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Polymerization stress of resin composites as a function of system compliance

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ABSTRACT

Objectives. Evaluate the effect of testing system compliance on polymerization stress and stress distribution of composites.

Methods. Composites tested were Filtek Z250 (FZ), Herculite (HL), Tetric Ceram (TC), Helio Fill-AP (HF) and Heliomolar (HM). Stress was determined in 1-mm thick specimens, inserted between two rods of either poly(methyl methacrylate), PMMA, or glass. Experimental nominal stress (σ_{exp}) was calculated by dividing the maximum force recorded 5 min after photoactivation by the cross-sectional area of the rod. Composites' elastic modulus (*E*) was obtained by three-point bending. Data were submitted to one-way ANOVA/Tukey's test ($\alpha = 0.05$). Stress distribution on longitudinal (σ_y) and transverse (σ_x) axes of models representing the composites with the highest and lowest E (FZ and HM, respectively) were evaluated by finite element analysis (FEA).

Results. σ_{exp} ranged from 5.5 to 8.8 MPa in glass and from 2.6 to 3.4 MPa in PMMA. Composite ranking was not identical in both substrates, since FZ showed σ_{exp} statistically higher than HM in glass, while in PMMA FZ showed values similar to the other composites. A strong correlation was found between stress reduction (%) from glass to PMMA and composite's *E* ($r^2 = 0.946$). FEA revealed that system compliance was influenced by the composite (FZ led to higher compliance than HM). σ_x distribution was similar in both substrates, while σ_y distribution showed larger areas of compressive stresses in specimens built on PMMA.

Significance. σ_{exp} determined in PMMA was 53–68% lower than in glass. Composite ranking varied slightly due to differences in substrates' longitudinal and transverse deformation.

1. Introduction

Polymerization stress developed at the tooth/composite interface is one of the main causes of failure in resin composite restorations [1–3]. Several studies have been conducted to try and determine the factors involved in polymerization stress development [4–6]. Most of them use universal testing machines in which the composite is inserted and polymerized between flat surfaces of glass or steel. The load cell records the force developed by the composite as it shrinks, which is then divided by the specimen's cross-sectional area to obtain the nominal stress [7–9].

The stress values recorded in the mechanical test are influenced by deformation of the system components sub-

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jected to composite shrinkage forces. These deformations are commonly referred to as 'system compliance'. Generally speaking, the higher the testing system compliance, the lower the stress values recorded [6,7,10]. The analytical compliance of a testing system can be estimated by the sum of the compliance of its components. This calculation is only possible when the deformations that can effectively interfere with the load cell readings are limited to the components comprehended within the limits of a gauge length transducer. Deformations in components outside the boundaries of the transducer are promptly detected and compensated by cross-head movement in the opposite direction. Therefore, a system's analytical compliance, expressed in mm/N, can be estimated using the formula:

$$C = \frac{L_0}{AE}$$

where L_0 is the initial length, A the cross-sectional area and E is the elastic modulus of the system components.

There are few studies evaluating the influence of system compliance on polymerization stress. A finite element analysis (FEA) study comparing testing systems with different compliances reported that high compliance systems showed a better agreement between experimental stress results and those obtained by finite element analysis (FEA), than low compliance systems [10]. In another study, it was observed that a five times increase in compliance was achieved by increasing the length of the bonding substrate corresponded to a 68% reduction in stress [7]. A recent FEA study found that polymerization stress values obtained in a hypothetic system with null compliance would be 20% higher than those obtained in a system with compliance of 3.5×10^{-6} mm/N. When compared to a system with compliance of 51.9×10^{-6} mm/N, the difference would reach 3.6 times [6].

Low compliance systems are frequently used in the literature. However, they have received some criticism, the most common being that such *in vitro* situations may overestimate the stresses that are actually developed *in vivo*. Indeed, several studies on cuspal deflection related to composite volumetric shrinkage suggested that the tooth structure has a relatively high compliance [12,13]. Stress values reported in studies conducted in low compliance systems ranged from 4 to 25 MPa [4,11,14,15], whereas values obtained in high compliance systems hardly exceeded 5 MPa [16,17]. Although the actual geometry and compliance of *in vivo* cavity preparations are not likely to be accurately reproduced in a mechanical testing apparatus, it is licit to consider the use of high compliance systems as a step toward a more clinically representative situation.

The objective of this study was to compare polymerization stress values obtained by five commercial composites tested in a high compliance system (using a low elastic modulus substrate, PMMA) to those obtained in a low compliance system (using glass as bonding substrate). The working hypothesis was that on both substrates, composite ranking and the occurrence of statistically significant differences would be similar. Stress distribution in the composite bonded to both substrates was evaluated by FEA. Finally, system compliance was determined both analytically and using data extracted from FEA.

2. Material and methods

Five commercially available composites (Table 1) were tested, two microfill (Heliomolar and HelioFill–AP) and three hybrid (Herculite XRV, Filtek Z250 and Tetric Ceram).

2.1. *Bonding substrate preparation*

The polymerization stress test was performed using glass or poly(methyl methacrylate) (PMMA) cylinders with 5 mm in diameter and 13 or 28 mm in height as bonding substrates. In order to allow for maximum light transmission during photoactivation, one of the flat ends of the PMMA shorter rods was polished using 600–1200 grit silicon carbide sandpaper and felt disks with 1 μm alumina paste (Alumina 3, ATM, Altenkirchen, Germany). Such procedure was not necessary for the glass rods because the surface obtained after rod sectioning was sufficiently polished. The lateral surface of the glass rods was slightly coarsened by sandblasting in order to improve the retention of the testing machine clamps.

The bonding surface of the rods was subjected to 180 grit silicon carbide sandpaper and sandblasting with 150–200 μm alumina. For the glass rods, the sandblasted surface was coated with an organosilane (Ceramic Primer, 3M ESPE). For the PMMA rods, the bonding surface received a layer of

Table 1 – Materials used in the study

Composite	Composition	Manufacturer	Batch
Herculite XRV	BisGMA, TEGDMA, colloidal silica and borosilicate glass (0.6 μm, 59 vol%)	Kerr, West Collins Orange, EUA	404685
Filtek Z250	BisGMA, UDMA, BisEMA, silica/zircon (0.19–3.3 μm, 60 vol%)	3M ESPE St. Paul, EUA	5BT
Tetric Ceram	BisGMA, UDMA, TEGDMA, Barium and Aluminum fluorsilicate glass, trifluoreto de itérbio (0.04–3 μm, 60 vol%)	Ivoclair Vivadent, Schaan, Liechtenstein	G17491
HelioFill-AP	BisGMA, UDMA, TEGDMA, colloidal silica, pre-polymerizated filler (0.04 μm, 82 wt%)	Vigodent, Rio de Janeiro, Brazil	018/05
Heliomolar	BisGMA, UDMA, decandiol dimethacrylate, colloidal silica (0.04–0.2 μm, 46 vol%)	Ivoclar Vivadent, Schaan, Liechtenstein	C30500