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Polymerization stress evolution of a bulk-fill flowable composite under different compliances ☆

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ABSTRACT

Objective. To use a compliance-variable instrument to simultaneously measure and compare the polymerization stress (PS) evolution, degree of conversion (DC), and exotherm of a bulk-fill flowable composite to a packable composite.

Methods. A bulk-fill flowable composite (Filtek Bulk-fill, FBF) and a conventional packable composite (Filtek Z250, Z250) purchased from 3 M ESPE were investigated. The composites were studied using a cantilever-beam based instrument equipped with an *in situ* near infrared (NIR) spectrometer and a microprobe thermocouple. The measurements were carried out under various instrumental compliances (ranging from 0.3327 μm/N to 12.3215 μm/N) that are comparable to the compliances of clinically prepared tooth cavities. Correlations between the PS and temperature change as well as the DC were interpreted.

Results. The maximum PS of both composites at 10 min after irradiation decreased with the increase in the compliance of the cantilever beam. The FBF composite generated a lower final stress than the Z250 sample under instrumental compliances less than ca. 4 μm/N; however, both materials generated statistically similar PS values at higher compliances. The reaction exotherm and the DC of both materials were found to be independent of compliance. The DC of the FBF sample was slightly higher than that of the packable Z250 composite while the peak exotherm of FBF was almost double that of the Z250 composite. For FBF, a characteristic drop in the PS was observed during the early stage of polymerization for all compliances studied which was not observed in the Z250 sample. This drop was shown to relate to the greater exotherm of the less-filled FBF sample relative to the Z250 composite.

Significance. While the composites with lower filler content (low viscosity) are generally considered to have lower PS than the conventional packable composites, a bulk-fill flowable composite was shown to produce lower PS under a lower compliance of constraint as would be experienced if the composite was used as the base material in clinical procedures.

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1. Introduction

Extensive efforts have been employed over the years to improve the physical and mechanical properties of photopolymerized dental composites that are used to restore the appearance and function of teeth [1]. As monomers used in dental composite resins react to form covalent bonds during the polymerization process, the volume of the resulting polymer contracts. Subsequently, enormous polymerization stresses (PS) can develop due to external constrains (i.e., tooth walls or substrates) during the process [2,3]. This stress is considered undesirable and could lead to deleterious clinical signs and symptoms, such as post-operative sensitivity, debonding, marginal discoloration, secondary caries, and cusp fractures [4–6]. Incorporating a larger amount of filler, increasing the molar mass or polarity of monomers, and tuning the reaction kinetics are some of the strategies used to mitigate the adverse effects of polymerization shrinkage. Conventionally, the restorative resins are incorporated with a high content (ca. 80% by mass) of silica filler. The presence of filler in these composite resins, known as "packable composites", reduces the overall shrinkage relative to an unfilled resin. In addition, these composites have an increased modulus due to the presence of the filler which improves the hardness and performance life time of the composite in the tooth cavity. However, PS is primarily determined by the reciprocal relationship between the shrinkage and modulus. Recently, with modifications in the filler content and/or the organic matrix, a new generation of composites known as "bulk-fill flowable composites" has been introduced which claim to exhibit low PS as one of the main advancements [7,8]. The lower filler content of the bulk-fill flowable composites (ca. 60 mass%) results in a lower modulus and is considered to be the main contributing factor to the reduced PS [9,10]. It has been recommended that most of the bulk-fill flowable materials be used as base materials in dental cavities, which are then veneered with 2 mm of the higher filler content packable composites with relatively better mechanical properties such as hardness, stiffness and strength [8,10]. Besides showing the reciprocal relationship between the shrinkage and modulus, many studies also indicate that the effect of the filler content on PS can be significantly influenced by the compliance of the testing systems used to measure the PS [11,12]. Clinically, the compliance is characterized by the geometry of the prepared tooth cavity and the stiffness (or compliance) of the remaining tooth structure [13,14]. Thus, it remains elusive whether bulk-fill flowable materials always generate relatively lower PS under varied compliances, or whether the flowable composites are suitable as a base material in the dental restoration. The main goal of this study is to compare the evolution in the PS of a bulk-fill flowable composite under different compliances to a conventional packable composite during polymerization.

Numerous studies have investigated the effect of filler content on PS with different testing systems with conflicting results. This could be attributed to the fact that these studies did not take into account the compliance of the testing system as a systematic variable. Condon et al. evaluated the magnitude of the PS of a variety of commercial composites containing different levels of filler content using a mechanical testing instrument with very low compliance and concluded that the PS increased with increasing filler content [15]. Boaro et al. reported the same trend of PS in relation to filler content by investigating seventeen commercial dental composites using a stress-strain analyzer with a feedback system, which allows for a near zero compliance [16]. Braga et al. found an inverse trend when evaluating the PS of eight, and then twenty in their later study, experimental composites loaded with incremental filler content in a universal test machine using an acrylic as a bonding substrate. The presence of the acrylic material resulted in an increase in the compliance of the testing system [17,18] relative to the previously mentioned studies where glass was usually adopted as the bonding substrate. Stansbury et al. measured the PS of five composites with incremental filler content using an instrument with relatively low compliance [19]. They reported no significant statistical difference in the PS due to the filler content. Nevertheless, these studies of PS development as a function of filler content were performed under testing systems with a fixed compliance that might not be clinically relevant; no systematic variation of compliance has been incorporated in their studies. Recently, Fok et al. developed a mathematical model to predict the development of PS and reported that differences in the compliance of the experimental systems would significantly influence the effect of the filler content on the PS. This study showed that with increasing filler content, the PS could increase or stay constant depending on the compliance of the testing system [12]. Recently, a work was conducted in our lab using experimental and analytical approaches to systematically study the effect of filler content on PS using model composites with incremental filler contents (0–75% by mass). This study demonstrated that the PS actually increases, decreases, or remains constant with increasing filler content depending upon the instrumental compliance [20]. This work also emphasized the importance of the testing systems compliance in obtaining unbiased or misleading test results in PS evaluation.

Another important aspect of the polymerization of dental materials is the degree of conversion (DC) of the methacrylate monomers to polymer. This conversion is correlated with the volumetric shrinkage and modulus development in the polymerization process. It has been shown that the degree of conversion of the methacrylate monomer progressively decreases with increasing filler content [19,21]; an inverse relationship was also found between the filler content and the magnitude of the polymerization exotherm (i.e., less filled flowable composites would show higher DC and exotherm than conventional composites [22–24]). The exotherm would affect not only the pulp vitality during dental treatment, but also the polymerization process [25]. Therefore, measurements of DC and exotherm are indispensable for better interpretation of the PS evolution during polymerization process.

In the present study, real-time and simultaneous measurements of the PS, DC and exotherm were performed on commercially available bulk-fill flowable and packable composites using a NIST-developed cantilever-beam based instrument [26,27]. The key advantage for the simultaneous measurements is that these properties can be correlated directly, thus providing higher measurement confidence and