


A Narrative Review of the Material Properties, Clinical Efficacy, and Developmental Prospects of Bulk-Fill Resin-Based Composites

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Abstract: Bulk-fill resin-based composites (RBCs) have been developed as alternatives to conventional RBCs, offering advantages such as simplified clinical handling, reduced polymerisation shrinkage, improved restoration integrity, and increased resistance to microleakage that can compromise long-term clinical outcomes. These materials are applied in a single increment of 4–5 mm during restorative procedures, thereby minimising chair time and technique sensitivity without compromising restoration quality. Nonetheless, their clinical performance can be influenced by several factors, including material type and inherent properties (mechanical, optical, biocompatibility, polymerisation shrinkage, and conversion rate), curing parameters, the restorative technique used, storage conditions, the external oral environment, and preheating treatments. This article presents a comprehensive review of bulk-fill RBCs, discussing their concept, classifications, clinical applications, principal properties, and the critical factors that affect successful clinical outcomes. Additionally, it addresses the clinical limitations of bulk-fill RBCs and explores potential future developments. By synthesising the current evidence, this article aims to serve as a practical guide for clinicians and researchers, promoting informed decision-making and effective application of bulk-fill RBCs in restorative dentistry.

Keywords: bulk-fill, clinical performance, composites, mechanical properties, shrinkage stress

Introduction

Resin-based composites (RBCs) have become the material of choice in clinical dentistry due to their excellent aesthetic properties and versatility.¹ Composed of a mixture of polymers and fine ceramic particles, these materials have evolved in composition and technology with improved mechanical strength properties.² Consequently, dental restorations made of RBCs achieve clinical success rates comparable to traditional amalgam restorations, which have long been valued for their longevity.³ In addition to their well-known aesthetic appeal, the ability of RBC materials to bond chemically to dental tissues makes them even more attractive for tooth restoration and minimally invasive dental procedures.⁴

Despite their benefits, a primary limitation of conventional RBCs is their limited depth of cure, typically 2 mm per layer, which necessitates the placement of multiple incremental layers when restoring deeper or larger defects.⁵ Consequently, clinicians may need to save more time and effort to achieve complete polymerisation and optimal restoration durability, especially in cases involving extensive decay or structural damage. To address this limitation, manufacturers have developed more advanced bulk-fill RBCs.^{6–8} These materials are designed with specific properties that enhance the efficiency of restorative procedures for dental practitioners.^{6–8} Bulk-fill RBCs offer several beneficial properties that improve treatment outcomes. One advantage is reduced polymerisation shrinkage stress, a major cause of marginal gap formation and subsequent restoration failure.⁷ By minimising shrinkage stresses, these materials improve the marginal integrity and longevity of restorations. Moreover, bulk-fill RBCs are engineered with optimal viscosity and flow properties, enabling better adaptation to cavity walls. In combination with higher translucency and modified photoinitiator systems, these properties result in excellent light transmittance and resin polymerisation at depths of 4



to 5 mm.^{7,8} This allows clinicians to place restorations in a single increment, rather than the multiple-layering steps required with conventional RBCs. Such a reduction in the layering process shortens chair time and decreases procedural complexity, thereby improving patient comfort and compliance. Furthermore, this simplified placement technique significantly reduces voids between layers, which enhances the mechanical properties and overall longevity of the restoration.^{7,8} However, although these improved properties are widely reported in literature,^{6–8} their true clinical significance depends on consistent evidence demonstrating improved marginal integrity, more effective curing under varied clinical conditions, and reduced technique sensitivity. Therefore, it is necessary to critically evaluate whether the claimed benefits of bulk-fill RBCs translate into meaningful clinical improvements across different operative situations, which include variations in cavity depth, curing light intensity, and restorative techniques.

Several studies have evaluated the properties of bulk-fill RBCs, besides their clinical performance and the factors influencing their long-term outcomes, highlighting their significance in contemporary dental practice. Although research in this area is expanding, the literature remains fragmented and is characterized by considerable variability in study methodologies, material classifications, curing protocols, and outcome measures. Differences in bulk-fill RBC types, experimental setups, and clinical evaluation criteria often lead to inconsistent findings, which makes it difficult to formulate clear evidence-based recommendations for clinical practice. This variability highlights the need for a comprehensive and integrated assessment of the existing evidence to clarify the actual performance of bulk-fill RBCs. Therefore, this narrative review provides a comprehensive overview of bulk-fill RBCs, which includes their fundamental concept, material classifications, clinical applications, advantages/disadvantages, general properties, determinants of clinical performance, inherent limitations, and prospective developments. The review further aims to provide clinical guidance on the optimal use of bulk-fill RBCs in modern restorative dentistry.

Methodology

This study was conducted as a narrative review to synthesize the current evidence on the material properties, clinical applications, performance, advantages/disadvantages, limitations, and prospective developments of bulk-fill RBCs. The review followed the principles outlined in the Scale for the Assessment of Narrative Review Articles (SANRA).⁹ It aimed to address the following general research question: “What does current evidence reveal about the material properties, clinical applications, performance, advantages/disadvantages, limitations, and future directions of bulk-fill RBCs in restorative dentistry?” A comprehensive search of the scientific literature was conducted in two electronic databases: PubMed (US National Library of Medicine) and Web of Science (WoS) (Clarivate, London, UK). Searches were performed using a combination of MeSH terms and free-text keywords. Key search terms included “bulk-fill resin-based composite”, “bulk-fill composite”, “bulk-fill RBC”, “bulk-fill dental composite”, “bulk-fill restorative material”, “composite resins” [MeSH Terms], “dental restoration” [MeSH Terms], “dental restorative materials” [MeSH Terms], “polymerization shrinkage”, “polymerization” [MeSH Terms], “depth of cure”, “degree of conversion”, “mechanical properties”, “flexural strength”, “marginal integrity”, “translucency”, “clinical performance”, “restoration longevity”, “marginal adaptation”, “microleakage”, “postoperative sensitivity”, “single-increment”, “bulk placement”, “curing protocols”, “light-curing units”, “LED curing”, “high-intensity curing”. To refine the search results, Boolean operators (AND, OR) were employed. Additionally, the reference lists of pertinent articles and review papers were manually searched for further sources.

Studies were considered eligible for inclusion if they focused on bulk-fill RBCs and presented relevant laboratory data, clinical findings, or material-science evaluations. Eligible studies included laboratory investigations, clinical trials, observational studies, review articles, meta-analyses, and independent technical reports published between 2010 and 2025. Only articles published in English were included. Studies were excluded if they examined only conventional RBCs without addressing bulk-fill materials, lacked primary or analytical evidence, were not available in full text, or were published in languages other than English.

Titles and abstracts obtained from the database search were screened for relevance according to predefined criteria. Full-text articles for potentially eligible studies were evaluated to ensure they met the inclusion and exclusion criteria. In cases where multiple publications presented overlapping findings, preference was given to the most comprehensive or recent version. Data were extracted on material composition, mechanical and optical properties, polymerization

behaviour, shrinkage stress, biocompatibility, and clinical performance. 262 and 223 potential articles were retrieved from PubMed and WoS, respectively. 194 duplicate records were removed first, and nine articles without English versions were removed as well. Then, the remaining 282 articles were preliminarily screened by title and abstract to remove studies that were not relevant. The full texts of the remaining 88 studies were retrieved and assessed for eligibility for inclusion in the review. Following that, 62 articles met the criteria and were included in this review. Due to the narrative nature of the review, the findings were synthesized qualitatively and organized thematically to provide an integrated understanding of the material composition, material properties, advantages, limitations, clinical applications, factors affecting clinical performance, and developmental prospects of bulk-fill RBCs.

Results and Discussion

Bulk-Fill RBCs: Concept, Classifications, Clinical Applications, and Advantages/Disadvantages

Bulk-fill RBCs represent a significant advancement in dental restorative materials. These materials are designed to be placed in relatively thick layers, typically 4–5 mm, which streamlines the restoration process and reduces overall chair time for both clinician and patient. Bulk-fill RBCs can be classified into high- and low-viscosity types based on their rheological properties (Table 1). High-viscosity RBCs provide superior strength and are well-suited for load-bearing areas, but their viscosity limits their adaptation to complex cavity preparations. In contrast, low-viscosity (flowable) RBCs adapt more readily to cavity walls due to their fluidity, but a final surface layer of a stronger RBC is often required for reinforcement.¹⁰ Regarding their polymerisation, bulk-fill RBCs can be either light-cured or dual-cured (Table 1). Light-cured materials rely entirely on photoactivation, which in turn requires sufficient light penetration. On the other hand, dual curing uses both light and chemical initiators to ensure proper curing even in areas with limited light access, which improves both conversion rate and restoration durability.^{11,12} Bulk-fill RBCs, whether high- or low-viscosity, light-cured, or dual-cured, should be selected based on the clinical situation, considering factors such as cavity size, aesthetic requirements, and functional demands.¹³ Table 2 summarises the general advantages and disadvantages of bulk-fill RBCs.

Bulk-fill RBCs offer several benefits over conventional RBCs, and Table 3 presents the overall differences between the two RBC materials. Regarding clinical applications, bulk-fill RBCs exhibit adequate mechanical properties with reduced polymerisation shrinkage, making them well-suited for posterior restorations that require durability and occlusal stability.^{14–16} They are also commonly used after endodontic treatment due to their effective cavity-sealing properties, which help minimise microleakage and secondary caries.¹⁴ However, due to their low optical properties, using them in

Table 1 Classification of Bulk-Fill RBCs Based on Viscosity and Polymerization

Viscosity	Filler Content	Material Examples	Method of Cure	Maximum Depth per Increment	Characteristics	Indications
High-viscosity	~75–80%	Filtek Bulk-Fill Posterior Restorative (3M ESPE) Tetric EvoCeram Bulk-Fill (Ivoclar Vivadent)	Light	4mm	Higher filler content, strong mechanical properties	Posterior restorations, occlusal load
Low-viscosity (Flowable)	~60–70%	Tetric EvoFlow Bulk-Fill (Ivoclar Vivadent) SDR (Dentsply)	Light	4mm	Lower viscosity, better adaptation, requires capping layer	Base layer, deep cavities
Dual cure	~75–80% ~60–70%	Fill Up (Coltene)	Dual	Any depth	Chemical + light curing for deep cavities	Posterior restorations and Base layer

Table 2 General Advantages and Disadvantages of Bulk-Fill RBCs

Advantages	Disadvantages
Faster placement (single increment)	Limited long-term clinical data
Reduced polymerization shrinkage stress	Slightly lower surface hardness in some cases
Good depth of cure (up to 4–5 mm)	Requires high-quality curing light
Improved handling and adaptation	Some materials need occlusal capping layer

Table 3 General Comparison Between Conventional RBCs and Bulk-Fill RBCs

Feature	Conventional RBCs	Bulk-Fill RBCs
Incremental Placement	Required (2 mm layers)	Single increment up to 4–5 mm
Curing Depth	Limited (2mm)	Enhanced translucency for deep curing (4–5 mm)
Filler content	High filler loading for strength	Optimized filler size and translucency for curing depth
Viscosity	Flowable or high-viscosity	Flowable or high-viscosity but with improved handling properties
Working time	Longer due to multiple increments	Shorter (single-step placement)
Clinical Indications	Anterior and posterior restorations with small to medium cavities	Posterior restorations with deep cavities
Mechanical Properties	High strength, good wear resistance	Low or comparable strength, reduced wear resistance
Shrinkage Stress	Higher due to layering	Reduced due to bulk-fill technology and modified resin chemistry

highly aesthetic areas such as anterior restorations can be challenging. In contrast, conventional RBCs are primarily indicated for both anterior and posterior restorations with cavities less than 2 mm deep and require incremental layering to ensure complete curing and optimal aesthetics.^{17,18} Thus, the choice between bulk-fill and conventional RBC systems should be guided by the specific clinical requirements of cavity depth, location, and desired outcomes.

General Properties of Bulk-Fill RBCs

A range of material properties fundamentally determines the clinical performance of bulk-fill RBCs. These include mechanical, optical, and biocompatibility characteristics, as well as the degree of monomer-to-polymer conversion, polymerisation shrinkage, and curing depth.

Mechanical Properties

In restorative dentistry, the primary function is the restoration of masticatory efficiency, which requires that the mechanical properties of the restorative materials closely mimic those of the natural hard tissues of the tooth.^{15,18} These properties include compressive strength, hardness, viscoelasticity, and creep resistance. Collectively, they ensure the restorations deform compatibly with the surrounding dentition under occlusal loading, thereby reducing interfacial stress concentrations and enhancing the longevity of the restoration.

The inorganic filler content in Bulk-fill RBCs directly affects their mechanical performance.^{16,19} A higher filler content within the resin matrix generally increases compressive strength, hardness, and viscoelasticity, while a lower

filler content has adverse effects on these properties. Figure 1 shows strength and polymerization shrinkage vary with filler content in the resin matrix. Bulk-fill RBCs typically use a combination of inorganic fillers to achieve strength, radiopacity, and reduced polymerization shrinkage.^{1,16,19} These fillers are optimized for high translucency, which allows deep light penetration for curing and low shrinkage stress, while maintaining adequate strength for posterior restorations. The most common filler used is silica (SiO₂), which provides hardness and wear resistance and is often used as nano-sized particles to improve polishability and translucency.^{1,16} Barium or strontium glass fillers have been used to enhance radiopacity for easier detection on X-rays and to improve strength. Zirconia fillers are also added to enhance toughness and fracture resistance and contribute to radiopacity. In some brands, pre-polymerized resin fillers are added to reduce polymerization shrinkage and stress, and to improve handling and bulk-fill depth of cure.

Several strategies are commonly employed to improve adhesion between filler particles and the resin matrix, which enhance the physical and mechanical properties of bulk-fill RBCs.^{16,19} Silane coupling agents are widely used as chemical bridges between inorganic fillers and the organic resin matrix. One end of the silane bonds to hydroxyl groups on the filler surface (silica or glass), while the other end contains methacrylate groups that co-polymerize with the resin during curing. This strategy improves bond strength, reduces microcracks, and enhances wear resistance.²⁰ In addition, surface treatments of fillers, such as acid etching or plasma treatment, can increase the surface energy of fillers and create reactive sites for silane bonding, which improves wetting and dispersion of fillers within the resin.²¹ The use of nano-sized fillers is another strategy that further increases the available surface area for bonding. When properly silanized, these particles can improve mechanical strength and polishability.²² Optimizing the resin chemistry itself by incorporating monomers, such as Bis-GMA and UDMA, with specialized functional groups that interact strongly with silane-treated fillers can also enhance stress distribution and reduce debonding under load.^{1,16}

Optical Properties

The aesthetic efficacy of bulk-fill RBCs is largely determined by their optical properties, including colour and translucency. Compared with conventional packable RBCs, bulk-fill RBCs typically have lower filler content, which can lead to poor aesthetic outcomes, increased surface roughness, and reduced wear resistance.^{20,21} Moreover, bulk-fill RBC systems are generally available in a more limited colour range, limiting their application primarily to clinical cases with less aesthetic demands. However, the increased translucency of bulk-fill RBCs compared to conventional RBCs facilitates greater light transmission, which promotes more effective polymerisation in deeper areas.²¹ For optimal aesthetic outcomes, a common clinical technique involves using bulk-fill RBCs as the inner layer and overlaying with a conventional RBC to improve shade match and surface polish. This layered approach combines the superior optical properties of conventional RBCs with the practical advantages of bulk-fill RBCs in an attempt to achieve efficient deep curing.

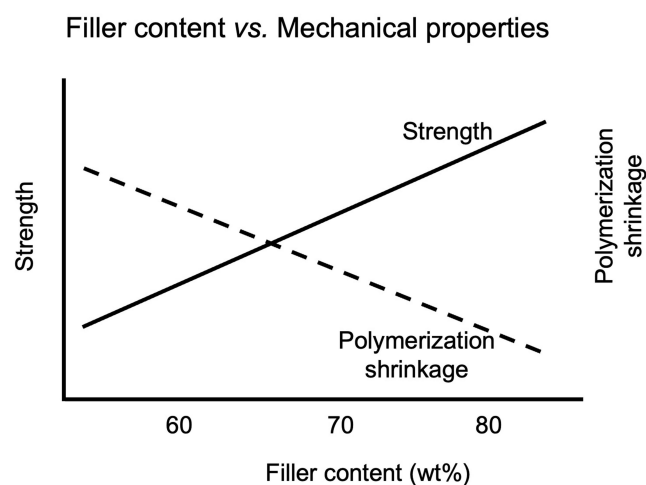


Figure 1 Graph showing the correlation between filler content, strength, and shrinkage.

Biocompatibility

Several studies on dental RBCs have shown that certain components, such as unreacted monomers, initiators, and additives, can leach out from resin material over time and potentially cause adverse tissue reactions.^{22,23} Consequently, both immediate and long-term adverse tissue reactions must be considered when selecting RBCs. Previous studies show that inadequate biocompatibility may lead to postoperative sensitivity, pulpitis, or irreversible pulp damage.^{22,23} However, current bulk-fill RBCs have shown biocompatibility and cytotoxicity comparable to those of conventional RBCs, which support their safe clinical use. Furthermore, proper handling and curing of these materials, along with careful removal of excess material, are essential steps to minimise residual monomer release and promote optimal tissue biocompatibility.

Conversion Rate, Polymerisation Shrinkage, and Curing Depth

The degree of monomer to polymer conversion significantly affects both the mechanical properties and biocompatibility of RBCs. A higher conversion rate enhances hardness and strength while reducing solubility, which improves the clinical longevity of restorations and lowers the occurrence of cytotoxic residual monomer leaching.^{24–26} In contrast, a lower conversion rate reduces mechanical properties and increases residual monomer levels. Several factors, including resin composition and filler content, influence the conversion rate.^{24–26} Previous studies have shown that the presence of opaque fillers can reduce light transmittance, consequently decreasing conversion rate.²⁵ Additionally, studies have shown that bulk-fill RBCs achieve conversion rates comparable to conventional RBCs, further supporting their successful clinical use.²⁶

Polymerisation shrinkage and the resulting stress continue to represent significant challenges for bulk-fill RBCs.^{27,28} The volumetric shrinkage that occurs during polymerisation is primarily due to the formation of covalent bonds between dimethacrylate molecules, which reduce intermolecular distances and increase internal stress within RBCs. This can compromise marginal adaptation of restoration, leading to microgaps, microleakage, and an elevated risk of secondary caries. Polymerisation shrinkage is affected by resin matrix composition, filler content, and the specific restorative technique employed.

Curing depth is another critical property that indicates the maximum thickness at which RBCs can be fully polymerised under standard conditions. Adequate curing depth ensures optimal monomer-to-polymer conversion in the deeper layers of the material, thereby minimising postoperative sensitivity, microleakage, and the risk of secondary caries. The primary factor influencing curing depth is the material's light transmittance, which can be compromised by increased filler content, opacity, or darker shades, all of which limit effective light penetration.^{28,29} To ensure complete polymerisation of the resin, conventional RBCs must be applied and cured incrementally. Conversely, bulk-fill RBCs are formulated with modified photoinitiators that incorporate components in addition to camphorquinone, which enables effective polymerisation of layers up to 4 mm or more. Commercially available bulk-fill RBCs are typically recommended in increments of 4 to 6 mm. However, to ensure a full cure, increments should not exceed 4 mm during clinical application. [Table 4](#) presents three common photoinitiators used in bulk-fill RBCs.

Determinants of Bulk-Fill RBC Performance in Clinical Settings

Several clinical studies have shown that bulk-fill RBCs perform comparably to conventional RBCs with respect to longevity, marginal integrity, and postoperative sensitivity.^{13,30–32} A previous study with follow-up periods reaching 5

Table 4 Chemical Names, Abbreviations, and Structural Formula of Three Common Photoinitiators Used in Bulk-Fill RBCs

Chemical Name	Abbreviation	Function
Camphorquinone	CQ	Primary initiator for light cure
Ivocerin	IVO	Enhances depth of cure
2,4,6—trimethylbenzoyl-diphenylphosphine oxide	TPO	Improves polymerization kinetics

years reports survival rates exceeding 90%, even for large posterior restorations.³⁰ Bulk-fill RBCs exhibit reduced polymerization shrinkage stress and improved cavity adaptation, resulting in fewer marginal gaps and a lower incidence of secondary caries.³¹ Randomized controlled trials further indicate that both flowable and high-viscosity bulk-fill RBCs maintain acceptable wear resistance and colour stability over time.¹³ However, some studies have reported that bulk-fill RBCs may exhibit slightly lower surface hardness than conventional RBCs, which highlights the importance of appropriate finishing and polishing procedures.³² Overall, the available clinical evidence supports bulk-fill RBCs as a reliable alternative for posterior restorations in deep cavities. The main determinants of successful performance of bulk-fill RBCs in clinical settings, including material selection, curing parameters, restorative techniques, storage conditions, the external oral environment, and preheating protocols, are discussed in the following sections.

Material Selection and Properties

The inherent properties of bulk-fill RBCs, which vary among manufacturers, significantly influence their clinical performance. Careful selection of materials based on resin matrix composition and filler content is essential, as these factors significantly impact their mechanical, optical, and biological properties, ultimately affecting clinical outcomes. It has been shown that there is an inverse correlation between maximum creep strain and filler content.^{33,34} As filler content increases, materials exhibit reduced susceptibility to creep strain, improving resistance to long-term deformation under occlusal forces. Additionally, properties such as Vickers hardness are also affected by the type and amount of filler, with higher filler contents generally resulting in increased hardness and improved wear resistance.³⁵ Furthermore, the hydrophilicity of the resin matrix affects water sorption and solubility of bulk-fill RBCs. It has been shown that resins containing BisGMA and urethane dimethacrylate-BisGMA (UDMA-BisGMA) combinations are more hydrophobic and less soluble than those composed solely of BisGMA, resulting in improved stability and reduced water uptake over time.³⁶

Material selection significantly affects both the polymerisation shrinkage and the degree of conversion in bulk-fill RBCs.^{28,29,34,35} In these materials, curing depth is generally improved by using effective photoinitiator systems and increased translucency.^{28,29} Translucency, which is determined by filler content, allows bulk-fill RBCs with lower filler content to allow greater light penetration, resulting in improved polymerisation at increased depths.^{28,29} This is important, as inadequate polymerisation decreases mechanical strength. Typically, low-viscosity bulk-fill RBCs exhibit greater polymerisation shrinkage than their high-viscosity counterparts.^{28,29} However, variations in light transmittance during polymerisation have minimal effect on the final curing depth or degree of conversion, despite slower polymerisation in deeper layers. Furthermore, flowable bulk-fill RBCs generally exhibit lower mechanical strength and higher conversion rates relative to packable bulk-fill RBCs.³³ The latter are comparable to conventional RBCs in terms of shear modulus, flexural modulus, and creep resistance, yet their curing efficiency does not match that of most flowable bulk fillers.³³

Previous studies show that the different components of bulk-fill RBCs significantly affect their colour stability.^{37,38} Compared to conventional RBCs, bulk-fill RBCs have different optical properties that render them more prone to discolouration.³⁷ Colour changes observed during the polymerisation of bulk-fill RBCs are generally attributed to increased diffuse reflection of the resin matrix, a phenomenon resulting from a rise in the refractive index as monomers are converted to polymers.³⁸ Additionally, changes in camphorquinone colouration and the refractive index after polymerisation further contribute to discolouration.³⁹ It has been shown that both the resin composition and the size of the filler particle affect colour stability, and that, following polymerisation, colour changes in bulk-fill RBCs become more pronounced.^{38,40} Moreover, the colour stability of bulk-fill RBCs is affected by resin monomer chemistry, varying concentrations of activators, initiators, and inhibitors, as well as the oxidation of unreacted monomers.^{37,41} Hydrophilicity and water sorption further influence colour stability, with hydrophilic resins being more prone to discolouration than hydrophobic resins.³⁸ Consequently, clinical shade selection of bulk-fill RBCs should be approached with caution. Relying on the colour of unpolymerized composite resin as a representative for the final restoration shade can mislead clinicians, leading to post-polymerization colour mismatches.

While bulk-fill RBCs show clear material advantages, it is essential to recognise that much of the variability in their properties between studies reflects differences in testing protocols, specimen preparation, ageing methods, and analytical techniques rather than actual differences in performance. For instance, discrepancies in flexural strength, hardness, and elasticity often arise from variations in specimen dimensions, curing-light characteristics, and storage conditions, which make direct comparisons difficult.^{38–40} Moreover, much of the evidence for enhanced depth of cure and improved polymerisation efficiency comes from *in vitro* studies conducted under optimal light-curing conditions that rarely mimic the real clinical situation, where anatomical constraints, reduced light access, and operator technique can limit curing effectiveness.^{37,41} These methodological differences highlight the need for cautious interpretation of material property data and highlight that laboratory performance does not always predict long-term clinical outcomes. Clinicians should therefore weigh both the material's theoretical benefits and the limitations of the current evidence when deciding on its clinical use.

Curing Parameters

Curing parameters significantly affect the polymerisation behaviour of bulk-fill RBCs, including shrinkage, conversion rate, and shrinkage stress, which in turn directly affect their structural integrity and clinical performance.^{10,42,43} Variations in exposure time, irradiance, wavelength, and curing distance determine the degree of monomer to polymer conversion, which is critical for achieving optimal mechanical properties. Achieving optimal polymerisation requires a light-curing device capable of delivering sufficient exposure time and irradiance.^{42,43} Insufficient exposure times, such as ten seconds, have been shown to reduce conversion rates, microhardness, and flexural strength, thereby compromising the clinical load-bearing properties and wear behaviour of the restoration.^{10,42,43} Conversely, prolonged exposure time increases conversion rates, microhardness, and overall structural strength, but it also affects the extent of polymerisation shrinkage and the development of internal stresses, compromising marginal adaptation. It is recommended that the light exposure be at least thirty seconds to ensure adequate polymerisation, particularly in deeper cavity preparations.^{44,45} Several studies have also examined the effects of irradiance on the depth of cure and degree of conversion in bulk-fill RBCs.^{43–46} Irradiance is a principal factor for the efficiency of polymerisation in RBCs. So, together with the exposure time, it controls the energy density transmitted to the material and therefore influences the conversion rate and the final mechanical properties. High irradiance can accelerate polymerisation and enhance curing depth and speed, but it can also cause high polymerisation shrinkage stress, which can compromise marginal integrity.^{31,46} In contrast, insufficient irradiance leads to incomplete polymerisation with more residual monomers that reduce strength and biocompatibility.^{31,47} Moreover, the wavelength of the curing light must match the absorption spectrum of the photoinitiator, such as camphorquinone, which peaks around 470 nm; deviations can reduce polymerisation efficiency and compromise depth of cure. Similarly, curing distance significantly affects irradiance at the composite surface.^{44,45} Greater distances reduce light intensity and energy delivery, which leads to lower microhardness and inadequate polymerisation in deeper layers.^{31,47} Therefore, maintaining the light tip as close as possible and using appropriate wavelength-emitting devices are essential for optimal curing outcomes.

It is vital to consider the heat generated during light-curing of bulk-fill RBCs. Excessive heat can increase the risk of pulp tissue damage, which can potentially lead to irreversible inflammation or necrosis. Previous studies have shown that RBC polymerisation is associated with a significant increase in temperature, which indicates that even short exposures can negatively affect pulp vitality.^{48,49} These findings highlight the importance of optimising intensity and duration of light curing, as well as the distance between curing light and restoration surface, to ensure adequate polymerisation while minimising harmful thermal effects.

It is important to note that findings on curing parameters vary considerably across the literature due to methodological differences in study design, including variations in light-curing units, irradiance calibration, specimen thickness, and measurement techniques such as microhardness ratios versus real-time degree-of-conversion analyses.^{42–46} These inconsistencies partly explain the conflicting reports on optimal irradiance levels and exposure durations. Some *in vitro* studies demonstrate adequate curing at shorter exposure times under ideal laboratory conditions.^{43,44} In contrast, in the clinic, it is often expected that reduced curing efficiency will result from light attenuation, anatomical constraints, and operator variability. Therefore, when interpreting findings on curing parameters, it is necessary to consider these

methodological limitations and the distinction between laboratory performance and real clinical outcomes, ensuring that conclusions about curing efficiency are applied with appropriate caution in clinical practice.

Restorative Techniques

Bulk-fill RBCs can be placed in prepared cavities using various restorative techniques, including bulk-filling, layered-filling, and mixed-filling. In the bulk-filling technique, a single thick increment of resin, typically 4 mm or more, is placed and cured in one step. This method enhances procedural efficiency by reducing the number of increments and decreasing chair time. On the other hand, the layered-filling technique follows conventional protocols in which the material is applied in increments of no more than 2 mm to ensure optimal polymerisation. The mixed-filling technique combines both approaches, typically using a flowable bulk-fill RBC at the base, followed by a conventional RBC layer to enhance aesthetics and mechanical properties.

The thickness of the increment material plays a critical role in influencing the biological properties of bulk-fill RBCs. Previous studies have shown that specimens with a thickness of 4 or 6mm exhibit greater monomer elution than those with a thickness of 2 mm.^{50,51} These findings indicate a clear correlation between increased filling thickness in bulk-fill RBCs and higher monomer elution, which adversely affects their biological performance compared to conventional RBCs. Consequently, it is essential to adhere to the manufacturer's instructions regarding filling thickness and avoid arbitrary increases.

Previous studies show that regardless of restorative methods used, the degree of conversion and cusp deflection in bulk-fill RBCs is generally lower than that observed in conventional layered RBCs.^{52,53} To address this, overlaying bulk-fill RBCs with conventional RBCs has been shown to significantly reduce cusp deflection and microleakage.^{54,55} These findings suggest that applying a conventional RBC layer over bulk-fill RBCs enhances coronal sealing and marginal integrity, thereby lowering the risk of secondary caries. However, no significant differences in microleakage have been reported between bulk-filling and layered-filling techniques, suggesting that the marginal integrity of bulk-fill RBCs is independent of the placement method.⁵⁶ Thus, using bulk-fill approaches does not compromise interface sealing. Nevertheless, layered RBCs typically exhibit higher Vickers hardness than bulk-fill RBCs.⁵⁷ While the degree of conversion decreases with increased bulk-fill thickness, this reduction does not significantly affect either microhardness or dentin bond strength.⁵⁸ In summary, the choice of restorative method has a minimal impact on clinical performance, emphasising the benefits of bulk-filling resin technology.

Storage Conditions, External Oral Environment, and Preheat Treatment

The mechanical properties of bulk-fill RBCs are significantly affected by storage conditions and environmental factors commonly encountered in clinical practice. Studies have shown that storing materials in a humid environment at elevated temperatures increases their creep strain and permanent deformation.^{33,59} At the same time, key properties such as creep recovery, shear modulus, and bending modulus are reduced when compared to RBCs stored under dry conditions.^{33,59} Therefore, it is recommended to minimise the exposure of bulk-fill RBCs to humid environments during storage.

Previous studies have shown that the external oral environment significantly influences surface characteristics and mechanical properties of bulk-fill RBCs.^{60,61} Key mechanical properties, such as elastic modulus, Vickers hardness, and tensile strength, are adversely affected following exposure to acidic conditions. These findings suggest that the consumption of acidic beverages may compromise both conventional and bulk-fill RBCs, which increases the risk of surface degradation and potential material failure. Moreover, external environmental factors further impact their colour stability. Previous comparative studies assessing colour stability in various solutions, including distilled water, red wine, and coffee, found that only a few bulk-fill RBCs exhibited significant colour changes in distilled water.^{62,63} Conversely, all tested RBCs demonstrate significant and progressively increasing colour changes when exposed to red wine and coffee over time. Consequently, patients who frequently consume beverages should be informed about the potential risk for material weakening and staining. The surrounding medium also significantly affects the viscoelasticity and flexural strength of bulk-fill RBCs.^{64,65} Therefore, it is essential to maintain strict moisture control during the placement of bulk-fill RBCs to avoid saliva contamination, which can adversely affect the material properties. Moreover, a study assessing the water sorption of bulk-fill RBCs after one year of storage in both water and artificial saliva found no significant

difference between the two media, suggesting that artificial saliva does not compromise the water sorption characteristics of bulk-fill RBCs.^{64,65}

Preheating bulk-fill RBCs before clinical application has been shown to improve their overall performance and clinical outcomes. For optimal handling and performance, bulk-fill RBCs, like conventional composites, should be pre-heated to approximately 68 °C for 6 to 10 minutes before use.^{29,66} This temperature has been shown to significantly reduce extrusion force by around 75–80%, making injection and molding much easier, and to improve flow and marginal adaptation, ensuring better cavity fill and fewer voids.^{29,66} Elevated temperatures during application increase the flexural strength of bulk-fill RBCs, thereby improving their load-bearing capacity in clinical settings.²⁹ Additionally, it was reported that preheating significantly improves bottom-surface microhardness, critical for strong adhesion and long-term restoration stability.⁶⁶ Furthermore, preheating increases the degree of conversion in certain composites, reducing polymerisation shrinkage stress and, consequently, decreasing the risk of marginal gaps and postoperative sensitivity.^{29,66}

Although the effects of storage conditions, environmental challenges, and preheating treatments are well documented, it is essential to recognise that variability in results across studies often reflects differences in experimental design, storage media, exposure duration, and artificial ageing protocols.^{29,59,61,64,66} Discrepancies in monomer elution, colour change, or mechanical degradation may result from variations in immersion solutions or accelerated ageing models that do not fully replicate the oral environment, which includes fluctuating temperatures, salivary enzymes, and mechanical loading. Moreover, much of the evidence supporting the benefits of preheating comes from controlled *in vitro* studies, in which uniform heating and ideal curing conditions can be achieved.^{29,66} These conditions may not consistently occur clinically due to heat dissipation, variable warming times, or differences in cavity geometry. Thus, while current evidence highlights the influence of storage conditions and preheating on bulk-fill RBC performance, it should be interpreted cautiously and applied clinically only after considering real-world limitations and patient-specific factors.

Clinical Guidance for Using Bulk-Fill RBCs

When using bulk-fill RBCs, clinicians must adhere strictly to the manufacturer's guidelines on maximum increment thickness, recommended curing times, and any specified curing protocols to ensure adequate polymerization and optimal properties.^{42,43} Exceeding the recommended increment thickness leads to insufficient light penetration, which results in an under-cured area on the internal surface, compromised mechanical performance, increased wear, and a higher risk of marginal breakdown and postoperative sensitivity.^{42,43} Moreover, high-quality LED curing units with verified light intensities exceeding 1000 mW/cm² should be used, and their output should be regularly checked to confirm consistent performance over time.^{43–46} The curing tip must be kept clean and positioned as close as possible to the restoration surface to maximize light penetration and energy delivery to the material.^{43–46} Furthermore, selecting a suitable adhesive system is equally crucial for the clinical success of bulk-fill RBCs. Studies on bulk-fill materials highlight that proper bonding techniques, including appropriate isolation, correct etching, and adhesive application, together with compatible adhesive systems, are essential for minimizing postoperative sensitivity and marginal leakage.⁶⁷ In high-stress areas such as molars or occlusal surfaces, clinicians should consider using high-viscosity bulk-fill RBCs or applying conventional RBCs as an occlusal capping layer to enhance wear resistance.^{54,55} Proper finishing and polishing techniques are also critical for achieving a smooth and anatomically correct surface, which improves surface hardness, reduces plaque accumulation, and enhances the aesthetics and longevity of the restoration.¹² Furthermore, regular follow-up appointments should be scheduled to monitor marginal integrity, assess occlusion, and detect early signs of secondary caries, marginal discoloration, or surface degradation.¹²

Limitations and Prospects

This review has several research-related limitations. Its narrative nature might introduce bias in study selection and data interpretation, as it lacks the predefined methodology of systematic reviews. Most available evidence is based on *in vitro* studies, which provide useful information but cannot fully mimic the clinical environment. Therefore, the clinical translation should be undertaken with caution. Additionally, substantial variability in material composition between manufacturers, such as filler type, resin matrix chemistry, and curing protocols, limits direct comparisons between studies, especially since these factors are often inconsistently reported. Moreover, long-term clinical studies are also

limited, with most studies reporting 2 to 5 years of follow-up, which may overlook late failures such as marginal degradation or secondary caries. These research-related limitations highlight the need for standardized protocols and long-term clinical trials.

Regarding material-related limitations, current bulk-fill RBCs exhibit reduced mechanical properties compared to conventional RBCs. In the restoration of posterior teeth, conventional RBCs are often preferred, either as the sole restorative material or as an overlay to reinforce bulk-fill RBCs. The overlay technique can improve the mechanical strength of bulk-fill RBCs, thereby reducing the risk of fractures and minimising marginal gaps.^{49,50} Aesthetic limitations of bulk-fill RBCs compared to conventional RBCs include increased susceptibility to discoloration over time and a more restricted shade range, reducing their suitability for anterior restorations.^{32–34}

In addition to their mechanical and aesthetic limitations, bulk-fill RBCs also exhibit limited antibacterial activity and bioactive behaviour, which reduces their ability to inhibit bacterial growth and actively promote remineralization or regeneration of the surrounding dental tissues.^{68–70} Future developments should therefore extend beyond improving the mechanical and optical properties of bulk-fill RBCs. Incorporating antibacterial agents such as silver nanoparticles and chlorhexidine-loaded fillers may help reduce bacterial growth at the restoration interface and prevent recurrent caries.^{68–70} Moreover, enhancing bioactivity with additives such as bioactive glass, calcium silicate, or hydroxyapatite nanoparticles could promote remineralization and minimize restoration failure.^{68–70} These combined improvements can significantly enhance clinical performance and enable next-generation bulk-fill RBCs to replace conventional materials, offering simplicity, durability, superior aesthetics, and improved biocompatibility.

Conclusion

Within the limitations of this study and based on the reviewed evidence, the following key conclusions can be drawn:

- Deeper curing capability of bulk-fill RBCs permits bulk placement up to 4–5 mm without compromising polymerization efficiency.
- Reduced operative time and improved handling properties improve workflow efficiency, particularly when moisture control is challenging.
- Mechanical properties are clinically acceptable and suitable for restorations in both posterior and anterior regions when materials are appropriately selected.
- Some bulk-fill formulations exhibit slightly lower mechanical strength compared with conventional RBCs, necessitating cautious selection for high-stress occlusal areas.
- Colour stability remains a concern for bulk-fill RBCs, particularly in long-term aesthetic zones.
- Material-dependent variations in translucency and wear resistance require case-specific decision-making.
- Bulk-fill type (flowable vs high-viscosity) should be selected based on cavity depth, occlusal loading, and aesthetic requirements.
- Best clinical outcomes are achieved through appropriate material selection, adherence to recommended curing protocols, and precise restorative techniques.
- Layering or capping with conventional composites is recommended when enhanced aesthetics or higher wear resistance is required.
- Future formulation advancements should focus on improved mechanical properties, optical stability, enhanced wear resistance, and improved antibacterial and bioactive performance.

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