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Resin-based composites show similar kinetic profiles for dimensional change and recovery with solvent storage

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ABSTRACT

Objectives. To investigate the sorption, solubility, mass change and hygroscopic expansion (solvent swelling) of resin-composites after long term storage in different solvents.

Methods. Eight materials were studied: two bulk-fill flowable materials (SDR and Venus bulk fill, V-BF), a packable bulk-fill material (Tetric Evoceram bulk-fill, TET-BF), a fiber reinforced material (Ever X posterior, EVX), a nano-hybrid conventional material (Tetric Evoceram, TET) and micro-hybrid conventional materials (G-aenial anterior, GA-P and posterior, GA-A). Three groups of disk shaped specimens were prepared using split stainless steel molds. Each group was stored, respectively, in: water, 75% ethanol/water and methyl ethyl ketone (MEK). The total storage time was 180 d plus a reconditioning time of 120 d. A non-contact laser scanning micrometer was used to measure the diametral changes.

Results. Significant differences were found in the sorption and solubility of the materials. Generally, MEK stored specimens had the highest values followed by 75% ethanol/water then water. A similar trend was found with the mass and volume changes (except for EVX). V-BF showed the highest sorption ($98.1 \mu\text{g}/\text{mm}^3$) and solubility ($10 \mu\text{g}/\text{mm}^3$) after MEK storage. Mass and volume changes showed near-linear correlation, with high Pearson coefficients (0.86–0.99).

Significance. Generally the materials were most greatly affected by MEK storage compared to the other two solvents. The glass-fiber-reinforced EVX, however, was most affected by water immersion. The pattern of change/recovery behavior of the materials, during solvent challenge, was similar to the pattern of viscoelastic creep/recovery behavior of resin-composite materials.

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1. Introduction

Advances in dental resin-composite materials make it possible to expand their uses from small conservative restorations to direct restoration of extensively damaged teeth. One of the limitations of this varied group of material is their potential for dimensional and chemical instability in the aqueous oral environment to which they are constantly exposed [1–5]. Water and solvents diffuse into the resin matrix with two main consequences: expansion of the polymer network and, in some cases, chemical degradation [2,3,6].

Many resin-composite materials are considered to be chemically and thermally stable. However, their polymer networks absorb different chemicals from the oral environment and may release some of their components, also from the dispersed filler phase, to the surrounding. These phenomena are called sorption and solubility. The processes of uptake and release from these network structures may lead to detrimental biological and physical effects on the material [6]. Sorption and solubility have a significant effect on the longevity of resin-composite restorations as they impact their physical and mechanical properties including their dimensional stability, color stability, wear resistance, hardness and strength [6–11].

Volumetric expansion that results from the process of sorption may lead to relaxation of internal polymerization shrinkage stress [9,11,12]. However, studies suggest that the resultant expansion is uncontrolled and may generate hoop stresses on the cavity walls and consequently micro-cracks in the restored tooth [5,11]. The oral environment may include a variety of chemicals including acids, bases, salts, alcohol, etc. The chemical nature and exposure period with these agents determine the magnitude of their effects on dental restorations [6]. In addition to the exogenous factors of the oral environment, the nature of the resin composite network plays an important role. The hydrophilicity, the crosslink density and the porosity of the network, the nature of the filler system and the quality of the matrix/filler interface are all significant factors [10,13–15].

The interaction between the resin-composite and the oral environment involves leaching of some unreacted monomers and other constituents and probably degradation of polymer network [1,6,16,17]. The solubility parameter of the solvent is a major factor: the greater the match between the solubility parameters of the solvent and the resin matrix the greater the solvent effect [18–20]. In other words, the solvent has greater effect when forces of attraction between the polymer chains of resin composite are exceeded by the forces of attraction between the solvent and the component of the polymer itself [6,18].

Sorption (or uptake) of a liquid from the oral environment may lead to extraction of unreacted monomers and other constituents of the material which causes mass loss and changes in material properties. In addition, fluid uptake can fill all the porosity and free volume of the network structure and then may lead to expansion by separating the chains in the polymer network [1,6–11,17,21]. Thus, the dimensional changes of resin-composite material in solvents are complex, unpredictable and greatly depend upon both the liquid and the material [6,8].

In this study the aim was to investigate the sorption and solubility of eight commercially available resin-composite materials after being stored in three different solvents: de-ionized water, 75% ethanol/water and methyl ethyl ketone (MEK) over an extended period of time (a sorption and desorption cycle total of 300 d). In addition, the hygroscopic dimensional change was monitored during the cycle of sorption and desorption. The relationship between the mass and dimensional changes was investigated. The null hypotheses were that:

1. The sorption and solubility of the investigated materials do not change by changing the solvent.
2. The hygroscopic dimensional changes of the investigated materials do not change by changing the solvent.
3. There is no relationship between the mass and dimensional changes after solvent storage.

2. Materials and methods

Eight resin-composite materials were investigated (Table 1). 120 disk-shaped specimens were produced using stainless steel split molds with an internal diameter of 10.0 ± 0.1 mm and 4 ± 0.1 mm thickness, ($n=15$ per material). The specimens were made carefully to avoid any air entrapment during placement into the molds of the uncured material, at a room temperature of 23 ± 1 °C and relative humidity of $50 \pm 2\%$. Each mold was sandwiched between two polyester films and microscope slides (1 mm thickness) on each side. Irradiation was made for 20 s at an output irradiance of 1200 mW/cm² using a LED light-curing unit (LCU), (Elipar S10, 3M ESPE, Germany). A calibrated radiometer was used to verify the irradiance at each use of the LCU. The specimens were irradiated from top and bottom surfaces in five overlapping sections. The specimens were finished to remove any irregularities using 1000 grit abrasive papers. Specimens were visually inspected to ensure a smooth finish. The specimens' preparation and measurement were generally made according to the ISO 4049 Standard for sorption and solubility.

A desiccator containing freshly dried silica gel (5 h at 130 °C) was used to store the specimens in an oven at a 37 ± 1 °C. After 22 h the specimens were placed in a second desiccator that was maintained at 23 ± 1 °C for 2 h. Then specimens were weighed using an analytic balance to an accuracy of 0.01 mg (Analytic plus, Ohaus, Switzerland). This cycle was repeated until an initial constant mass was obtained for each specimen (m_1): the mass change was not more than 0.1 mg in any measuring cycle.

Thickness and diameter were measured after final drying. A digital calliper was used (Absolute Digimatic, Mitutoyo Corp., Japan) to take two measurements of the diameter, at right angles to each other and four thickness measurements. After obtaining the mean dimensions of the specimens (r is the radius and h is the thickness), the volume was (v) calculated in mm³.

$$v = \pi r^2 h \quad (1)$$

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