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EFFECT OF VOID FORMATION ON POLYMERIZED SHRINKAGE IN DENTAL RESIN COMPOSITE USING FINITE ELEMENT APPROACH

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ABSTRACT

Resin-based dental composites are widely used in modern dentistry due to their esthetic properties, adhesive capability, and conservative preparation requirements. However, their long-term success is threatened by two persistent challenges: polymerisation shrinkage and void formation. Polymerisation shrinkage, typically ranging from 1.5% to 5%, generates internal stress at the tooth–restoration interface, leading to marginal gaps, microleakage, postoperative sensitivity, and eventual restoration failure, while voids introduced during clinical placement or material handling act as stress concentrators that weaken the restoration and increase probality to fracture, debonding, and bacterial infiltration. Although shrinkage behavior has been extensively studied, limited attention has been given to the combined influence of void size and location on the biomechanical integrity of composite restorations. This study addresses the gap by employing a hybrid experimental–computational approach in which a human molar tooth was reconstructed into a three-dimensional Class I cavity model using high-resolution micro-computed tomography (micro-CT), restored with a bulk-fill resin composite (3M ESPE), and simulated with finite element models of void-free and voided composites containing spherical voids of 1 mm and 2 mm placed at the centre, side, and margin of the cavity. Experimental micro-CT analysis provided validation of polymerisation shrinkage, which was then correlated with finite element analysis (FEA) simulations of volumetric contraction, linear displacement, and stress distribution under curing and simulated occlusal loading of 120 N. Results showed strong agreement between micro-CT and FEA, with deviations within the accepted tolerance of 10%, confirming the robustness of the computational model. Voids were found to significantly alter stress distribution, with larger and marginally located voids producing higher tensile stress concentrations and greater displacement at critical regions, whereas central voids exerted minimal influence. By integrating validated FEA with experimental characterisation, this study advances understanding of the mechanical consequences of voids in resin composites and underscores the importance of minimising void formation while providing clinically relevant guidelines for recognising surface displacement patterns associated with internal voids, ultimately contributing to more durable and reliable restorative outcomes.

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INTRODUCTION

1.1 Research Background

Dental composite restorations are widely used in modern dentistry due to their excellent esthetics, conservative preparation, and ease of application. The general procedure involves cleaning and preparing the cavity, applying an adhesive bonding agent, followed by the incremental placement and curing of a tooth-colored resin composite. Globally, untreated dental caries remains the most prevalent health condition, affecting an estimated 2.5 billion people with decay in permanent teeth and over 514 million children suffering from caries in primary teeth [1]. With such a high disease burden, the demand for direct restorative procedures, especially using composite materials, is substantial [2]. The global push for mercury-free dentistry, combined with patient preference for aesthetic, minimally invasive treatment, continues to increase the popularity of resin composites for both anterior and posterior restorations[3].

The evolution of dental composites since the 1950s has been marked by continuous advancements in material composition, curing methods, and clinical performance. The earliest formulations began with glass-filled PMMA, but the 1960s saw a significant advancement with the introduction of Bis-GMA as a resin matrix, forming the foundation of modern composites . The 1970s introduced UV-curing followed by visible light curing, which improved handling and polymerization control [2]. During this period, the evolution from macrofill to microfill composites took place, and in the 1980s, hybrid composites emerged to balance strength and polishability . The 1990s marked the development of flowable and packable composites that enhanced clinical usability[4]–[6]. Around 2010, self-adhesive and silorane-based composites were introduced to simplify bonding procedures and reduce shrinkage-related problems [7]. In the last decade, composites have advanced to nanohybrid and nanofilled forms that offer better aesthetics, strength, and wear resistance. More recently, innovations have introduced bulk-fill composites for deeper layering, bioactive composites that aid remineralization and reduce bacterial activity, and smart materials with self-healing or