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Simulated cuspal deflection and flexural properties of high viscosity bulk-fill and conventional resin composites

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ABSTRACT

Objectives: The purpose of this study was to investigate the simulated cuspal deflection and flexural properties of high viscosity bulk-fill and conventional resin composites.
Methods: Seven high viscosity bulk-fill resin composites and eight conventional resin composites were used. Aluminum blocks (10 mm x 8 mm x 15 mm) with a mesio-occlusal-distal (MOD) cavity [4 (W) mm x 8 (L) mm x 4 (D) mm] were prepared and randomly divided into groups for different measurement techniques [micrometer vs CSLM] and further subdivided according to type of resin composite (high viscosity bulk-fill vs conventional resin composite). The simulated cuspal deflection resulting from the polymerization of resin composite bonded to a precisely machined MOD cavity within an aluminum block was measured with either a novel highly accurate submicron digimatic micrometer (MDH-25 M, Mitsutoyo, Tokyo, Japan) or a confocal laser scanning microscope (CLSM, VK-9710, Keyence, Tokyo, Japan) cuspal measurement method. In addition, flexural properties of tested resin composites were measured to investigate the relationship between simulated cuspal deflection and flexural properties. Scanning electron microscopy observation of tested resin composites was also conducted.
Results: The simulated cuspal deflection of high viscosity bulk-fill resin composites was similar to that of conventional resin composites, regardless of measurement method. There were no statistically significant differences ($p > 0.05$) between the micrometer and CLSM cuspal measurement methods. There were statistically significant differences ($p < 0.05$) in flexural strength and elastic modulus depending on the material, regardless of the type of resin composite. Pearson correlation analysis did not show any statistically significant ($p < 0.05$) relationship between flexural properties and cuspal deflection.
Conclusions: The results of this study indicate that high viscosity bulk-fill resin composites show similar cuspal deflection with bulk-filling techniques, to those shown by conventional resin composites with incremental filling techniques. Simulated cuspal deflection can be measured using either a micrometer or CLSM, but this experiment failed to show any relationship between the flexural properties and simulated cuspal deflection of resin composites.
Significance: High viscosity bulk-fill resin composites produce the same level of cuspal deflection as a conventional incrementally filled resin composite.

1. Introduction

Resin composites have come to be considered the first choice material for direct posterior restoration worldwide due to improvements in their mechanical properties (Lynch et al., 2014). Heintze et al. (2017) reported in their systematic review that, based on the quantity of restorative materials sold, as reported for corporate market insight by Ivoclar Vivadent, it is estimated that around 800 million resin composite restorations were placed worldwide in 2015 alone, with about 80% in posterior teeth and 20% in anterior teeth. These approximately 800 million resin composite restorations represent one of the most prevalent medical interventions in the human body. Alvanforoush et al. (2017) reported that the overall clinical failure rates of resin composite restorations in posterior teeth were similar between 1995–2005 and

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2006–2016 (1995–2005: 10.59%; 2006–2016: 13.13%). These researchers also noted that resin composite fracture rates showed a notable increase dependent on the increase in the size and surfaces of resin composite restorations in posterior teeth (1995–2005: 28.84%; 2006–2016: 39.07%), in that resistance to fracture is an important mechanical property, especially for large restorations. Tsujimoto et al. (2018) stated that, based on these failure rates, it can be estimated that at least 32 million resin composite restorations placed in posterior teeth in 2015 will need to be repaired or replaced due to failure by 2025. This suggests the necessity of continued improvement in the mechanical properties of resin composite materials, such as flexural properties, and thus manufacturers are attempting to develop resin composites which are superior in these respects.

In order to attain superior mechanical properties in resin composites, adequate visible-light-initiated polymerization of the resin monomers to form a highly crosslinked polymer is essential (Cramer et al., 2011). However, the photopolymerization of resin composites is accompanied by volumetric shrinkage, typically in the range of 1.5–5% (Tsujimoto et al., 2016), due to the reduction in distance between monomer chains when the weak van der Waals forces are converted into covalent bonds. Volumetric shrinkage leads to the development of polymerization stresses as the resin is bonded to the tooth structures on most sides of the cavity (Kaisarly and Gezawi, 2016). Thus, polymerization shrinkage stress of resin composites can lead to internal and marginal gaps, microleakage, and micro-cracking of tooth structure due to cuspal deflection. The resultant issues associated with polymerization shrinkage are an important consideration in the failure of resin composite restorations (Ilie and Hickel, 2011). Some researchers (Condon and Ferracane, 2000; Ferracane, 2005; Pfeifer et al., 2008) have reported that resin composites with higher mechanical properties generally show higher polymerization shrinkage stress. This raises the risk that formulation modifications to avoid resin composite failure may increase the risk of problems related to this stress. While the mechanisms of polymerization shrinkage stress development within resin composite restorations are quite complex, the generation, measurement and characterization of polymerization shrinkage stress have been the subjects of much research for more than 50 years, beginning with studies by Bowen (1967) and Bowen et al. (1983), and proliferating after the appearance of work by Davidson and de Gee (1984) and Feilzer et al. (1987). Investigations of how best to measure the polymerization shrinkage stress of resin composite continue today in many research laboratories.

One method for analyzing the polymerization shrinkage stress of resin composite is the measurement of simulated cuspal deflection using aluminum blocks with linear variable differential transformers (LVDT), as developed by Park et al. (2008). The advantage of measurement using LVDT is that it can measure the cuspal deflection in real time during the polymerization of resin composites. However, LVDT is not widely used, because performing these measurements requires a custom-built apparatus to hold them and the specimens. As a result, research on simulated cuspal deflection using LVDT has been conducted almost exclusively at a single research institute (Park et al., 2008; Kwon et al., 2012; Kim et al., 2016). Therefore, in order to find an alternative to the LVDT method, this study measured the simulated cuspal deflection resulting from the polymerization of resin composite bonded to a precisely prepared MOD cavity within an aluminum block with a novel highly accurate submicron digimatic micrometer (Micrometer, MDH-25M, Mitutoyo, Tokyo, Japan) or with a confocal laser scanning microscope (CLSM VK-9710, Keyence, Tokyo, Japan). Methods using a micrometer and CLSM for measurement of cuspal deflection in an aluminum block have not been previously used for this purpose and they may allow for more accessible measurement processes. Aluminum blocks (grade EN-AW 6060, elastic modulus: 68.5 GPa) have been used in previous studies (Park et al., 2008; Kwon et al., 2012; Kim et al., 2016) to simulate cuspal deflection with polymerization of resin composites as their mechanical properties are within the broad range of natural variation shown by enamel (mean elastic modulus: 84.1 GPa) and dentin (mean elastic modulus: 18.5 GPa).

In addition, Park et al. (2008) reported that the cuspal deflection in the incremental filling technique was considerably lower than that in the bulk filling technique, and there was no significant difference between horizontal and oblique incremental filling techniques. Recently, high viscosity bulk-fill resin composites have been used to expedite the restoration process by enabling increments of up to 4 mm in thickness to be photo-polymerized, thereby avoiding the time consuming incremental filling process for the reduction of chair time. (Tsujimoto et al., 2017). Manufacturers claim that the polymerization shrinkage stress of high viscosity bulk-fill resin composites can be reduced with advanced technology in the filler content or monomer type, or by adding modulators to slow the polymerization rate. Therefore, it is possible that the use of high viscosity bulk-fill resin composites will lead to a reduced cuspal deflection even with the bulk-filling technique, when compared to that of conventional resin composites with the incremental filling technique. However, there has been no independent research comparing cuspal deflection between high viscosity bulk-fill and conventional resin composites with different filling techniques. The purpose of this study was to investigate measurement methods for the resultant polymerization shrinkage stress on simulated cuspal deflection of high viscosity bulk-fill and conventional resin composites, the values of that shrinkage stress, and its relationship with flexural properties. The null hypotheses tested were: (i) there would be no differences in simulated cuspal deflection between high viscosity bulk-fill and conventional resin composites; (ii) there would be no differences in the cuspal deflection of resin composites measured with different techniques; and (iii) there would be no relationship between simulated cuspal deflection and flexural properties for any measurement technique.

2. Materials and methods

2.1. Study materials

Seven high viscosity bulk-fill resin composites: 1) Beautifil-Bulk Restorative (BB, Shofu, Kyoto, Japan), 2) everX Posterior (EP, GC, Tokyo, Japan) and 3) Filtek One Bulk Fill Restorative (FB, 3 M Oral Care, St. Paul, MN, USA), 4) Quix Fill (QF, Dentsply Sirona, York, PA, USA), 5) Sonic Fill 2 (SF, Kerr, Orange, CA, USA), 6) Tetric N Ceram Bulk Fill (TN, Ivoclar Vivadent, Schaan, Liechtenstein) and 7) Tetric Evo Cerame Bulk Fill (TE, Ivoclar Vivadent), and eight conventional resin composites; 1) Beautifil II (B2, Shofu), 2) Clearfil AP-X (CA, Kuraray Noritake Dental, Tokyo, Japan), 3) Clearfil Majesty ES2 (CM, Kuraray Noritake Dental), 4) Estelite Sigma Quick (EQ, Tokuyama Dental, Tokyo, Japan), 5) Filtek Supreme Ultra Restorative (FS, 3 M Oral Care), 6) G-ænial Sculpt (GS, GC), 7) Harmonize (HM, Kerr), and 8) Z100 Restorative (ZR, 3 M Oral Care) were evaluated (Tables 1 and 2).

2.2. Cuspal deflection measurement

Aluminum blocks (EN-AW 6060; 10 mm x 8 mm x 15 mm) with a MOD trench [4 (W) mm x 8 (L) mm x 4 (D) mm] were fabricated using a CNC milling machine, creating two remaining cusps. These cusps were asymmetrical (widths of 4 mm and 2 mm) in order to more closely approximate the clinical situation in a tooth such as a premolar. The 10 mm width of the block had a tolerance 0.05 mm, and the 4 mm width of the trench had a tolerance of 0.03 mm. The 4 mm depth of the trench had a tolerance of 0.1 mm. The inside of the cavity was air-abraded with 50 μm Al_2O_3 powder. Scotchbond Universal Adhesive (3 M Oral Care) was applied prior to placement of high viscosity bulk-fill and conventional resin composites, following the manufacturer's instructions. The adhesive was light cured for 10 s at a standardized distance of 1 mm using a quartz-tungsten halogen (QTH) curing unit (Optilux 501, Demetron, Kerr, Danbury, CT, USA). The power density