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Probing the neutralization behavior of zwitterionic monomer-containing dental adhesive

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ABSTRACT

Objective. To investigate the polymerization kinetics, neutralization behavior, and mechanical properties of amine-functionalized dental adhesive cured in the presence of zwitterionic monomer, methacryloyloxyethyl phosphorylcholine (MPC).

Methods. The control adhesive was a mixture based on HEMA/BisGMA/2-N-morpholinoethyl methacrylate (MEMA) (40/30/30, w/w/w). The control and experimental formulations containing MPC were characterized with regard to water miscibility of liquid resins, photopolymerization kinetics, water sorption and solubility, dynamic mechanical properties and leachables from the polymers (aged in ethanol). The neutralization behavior of the adhesives was determined by monitoring the pH of lactic acid (LA) solution.

Results. The water miscibility decreased with increasing MPC amount. The water sorption of experimental copolymer specimen was greater than the control. The addition of 8 wt% water led to improved photo-polymerization efficiency for experimental formulations at MPC of 2.5 and 5 wt%, and significant reduction in the cumulative amounts of leached HEMA, BisGMA, and MEMA, i.e. 90, 60 and 50% reduction, respectively. The neutralization rate of MPC-containing adhesive was faster than control. The optimal MPC concentration in the formulations was 5 wt%.

Significance. Incompatibility between MEMA and MPC led to a decrease in water miscibility of the liquid resins. Water (at 8 wt%) in the MPC-containing formulations (2.5–5 wt% MPC) led to higher DC, faster R_p^{max} and significant reduction in leached HEMA, BisGMA, and MEMA. The neutralization rate was enhanced with the addition of MPC in the amine-containing formulation. Promoting the neutralization capability of dentin adhesives could play an important role in reducing recurrent decay at the composite/tooth interface.

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1. Introduction

Resin-based composite is rapidly becoming the most popular dental restorative material and with the global emphasis on the elimination of dental amalgam, it is anticipated that the popularity of composite will continue to increase [1–3]. In spite of its popularity, clinical studies report a failure rate for composite restorations that is double to triple that of amalgam [4]. NIDCR points to an average lifespan of 6–7 years for dental composites [5] and patients at highest risk for decay are particularly susceptible to early failure [6,7].

Since composite is too viscous to bond directly to the tooth, a low viscosity adhesive is used to form the bond between the tooth and composite. Acid-etching provides effective mechanical bonding between enamel and adhesive, but bonding to dentin has been fraught with problems. There are a variety of intrinsic and extrinsic factors that lead to acute and chronic degradation of the adhesive bond to dentin [8–13]. These factors include host-derived enzymes, e.g. matrix metalloproteinases (MMPs) that degrade exposed collagen at the adhesive/dentin (a/d) interface [13]; oral fluids, bacterial and salivary enzymes degrade the adhesive [14]; cariogenic and aciduric bacteria demineralize the tooth structure and the inability of the material to increase the local pH facilitates the outgrowth of more aciduric and cariogenic bacteria [15]. It is anticipated that the outgrowth of more aciduric and cariogenic bacteria would lead to increased acid production at the adhesive/dentin (a/d) interface. The acid could infiltrate the a/d interface—provoking demineralization of the tooth structure and potentially, degradation of the adhesive.

The primary reason that amalgam and composite restorations fail is recurrent caries, i.e. carious lesions on the margins of existing restorations, but the risk of recurrent caries is 3.5 times greater for composite [4]. Recurrent decay is most often localized at the gingival margin of Class II composite restorations and is linked to failure of the bond between the tooth and composite and increased levels of the cariogenic bacterium, *Streptococcus mutans*, at the perimeter of these materials [16–18]. At the vulnerable gingival margin, the adhesive is often the primary barrier between the prepared tooth and surrounding environment [2]. Degradation of the adhesive at the gingival margin leads to gaps at the composite/tooth interface—these gaps will be infiltrated by oral fluids, enzymes and bacteria. The infiltration of these noxious agents at the interface between the composite material and tooth structure will ultimately lead to failure of the restoration.

A dentin adhesive that is capable of neutralizing the acid in this local environment could mitigate the damage associated with oral fluid infiltration. It could play an important role in maintaining the integrity of the a/d bond and the seal at the composite/tooth interface. Reports of increased levels of the cariogenic bacterium, *S. mutans* [16–18] and the observation that the inability of the material to increase the local pH facilitates the outgrowth of more aciduric and cariogenic bacteria [15] highlight the need for materials that could buffer the pH at the microenvironment of the composite/tooth interface [19]. Thus, a dental adhesive that is capable of neutralizing the acid could play an important role in reducing recurrent decay at the vulnerable gingival margin.

The potential of amine-containing dental adhesives to provide buffering as well as the required physical and mechanical properties has been investigated recently [20,21]. Due to the highly crosslinked network structures, the neutralization rate for the bulk polymer was relatively slow, i.e. 4–8 weeks were required to reach neutral pH [20]. While these results are promising, the slow rate of neutralization may offer limited benefit under *in vivo* conditions.

The biocompatible, hydrophilic zwitterionic monomer, e.g. 2-methacryloyloxyethyl phosphorylcholine (MPC), has been used to create protein-repellent surfaces [22–27]. To date, there has been limited investigation of MPC as a co-monomer for dental adhesive development [28–31]. The lack of attention may be related, in part, to the limitations of the zwitterionic functional groups—these groups can bind water molecules more strongly than other hydrophilic monomers via electrostatically induced hydration [30]. The addition of zwitterionic monomer led to adhesive materials with remarkably improved hydrophilicity [32] and strong protein-repellent capability. The bond strength between adhesive and dentin was not compromised with lower MPC concentration in the adhesive formulations [31].

In previous studies from our group [20,21], tertiary amine-functionalized dental adhesive copolymers showed neutralization capabilities in lactic acid solution but, due to the highly crosslinked network structures, the neutralization rate was relatively slow. Understanding the relationship between neutralization kinetics and the crosslinked network is necessary for the development of dental adhesives that can offer buffering of the interfacial micro-environment while also providing the required physicochemical and mechanical properties. The objectives of this study were to investigate the neutralization behavior of dental adhesive incorporating both amine monomer and zwitterionic monomer, MPC. The study tested the hypotheses that incorporating MPC into the amine-containing dental adhesive would: (1) improve the water compatibility; (2) accelerate the rate of neutralization; and (3) not significantly decrease the mechanical properties under wet conditions.

2. Materials and methods

2.1. Materials

2,2-Bis[4-(2-hydroxy-3-methacryloxypropoxy) phenyl]propane (BisGMA), 2-hydroxyethyl methacrylate (HEMA), 2-N-morpholinoethyl methacrylate (MEMA), and 2-methacryloyloxyethyl phosphorylcholine (MPC) were obtained from Sigma-Aldrich (St. Louis, MO) and used as received without further purification as monomers. Camphoroquinone (CQ), ethyl-4-(dimethylamino) benzoate (EDMAB), diphenyliodonium hexafluorophosphate (DPIHP), and L(+)-lactic acid (LA) were obtained from Sigma-Aldrich (St. Louis, MO). All other chemicals were reagent grade and used without further purification.