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Novel antibacterial orthodontic cement containing quaternary ammonium monomer dimethylaminododecyl methacrylate

Mary A.S. Melo [a,*], Junling Wu [a,b,c], Michael D. Weir [a], Hockin H.K. Xu [a,d,e]

[a] Biomaterials & Tissue Engineering Division, Department of Endodontics, Prosthodontics and Operative Dentistry, University of Maryland Dental School, Baltimore, MD 21201, USA
[b] Department of Prosthodontics, School of Stomatology, Shan Dong University, Jinan 250012, China
[c] Shandong Provincial Key Laboratory of Oral Biomedicine, Jinan 250012, China
[d] Center for Stem Cell Biology & Regenerative Medicine, University of Maryland School of Medicine, Baltimore, MD 21201, USA
[e] Department of Mechanical Engineering, University of Maryland, Baltimore County, MD 21250, USA

ARTICLE INFO

Article history:
Received 20 March 2014
Received in revised form
20 June 2014
Accepted 7 July 2014

Keywords:
Antibacterial
Microcosm biofilm
Quaternary ammonium methacrylate
Bond strength
Lactic acid
Metabolic activity

ABSTRACT

Objectives: Demineralized lesions in tooth enamel around orthodontic brackets are caused by acids from cariogenic biofilm. This study aimed to develop a novel antibacterial orthodontic cement by incorporating a quaternary ammonium monomer dimethylaminododecyl methacrylate (DMADDM) into a commercial orthodontic cement, and to investigate the effects on microcosm biofilm response and enamel bond strength.

Methods: DMADDM, a recently-synthetized antibacterial monomer, was incorporated into orthodontic cement at 0%, 1.5%, 3% and 5% mass fractions. Bond strength of brackets to enamel was measured. A microcosm biofilm model was used to measure metabolic activity, lactic acid production, and colony-forming units (CFU) on orthodontic cements.

Results: Shear bond strength was not reduced at 3% DAMDDM ($p > 0.1$), but was slightly reduced at 5% DMADDM, compared to 0% DMADDM. Biofilm viability was substantially inhibited when in contact with orthodontic cement containing 3% DMADDM. Biofilm metabolic activity, lactic acid production, and CFU were much lower on orthodontic cement containing DMADDM than control cement ($p < 0.05$).

Conclusions: Therefore, the novel antibacterial orthodontic cement containing 3% DMADDM inhibited oral biofilms without compromising the enamel bond strength, and is promising to reduce or eliminate demineralization in enamel around orthodontic brackets.

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1. Introduction

The higher incidence of demineralized enamel areas around orthodontic brackets (white spot lesions) has been reported as a prevailing and challenging problem in fixed orthodontic therapy.[1] This widespread situation is alarming and affects more than 60% of patients, counteracting the efforts for caries prevention under orthodontic treatment.[2] Furthermore,

* *Corresponding author*. Tel.: +1 410 706 8705.
E-mail addresses: Mmelo@umaryland.edu, maryannesmelo@yahoo.com (Mary A.S. Melo), hxu@umaryland.edu (Hockin H.K. Xu).
http://dx.doi.org/10.1016/j.jdent.2014.07.006
0300-5712/Published by Elsevier Ltd.

special attention is urgently needed in the use of orthodontic appliances for young patients (pre-adolescents) with a high risk for the development of incipient caries.[3]

The development of initial caries lesions in a relatively short period of time is attributed to prolonged accumulation and retention of bacterial plaques on the enamel surfaces adjacent to the orthodontic appliances which are difficult to be cleaned in tooth brushing.[4] Brackets, metal ligature ties, arch wires, and elastomeric rings lead to increases in biofilm accumulation and elevated levels of cariogenic bacteria,[5] which trigger the enamel demineralization process. White spot lesions can develop quite rapidly in about four weeks, and cavitated caries lesion can occur under continuous net mineral loss. The average orthodontic treatment time in adults and adolescents are usually 2.5 years, which is long enough to cause serious lesions. The development of caries lesions complicates the orthodontic treatment, and it illustrates the great need for oral biofilm control during orthodontic treatments. Moreover, biofilm degradation on resin-based orthodontic adhesives may contribute to premature debonding of the brackets due to the decomposition of the resin matrix by acid from bacteria.

Preventive approaches to avoid the increased caries risk for patients with fixed orthodontic treatment involve fluoride therapy via fluoridated over-the-counter products (such as dentifrices and oral rinses) or the professional topical fluoride applications.[6] However, patient compliance is a limiting factor to achieving a successful outcome. Other strategies that do not depend on patient compliance could be more effective for preventing early demineralization. For example, fluoride-releasing materials, such as glass ionomer cements and fluoride-releasing composite materials can be used as orthodontic bonding agents.[7] However, it was noticed that a major drawback of glass ionomer materials was its low bond strength to dental substrate, resulting in high rates of debonding and bracket failures.[8]

A promising alternative is the development of orthodontic bonding agents with antibacterial properties or microbial-repellent actions.[9] Orthodontic bonding agents are in direct contact with the vulnerable enamel surface and their properties with respect to bacterial adhesion may play a key role on prevention of the starting process of net mineral loss. Preceding reports have suggested the incorporation of antibacterial agents such as nanosilver and nanohydroxyapatite into orthodontic cements to combat cariogenic biofilm.[10,11]

In previous studies, quaternary ammonium monomers successfully promoted antibacterial property in dental primers, including the maintenance of antibacterial effect after being photo-cured.[12] In recent investigations, novel polymers containing quaternary ammonium salts with different features have been synthesized with antibacterial activities.[13,14] Quaternary ammonium monomers (QAMs) present the advantage to be able to copolymerize with the dental resin matrix.[15,16] This strategy forms antibacterial dental resin-based materials that can effectively reduce oral biofilm formation. In this approach, the antibacterial agent is immobilized in the resin and not released or lost over time, thus promoting a durable antibacterial capability to the dental material.[17] Recently, a new quaternary ammonium monomer, dimethylaminododecyl methacrylate (DMADDM) was synthesized.[18] Pilot studies have highlighted the promising results of substantial reductions in biofilm formation over dental materials containing DMADDM. However, there has been no report of developing antibacterial orthodontic bracket cement containing DMADDM. In addition, efforts in producing antibacterial orthodontic cement should not cause adverse effects on the mechanical properties such as the enamel bond strength.

Therefore, the objectives of this study were to develop a novel antibacterial orthodontic bracket cement containing DMADDM, and to investigate the effects of DMADDM mass fraction in orthodontic bracket cement on enamel bond strength and dental plaque microcosm biofilms for the first time. The following hypotheses were tested: (1) DMADDM could be incorporated into a resin-based orthodontic bracket cement without decreasing the enamel bond strength; (2) DMADDM-containing orthodontic adhesive would greatly reduce dental plaque microcosm biofilm growth, metabolic activity, and lactic acid production; and (3) the antibacterial potency is proportional to DMADDM mass fraction in the orthodontic cement.

2. Materials and methods

2.1. *Synthesis of dimethylaminododecyl methacrylate (DMADDM)*

DMADDM has an alkyl chain length of 12 (Fig. 1A) and was recently synthesized via a modified Menschutkin reaction, in which a tertiary amine group was reacted with an organohalide as described previously.[18] A benefit of this reaction is that the reaction products are generated at virtually quantitative amounts and require minimal purification. Briefly, a 20 mL scintillation vial was added with 10 mmol of 1-(dimethylamino)docecane (DMAD, Tokyo Chemical Industry, Tokyo, Japan), 10 mmol of 2-bromoethyl methacrylate (BEMA, Monomer-Polymer and Dajac Labs, Trevose, PA), and 3 g of ethanol. A magnetic stir bar was added, and the vial was capped and stirred at 70 °C for 24 h. After the reaction was complete, the solvent was removed via evaporation. This yielded DMADDM as a clear, viscous liquid.[18] The reaction and products were verified via Fourier transform infrared spectroscopy (FTIR) in a previous study.[14]

2.2. *Preparation of antibacterial orthodontic bracket cement*

DMADDM was incorporated into a commercial orthodontic cement. Transbond XT (3 M Unitek, Monrovia, CA) consisted of silane treated quartz (70–80% by weight), bisphenol-A-diglycidyl ether dimethacrylate (10–20%), bisphenol-A-bis (2-hydroxyethyl) dimethacrylate (5–10%), silane-treated silica (<2%) and diphenyliodonium hexafluorophosphate (<0.2%), according the manufacturer. For enamel shear bond testing, DMADDM was mixed with the orthodontic cement at the following DMADDM/(DMADDM + orthodontic adhesive) mass fractions: 0%, 1.5%, 3% and 5%. They were selected following favourable results of preliminary tests. Therefore, four orthodontic cements were tested for shear bond strength: