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Evaluation of polymerization shrinkage of dental composites by an optical method

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ABSTRACT

This study proposes an alternative methodology for evaluating polymerization shrinkage of dental composites using an advanced video extensometer (AVE) system. This equipment measures the displacement between two points drawn on a tooth's wall without requiring physical contact with the tooth. By doing so, the polymerization process was monitored by the cusp deflection. This technique was used in human and bovine teeth, where the cavities were prepared under controlled conditions so that the volume of the composite used was the same in both types of teeth. After the cavity preparation, the specimens were acid etched, washed and dried, and then the adhesive was applied and polymerized. The composite was then inserted into the cavity. Polymerization was performed with two different light polymerizing units (LD Max and Optilight Max — Gnatus do Brasil), and the displacement curve of the tooth cusp was recorded for a period of 400 s. After a statistical analysis, it was concluded that the technique was capable of evaluating shrinkage by the deflection from the cusps and that the human and bovine teeth do not react in a similar manner towards the polymerization shrinkage of composites.

1. Introduction

The introduction of dental composites based on a polymer matrix replacing traditional amalgam has been causing great changes in esthetic restorative dentistry [1]. A considerable amount of studies have been conducted on these resins, leading to significant improvements in their properties [2,3]. Nevertheless, the polymerization shrinkage due to the curing process is an inherent feature that might impair the restoration performance. For instance, if high stress builds up during shrinkage (residual stress), the resin may detach from the teeth (adhesive failure) and the restoration life will be shortened, as emphasized in the literature [2–4]. Notably, the principal causes of restoration failure are associated with secondary carriage, wearing, chewing fracture forces, and high post-operatory sensibility [5].

Polymerization shrinkage occurs when the monomers react among themselves to form polymer chains. During this process, the molecules that are used to interact only by secondary forces begin to be covalently bonded, leading to an increase in density due to a total volume reduction [1]. According to Ferracane [6], this shrinkage varies between 1.5 and 5%, depending on the material composition. In fact, the polymerization shrinkage depends on the type, the quantity, the degree of conversion and the molecular weight of the monomers [7]. Furthermore, if a filler is present, its type, geometry and amount also play important roles. Usually, the larger the amount of the fillers used, the lower is the contraction and the higher is the elastic modulus of the composite material [8].

The tooth itself is also a very important player during the shrinking process because the tooth structure and the cavity geometry can be more or less compliant [9]. Additionally, the light source plays an important role because its type, power, intensity distribution and temperature affect the cure. It is well established that a higher intensity leads to a higher degree of polymerization of the material, a higher degree of conversion and, consequently, better mechanical properties. However, although the polymerization shrinkage and the respective rate will be greater, the, intensity might diminish the effects of the relaxation stresses [10]. Protocols with a lower intensity at the beginning of the procedure, called soft-start, have been tested in order to obtain a low shrinkage tension with the same degree of polymerization [10–12]. However, some authors have linked the low initial intensity with a greater polymer degradation, reporting the smallest number of free radicals formed; thus, a more linear polymer forms with a lower degree of crosslinking promoting degradation [11]. Inferior mechanical properties have also been related to this polymerization method [13].

Various methods have been used for evaluating polymerization shrinkage. The majority of these methods can be divided into two groups: those that evaluate the change in density and volume (dilatometer and pycnometer) and those that take linear measurements (linometer, interferometer, thermo-mechanical and optical analyses) [14]. Some of these methods involve direct contact with the sample, i.e., Linear Variable Differential Transformers (LVDT), dilatometers, pycnometers, and strain gauges. These methods may generate stresses or additional deformations,

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thus altering the measurement because the material is a viscous fluid at the very beginning of the polymerization and does not offer resistance even to small loads [15]. The outside temperature influences mercury and water dilatometers, immersion water may be absorbed by the sample, and mercury may interfere with the light path from the polymerizing unit. For the pycnometer, the major source of error is associated with the determination of the gas pressure. Furthermore, the method can only perform measurements before and after polymerization. Extra care must be taken during the removal of samples from the device before polymerization [16]. Strain gauges have also been used [17], but these systems are expensive, sensitive to changes in ambient temperature and cannot be re-used. In addition, they must also be in contact with the material in order to take the measurements [18].

Li et al. [19] discussed the non-contact techniques. For 3D microtomography, the image acquisition time is very long, making the polymerization kinetics difficult to measure. Digital image correlation (DIC) requires a flat surface for precise measurements [19]. Furthermore, Martinsen et al. [20] stated that the measurements cannot be made during the polymerization because the light from the unit hinders the measurements made by DIC and could lead to false results.

The shrinkage evaluation is also very dependent on the experimental set used. Some authors have tested the composite itself with the dilatometer [21] and the pycnometer, [16] while others have investigated the tooth-resin set, such as Michelson's interferometry [22] and the digital micrometer [23]. The tooth-resin set is a more realistic approach because it takes into consideration the effect of the dental adhesive and the walls of the tooth. Currently, the introduction of any technique that tries to avoid most of the drawbacks reported above would be helpful.

In this study, an alternative methodology was proposed to evaluate the power of different light sources, i.e., using an advanced video extensometer (AVE) optical system. This is a non-contact technique that allows the acquisition of the linear displacement versus time during the polymerization process because this process system is composed of the tooth, the dental adhesive and the composite. The displacement between the two points was successfully measured on the tooth wall, representing the tooth-resin set behavior. The tests were conducted using both human and bovine teeth, each one restored with two composites and using two different light sources. The results showed the AVE to be a powerful tool to measure the shrinkage behavior caused by the resin applied to the tooth. Additionally, a drastically different behavior for the human and the bovine teeth was observed, indicating that results found for a bovine tooth cannot be directly applied to a human tooth.

2. Methodology

2.1. Materials

The teeth used in this study were human pre-molars and the bovine incisors; 40 of each were used. The former teeth were donated from the tooth bank of the School of Dentistry of Universidade Federal Fluminense (UFF), Brazil. The teeth, after extraction, were conserved following a procedure established in the literature [24,25]. Essentially, they were cleaned, sterilized in an autoclave and then kept immersed in cold distilled water until their use. It is believed that this procedure does not interfere with the dentin protein and its adhesion ability, as noted by Rees [26].

The adhesive used was the Single-Bond 3M, while the composite resins were a nanofill (Z350 XT — 3M) and a nanohybrid (Evolux — Dentsply).

2.2. Polymerization shrinkage technique

The methodology proposed here for evaluating the polymerization shrinkage is based on the relative displacement of the two points marked on the tooth cusps, which is measured by an AVE. The displacement of the points is a result of, and therefore proportional to, the polymerization contraction.

The human tooth's roots were reduced to 10 mm in height. Then, the mesial surface of the tooth was entirely flattened in order to be perpendicular to the light beam of the AVE system, as shown in Fig. 1. Next, a mesio-occluso-distal (MOD) cavity was opened with a No. 4103 drill (KG Sorensen). The opening measured approximately 4 mm deep, 3 mm on the bucco-lingual wall and 7 mm on the mesio-distal wall (Fig. 1a). To maintain the tooth's stiffness as uniformly as possible, which is a function of the cusps' thickness (the remaining dental structure), only teeth with a diameter at the equator larger than 9 mm were chosen.

The bovine tooth cavity was prepared with dimensions of approximately 8 mm deep, 3 mm on the buccal wall and 3.5 mm on the mesio-distal wall (Fig. 1b). The geometrically different anatomies of both teeth did not allow for machining identical cavities to the same C factor. The cavity dimensions were determined so that both the human and the bovine teeth would be filled with the same volume of the composite, thus diminishing the number of variables in the study.

The marks for the optic readout by the AVE were made 1.5 mm below each cusp with a black Edding 751 pen, while the distance between the marks was 5 mm and 5.5 mm for the human and the bovine teeth, respectively. The tooth's root was then fixed to an acrylic resin

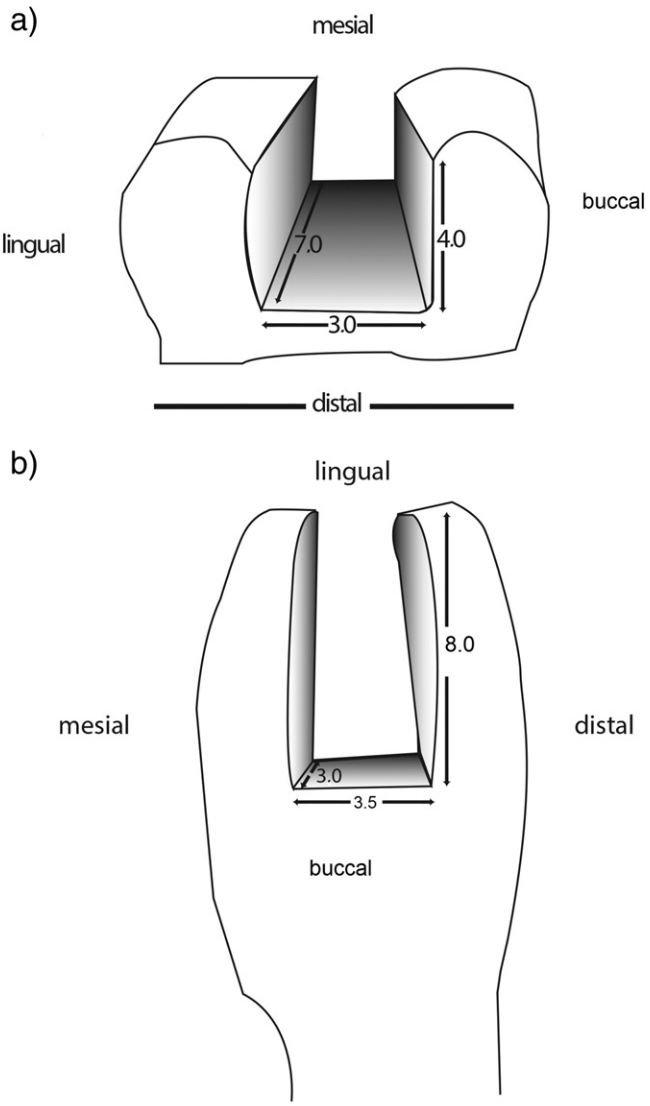

Fig. 1. Diagram of the human (a) and the bovine (b) tooth preparation with respective measurements.