOM analysis technique were able to obtain valid results after one day of training, additional experience may be needed to increase the concordance between operators.103

### 4.3.5- Scanning Electron Microscopy

The scanning electron microscopy (SEM) marginal analysis method is widely used at present because it enables accurate measurement and calculation of closed margin percentages, indicating perfect adaptation of the adhesive restoration at various time points.103 SEM provides a great depth of focus and allows observation under a wide range of magnifications. It is typically applied to evaluate dental structures and the possible penetration of bacteria along the margins with restorative materials. 99 Also, specimens must be dried before SEM evaluation.104 Since its inception and introduction in dental research, electron microscopy had many applications in dental biomaterials and hard or soft tissues. It aids in evaluating micro-cracks and deformities in biomaterials and hard tissues.

SEM assessed the marginal integrity of bonded resin composite restorations in posterior teeth, enamel, and dentin.105 SEM analysis also benefits from a wide range of magnifications, spanning from 10× to 100,000× magnification. SEM analysis of original tooth samples provides insight into all structures forming an adhesive bond. It aids in assessing the quality of the marginal adaptation of resin composite restorations.99 Due to its visible resin tags and hybrid layer, this might be a convenient tool for better understanding the quality of the marginal seal achieved.99

## 5. Aging and Thermomechanical Simulation

Thermal changes in the oral cavity, influenced by food, drink, and respiration, significantly affect dental materials. Such changes can cause differential expansion and contraction between these materials and natural teeth, leading to gaps or stress at the interface, which may reduce the durability of restorations. Thermocycling, used to simulate temperature variations, highlights how regular eating and drinking can impact the stability of dental materials over time.107 Thermal stress can be harmful in two ways. First, crack propagation through bonded interfaces.108 Second, as gap volumes vary in response to shifting gap dimensions, pathogenic oral fluids are pumped into and out of the gaps.106 In materials with poor thermal diffusion coefficients, the temperature gradients created at the surface take a long time to dissipate. A surface microcrack grows over time if the environment and stress work together, where it allows the formation of 'gaps' in the interface tooth/restoration.96

Furthermore, mechanical loading simulations provide a critical understanding of how dental restorations respond to complex forces in the oral cavity. By simulating stress distribution, fatigue, wear, and crack propagation, these models allow dental professionals to design restorations that are more durable, comfortable, and resilient. This approach helps in choosing the right materials, optimizing restoration design, and personalizing treatment plans for improved long-term success in dental restoration.109

Alsagob et al.83 Compared the marginal adaptability of nanohybrid RBCs in two different clinical protocols with two BFF-RBCs following exposure to TMC. They concluded that the marginal sealing of the BFF-RBCs is similar to that of traditional composites, but it is more reliable to use the traditional one. The study also showed that marginal leakage on the gingival surface was statistically higher than on the occlusal surface.

Peutzfeldt et al.84 Conducted a study on the development of marginal gaps along the proximal margins of Class II BFF-RBC restorations and compared it with the marginal gap formation of conventional packable resin composite restorations after artificial aging. Their research showed that the traditional resin composite had less gap formation in comparison to the two BFF-RBCs, both prior to and following artificial aging in enamel. In contrast, within dentin, one of the BF resin composites (SDR) exhibited less gap formation than the other two.

Oglakci et al.23 Used x-ray micro-computed tomography (micro-CT) to evaluate the volume of gap formation in premolars that were restored with various BF composites, both with and without a resin-modified glass-ionomer cement (RMGIC) liner. Their findings indicated that low-viscosity BF composites demonstrated superior adaptation to cavity walls and less gap formation compared to the other BF composites tested. Additionally, the application of an RMGIC liner resulted in a significant reduction in the volume of gap formation.

Nakano et al.76 The comparison of two self-adhesive materials, two BFF-RBCs, and two flowable composite controls revealed that the BFF-RBCs had similar or lower interfacial gaps and polymerization stress than the controls. In contrast, the self-adhesive composites exhibited a significantly higher gap percentage and polymerization stress compared to both the control and BFF-RBC materials.

Arbildo-Vega et al.85 A comparison of sculptable bulk-fill (BF) composites, flowable and sculptable two-step restorations, and conventional incremental composites showed that BF composites perform similarly to traditional composites. This holds for all restoration types (Class I, II, or non-carious cervical lesions), tooth types (primary or permanent), and restoration techniques (incremental, bulk, or two-step bulk).

De Albuquerque Jassé et al.86 A study assessed the marginal adaptation of Class II MOD restorations before and after thermomechanical loading of BFF-RBCs and conventional resin composite. Results showed significant improvement in marginal adaptation with BFF-RBC compared to traditional resin, both pre and post-loading. The findings indicate that BFF-RBCs perform similarly to or better than conventional resin in cervical marginal adaptation, but long-term clinical success requires further trials.

El Naga et al.24 A study compared the external marginal integrity of dentin-bonded materials and the indentation hardness of BF with conventional resin-based composites (RBCs) applied in bulk and incremental techniques. Marginal gaps were assessed at each tooth's mesial and distal gingival cavo surfaces. The results showed that BF restorations had similar marginal gap formation and microhardness to traditional universal RBCs. Thus, BF-RBCs could be a viable alternative to conventional RBCs due to their marginal adaptation and internal hardness.

Akarsu and Atasoy.87 Conducted a study comparing microleakage in Class V restorations using different resin composites (nanohybrid composites, BF composites, and BFF-RBCs) and various application techniques. Their findings showed that microleakage in the cervical margin of Class V restorations was greater than in the occlusal margin across all groups. They also observed no difference between different materials regarding the enamel margin, and incrementally placed materials exhibited less microleakage than other groups in terms of the dentin margin. Additionally, BFF-RBC material demonstrated less microleakage than the other two sculptable BF materials.

Abdelwahed et al .15 Examined the marginal adaptation and DC of BFF-RBCs and two packable BF resin composites and concluded that flowable and packable BF resin composites displayed similar marginal adaptation results.

Aravindhan and Sharma.88 Assessed the marginal sealing ability of two BFF-RBCs on enamel and dentin substrates in Class V cavities before and after TMC. Their results indicated that: there was no statistically significant difference between the two groups. BFF-RBCs provided a significantly better marginal seal in dentin, both before and after artificial aging. Both BFF-RBCs exhibited similar microleakage values at the enamel margins.

Balkaya et al.63 Conducted a micro-CT imaging study to assess the marginal gap (MG) of two FB-RBCs and one conventional flowable resin composite in standard Class II MOD cavities. Their results showed that both FB-RBC resins exhibited better marginal adaptation than the conventional flowable resin composite used in the research. The conventional flowable material demonstrated the highest MG values, while both FB-RBCs displayed similar MG values.

Baltacioğlu et al.89 The study evaluated the marginal adaptation of BF resin composites of different viscosities (paste-like and flowable) in Class II restorations with cavity floors 1 mm below the CEJ, using micro-CT imaging after TMC aging. It found that while viscosity did not significantly affect marginal adaptation, the brand of BF resin composite did. BF resin composites may serve as alternatives to traditional composites in this regard.

The International Organization for Standardization (ISO) proposed eight distinct wear simulator machines, one for each of the two or three body abrasions.110 Considering the importance of the marginal and internal adaptation of various flowable restorations and a shortage of research on these aspects in novel restorations, this study aims to evaluate the efficacy of this restoration in terms of marginal and internal adaptation compared to other restorative materials.111

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