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Electrical properties of resin monomers used in restorative dentistry

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ABSTRACT

Objectives. The application of an electric field has been shown to positively influence the impregnation of the resin monomers currently used in dentin bonding systems during hybrid layer formation. This study presents an experimental characterization of the electrical properties of these monomers with the aim of both correlating them to their chemical structures and seeking an insight into the mechanisms of the monomer migration under an applied electric field.

Methods. Some common monomers examined were TEGDMA (triethyleneglycoldimethacrylate), HEMA (2-hydroxyethyl methacrylate), UDMA (urethane dimethacrylate), 2-MP (bis[2-(methacryloyloxy)ethyl] phosphate, TCDM di(hydroxyethyl methacrylate) ester of 5-(2,5-dioxotetrahydrofurfuryl)-3-methyl-3-cyclohexenyl-1,2-dicarboxylic anhydride) and Bis-GMA [2,2-bis(4-2-hydroxy-3-methacryloyloxypropoxyphenyl)propane]. A customized cell produced for the measurement of the electrical properties of monomers was manufactured and electrical conductivity and permittivity of resin monomers were measured.

Results. The permittivity of the tested monomers is largely affected by electrical frequency. The large values of permittivity and dielectric losses observed as frequency decreased, indicate a dominant effect of ionic polarization, particularly evident in materials showing the highest conductivity. Permittivity and conductivity of the tested monomers showed a similar behavior, i.e. materials with the lowest permittivity also show small values of conductivity and vice versa.

Significance. The results of the present study revealed a good correlation between electrical properties and Hoy solubility parameters and, in particular, the higher the polar contribution (polar forces plus hydrogen bonding) the higher the permittivity and conductivity. The most relevant outcome of this study is that the electrophoretic mechanism prevails on the electroendoosmotic effect in determining the monomer migration under the application of electric fields.

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1. Introduction

Dentin bonding systems (DBS) allow restorative materials to bond to enamel and dentin [1,2]. Dentin bonding is achieved by infiltrating the substrate via passive diffusion of solvent and DBS monomers into the insoluble demineralized dentin collagen fibril network that is saturated with residual interfibrillar water [1]. The result is the formation of the hybrid layer, a structure composed by DBS monomers, residual solvent, dentin collagen fibrils and hydroxyapatite at different degrees in relation to the type of DBS used [1–3]. In the case of self-etch DBS, residual smear layer particles are embedded within the hybrid layer [2].

Silver nitrate-impregnated resin-bonded specimens analyzed under electron microscopy revealed different degree of nanoleakage (i.e. interfacial nanoporosities within the hybrid layer that are claimed to represent the weakest area of the adhesive interface) due to poor or incomplete resin infiltration of both etch-and-rinse and self-etch (or etch-and-dry) DBS leaving residual interfibrillar water [4,5]. High porosity hybrid layers lead to higher silver uptake along the adhesive interface, and result in reduced immediate bond strength and accelerated degradation [5–7].

The use of electricity has been proposed to facilitate resin monomers impregnation of the dentin [8–11]. Preliminary in vitro studies performed with different prototypes (ElectroBond, Seti, Italy) delivering current intensities ranging from 25 to 175 μA, confirmed that the application of DBS under the influence of an electric field increases bond strengths and reduces interfacial nanoleakage [8–11]. Initially iontophoresis was suggested to increase monomer impregnation, favoring the substitution of water by adhesive monomers [8–11]. However a recent study revealed that DBS monomer migration within an electric field can be affected by several parameters related either to the dentin substrate (buffer pH and ionic strength), or to the electric field (applied voltage), strongly affecting the prevalence of electromigration forces or electroendoosmotic flux (EEO) within the matrix [12]. Electromigration causes the migration of the negatively charged molecules toward the anode and the concurrent migration of mobile cations to the cathode (negative electrode) [13,14], thus determining monomers migration due to the pH-dependent ionization of molecules of weak acids [12]. The second effect, EEO, which is the water movement within organic matrices during electrophoresis as a result of the fixed negative charges and electromigration of positive counterions on the matrix, causes the migration of water and all dissolved substances toward the cathode, irrespective of charge [15,16]. If electromigration is higher than EEO monomers migrate toward the anode, while if electromigration is lower than EEO monomers migrate toward the cathode [12]. Thus monomer migration toward the anode or cathode can be achieved as desired by selective choice of pH and ionic strength of the substrate and the applied electric field [12].

However, despite these findings the interaction between the dentin substrate and electricity, the mechanism of how an electrical field can facilitate impregnation of monomers remains unclear since little is known about the electrical properties of monomers currently used in restorative dentistry (i.e. their electrical conductivity and electrical permittivity). The electrical conductivity describes the ability of a material to transport current when subjected to an electric field. In liquid dielectrics, conductivity is closely correlated to the ionization status of the material and to the electrical mobility of ions and electrons [17].

Permittivity is a physical quantity that describes how an electric field affects a dielectric medium [18]. It is determined by the ability of a material to polarize in response to electric fields, and thus reduce the total electric field inside the material. In general, the response of a solid medium to external fields depends on the frequency of the field. This frequency dependence reflects the fact that material polarization does not respond instantaneously to an applied field due to material inertia [19]. This leads to power losses generated by the polarization process (dielectric losses) and to a phase delay between polarization and electric field. When the applied electric field exhibits a sinusoidal behavior, this delay can be mathematically expressed by considering a complex quantity for the electrical permittivity, $\bar{\varepsilon}$ [20]:

$$\bar{\varepsilon} = \varepsilon' - j\varepsilon'' \tag{1}$$

The real part (ε') and the imaginary part (ε'') of the permittivity are associated with the extent of polarization and (1) by the vacuum permittivity constant $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m.

The aim of the present study was to investigate the electrical conductivity and the electrical permittivity of resin monomers currently used in DBS blends, since such information is not currently available in the literature. Additionally these electrical properties will be correlated to the chemical properties of these monomers, such as their structure and Hoy's solubility parameters [21–24]. The tested null hypothesis was that no correlation exists between electrical conductivity, electrical permittivity and Hoy's solubility parameters.

2. Materials and methods

2.1. *Tested monomers*

TEGDMA (triethylene glycol dimethacrylate), HEMA (2-hydroxyethyl methacrylate), UDMA (urethane dimethacrylate), 2-MP (bis[2-(methacryloyloxy)ethyl] phosphate, TCDM di(hydroxyethyl methacrylate) ester of 5-(2,5-dioxotetrahydrofurfuryl)-3-methyl-3-cyclohexenyl-1,2-dicarboxylic anhydride) and Bis-GMA [2,2-bis(4-2-hydroxy-3-methacryloyloxypropoxyphenyl)propane] were purchased from Sigma Chemical (St Louis, MO, USA) and used without further purification (Table 1).

2.2. *Cell fixture*

A customized cell fixture for the measurement of the electrical properties of monomers was manufactured, as no device was commercially available [25]. In fact, due to the high viscosity of some of these monomers, these liquids are not compatible with commercial measurement cells for liquid dielectrics [26,27]. Moreover, the cell has been specifically designed for