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Alternative methods for determining shrinkage in restorative resin composites

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ABSTRACT

Objectives. The purpose of this study was to evaluate polymerization shrinkage of resin composites using a coordinate measuring machine, optical coherence tomography and a more widely known method, such as Archimedes Principle. Two null hypothesis were tested: (1) there are no differences between the materials tested; (2) there are no differences between the methods used for polymerization shrinkage measurements.

Methods. Polymerization shrinkage of seven resin-based dental composites (Filtek Z250™, Filtek Z350™, Filtek P90™/3M ESPE, Esthet-X™, TPH Spectrum™/Dentsply 4 Seasons™, Tetric Ceram™/Ivoclar-Vivadent) was measured. For coordinate measuring machine measurements, composites were applied to a cylindrical Teflon mold (7 mm × 2 mm), polymerized and removed from the mold. The difference between the volume of the mold and the volume of the specimen was calculated as a percentage. Optical coherence tomography was also used for linear shrinkage evaluations. The thickness of the specimens was measured before and after photoactivation. Polymerization shrinkage was also measured using Archimedes Principle of buoyancy ($n = 5$). Statistical analysis of the data was performed with ANOVA and the Games–Howell test.

Results. The results show that polymerization shrinkage values vary with the method used. Despite numerical differences the ranking of the resins was very similar with Filtek P90 presenting the lowest shrinkage values.

Significance. Because of the variations in the results, reported values could only be used to compare materials within the same method. However, it is possible rank composites for polymerization shrinkage and to relate these data from different test methods. Independently of the method used, reduced polymerization shrinkage was found for silorane resin-based composite.

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1. Introduction

Despite the major developments in new restorative materials, all resin-based composites present a certain degree of volume reduction due to the polymerization reaction. Assuming that these materials are bonded to prepared dental cavities, this volume contraction will lead to internal stress generation, which in turn, compromises the mechanical and chemical stability of the restoration and may lead to the loss of marginal integrity [1]. As a consequence, marginal leakage of saliva and its components will occur resulting in post-operative sensitivity, discolored margins, recurrent caries and fractures of the restoration margins [2]. These clinical consequences are the main reasons for restoration substitution, and explain why polymerization shrinkage is recognized as the main limitation of these materials [3,4].

Many studies have been conducted to evaluate polymerization shrinkage of resin composites. The results indicate that the volume contraction is dependent on the filler concentration, polymerization characteristics, volume and cavity design, restorative procedure and light intensity used for photoactivation [2]. In addition, polymerization shrinkage has a strong influence on stress generation and most of these tensions are developed in the first few seconds after irradiance [5]. The characterization of the shrinkage behavior and the polymerization reaction itself are an important aspect in the development of new restorative materials [6].

To reduce shrinkage, the main approaches adopted so far are modifications in the filler amount, shape or surface treatment. Versatile methods to modify the monomer matrix have been developed, starting with typical dimethacrylates with a reduced reactive group. Other approaches include the development of liquid crystal monomers or ring-opening systems to produce non-shrinking or minimally shrinking dental composites that contain spiroorthocarbonates as additives to dimethacrylate or epoxy resins. A new resin system, called siloranes, claims to have combined the two key advantages of the individual components: low polymerization shrinkage due to the ring-opening oxirane monomer and increased hydrophobicity due to the presence of the siloxane species [7].

However, the magnitude of the shrinkage is dependent on the methodology used to measure it. The results obtained for any of the methods recently published also varies between operators. Therefore, comparisons between published results are quite difficult with research being carried out in different laboratories with different equipment and operators [8].

Many methods have been described to measure polymerization shrinkage: bonded disk method [9], mercury dilatometer [10], optical method [11,12], gas pycnometer [13], the use of a strain gage [8], linear displacement [10], free linear shrinkage, wall-to-wall shrinkage [14], among others. However, each method for polymerization shrinkage evaluation depends on one physical principle for measurement.

It is in this context that new polymerization shrinkage evaluation methods appear, not only to determine volume variations but mainly to enable comparisons between the results obtained for each method. This is of greater importance to assure the reproducibility and veracity of the results.

Coordinate measuring systems were developed at the end of the 20th century to fulfill the industrial sector's need for easy and quick inspections of fabricated pieces using automated manufacturing systems. The primary goal of coordinate measuring machines (CMMs) is to obtain the Cartesian coordinates of points on a solid surface [15].

A CMM is composed of four interconnected rigid parts, three mobile and one fixed base. A CMM with a fixed working table and a mobile bridge is the most common type. In this type of CMM, the object to be measured is placed on the fixed granite table and the operator dislocates each of the three mobile parts along the three axes using a joystick in the following sequence: the bridge (along the OX axes), the car (along the OY axes) and the probe column (along the OZ axes). Finally, a ruby probe touches a specific point on the object. Each part of the machine has a built-in guide rail, so that the relationship between the axes allows a point to be located in all three planes with one check. The resulting data are mathematically processed in a computerized system to provide dimensional and geometrical measurements of any kind of object with high precision [16].

Optical coherence tomography (OCT) is a non-invasive medical diagnostic imaging modality with high resolution that can give near-histologic images. The basic principle of OCT is analogous to computerized tomography (which uses X-rays), magnetic resonance imaging (which uses spin resonance), and B-scan ultrasound (which uses sound waves). Nevertheless OCT uses only light to derive its image in a non-contact, non-invasive system [17].

OCT is based on a Michelson interferometer with a low coherence, broadband light source. The light generated in an OCT system is divided in two: one part follows a sample arm containing the item of interest, and the other follows the reference arm, which is usually a mirror. Reflected light is then recombined. When the path length of light from the reference mirror is the same as the tissue or sample, an interference fringe is detected. Because the reference mirror is moved by known increments, the position of the reflected light within the sample can be determined by the optical scattering properties of tissues. These interference patterns generate a reflectivity profile, called an A-scan. A two-dimensional tomographic image can be created by combining a series of A-scans [18].

Archimedes Principle (buoyancy of a material in fluid) is a well-established test method that can be used to measure volumetric dimensional changes by measuring density variations. This principle states that a body immersed in a fluid is buoyed up by a force equal to the weight of the dispersed fluid. Whether a given body will float, sink, or remain static in a given fluid is dependent on both the weight and volume of that material. The relative density – the weight per unit volume of the body compared to that of the fluid – determines the buoyant force [1,19–21].

The determination of dimensional changes in resin composites, shrinkage or expansion, through density measurements using this principle is a relatively simple and low-cost method. It basically consists of weighing the material under study several times in two distinct environments of known density; air is conventionally used as one of environment. Several liquids such as mercury, distilled water