DENTAL MATERIALS XXX (2015) XXX.E1–XXX.E13

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Mechanisms of degradation of the hybrid layer in adhesive dentistry and therapeutic agents to improve bond durability—A literature review

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ARTICLE INFO

Article history:
Received 11 May 2015
Received in revised form
19 October 2015
Accepted 30 November 2015
Available online xxx

Keywords:
Collagen
Dentin
Hybrid layer degradation
Metalloproteinases
Cross-linking agent
EDC

ABSTRACT

Objective. Success in adhesive dentistry means long lasting restorations. However, there is substantial evidence that this ideal objective is not always achieved. Current research in this field aims at increasing the durability of resin–dentin bonds. The objective of this paper is to examine the fundamental processes responsible for the aging mechanisms involved in the degradation of resin-bonded interfaces and the potential approaches to prevent and counteract this degradation.

Methods. PubMed searches on the hybrid layer degradation were carried out. Keywords were chosen to assess hybrid layer degradation for providing up-dated information on the basis of scientific coherence with the research objective. Approaches to prevent and counteract this degradation were also reviewed.

Results. 148 peer-review articles in the English language between 1982 and 2015 were reviewed. Literature shows that resin–dentin bond degradation is a complex process, involving the hydrolysis of both the resin and the collagen fibril phases contained within the hybrid layer. Collagen fibers become vulnerable to mechanical and hydraulic fatigue, as well as degradation by host-derived proteases with collagenolytic activity (matrix metalloproteinases and cysteine cathepsins). Inhibition of the collagenolytic activity and the use of cross-linking agents are the two main strategies to increase the resistance of the hybrid layer to enzymatic degradation.

Significance. This review analyzes the issues regarding the durability of the adhesive interface, and the techniques to create stable resin–dentin bonds able to resist the collagenolytic hydrolysis that are currently studied.

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http://dx.doi.org/10.1016/j.dental.2015.11.007
0109-5641/

1. Introduction

Resin–dentin bonding involves a series of topical treatments to dentin that completely changes its physical and chemical properties from being a hydrophilic, crystalline, relatively impermeable acid-labile surface, to one that is more hydrophobic, organic, highly permeable, acid-resistant surface.

When dentin is cut or ground with high-speed drills, a 1–2 μm thick layer of cutting debris is left on the surface, called the smear layer [1]. When the smear layer is removed by acid-etching with 37 wt% phosphoric acid for 15 s, all of the mineral phase of the smear layer and underlying 5 μm of mineralized dentin are solubilized, causing the smear layer to dissolve and exposing the underlying type I collagen fibril meshwork of the dentin matrix.

The space between the collagen fibrils (interfibrillar space) is about 30 ± 11 nm [2]. These spaces serve as diffusion channels for solvated adhesive comonomers to infiltrate around collagen fibrils toward the base of the 5 μm deep, demineralized layer of the collagen matrix (Fig. 1) forming the so-called hybrid layer [3] (Fig. 2).

Unlike typical tissue engineering applications where a synthetic scaffold is designed to be resorbed and replaced by the host's own tissues with 2–3 months, dentin adhesion relies on *in situ* tissue engineering, which is designed to create a resin-enveloped collagen scaffold that, ideally, will remain in place for decades. Nevertheless, the hybrid layer may be degraded over time, leading to failure of the adhesive interface [4,5]. Although the incorporation of hydrophilic and acidic resin monomers has substantially improved the initial bonding of contemporary etch-and-rinse and self-etch adhesives to intrinsically wet dental substrates, potential problems associated with these hydrophilic formulations have been reported in several *in vitro* and *in vivo* studies [6–14]. The failure of the adhesive layer leads to the formation of microgaps that are readily penetrated by pathogens. Bonding failure in the presence of bacteria, esterases [15], and dental plaque biofilm [16] provokes a cascade of events leading to deterioration of the adhesive interface and failure of the composite restoration. Recent studies demonstrated that dental composite restorations continue to show limited clinical service as a result of decay and fracture [17,18] and recurrent decay at the composite-tooth interface has consistently been the primary reason for replacement of composite restorations [19].

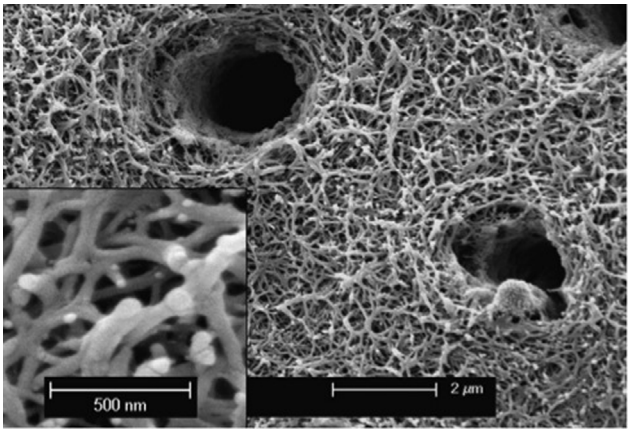

Fig. 1 – Scanning electron micrograph of acid-etched dentin showing two dentinal tubules containing remnants of peritubular dentin matrix. INSERT: High magnification of branching collagen fibrils (ca. 75 nm in diameter) separated by interfibrillar spaces that serve as channels for resin infiltrations during bonding. Reproduced from Pashley et al., Dent Mater 2011;27:1–16, with permission.

We are entering a new era in adhesive dentistry, where resin-bonding to enamel and dentin is beginning to be understood at the nanoscopic level. The long-term success and durability of resin–dentin bonds depends upon the ability of dentists to capitalize on new discoveries being made in adhesive technology.

The objective of this paper is to examine the fundamental processes responsible for the aging mechanisms involved in the degradation of resin-bonded interfaces and the potential approaches to prevent and counteract this degradation. For this purpose, an electronic search was conducted of the PubMed database with different combination of the following search terms: collagen, dentin, hybrid layer degradation, bonding agent, adhesive system, metalloproteinases, cysteine cathepsins, cross-linking agent, EDC. The search was restricted to articles written in English related to dentin collagen degradation. Only articles published in peer-reviewed journals were included. The PubMed search included literature reviews, *in vitro* and *in vivo* studies. Articles written in other languages, without available abstracts, those related to other field were excluded. 148 peer-review articles in the English language between 1982 and 2015 were reviewed.

2. Degradation of the adhesive interface

2.1. *Degradation of the adhesive resin*

Chronic deterioration of the hybrid layer involves hydrolysis and leaching of the adhesive resin that has infiltrated the demineralized dentin matrix [20–22]. Leaching is facilitated by water penetration into the loosely cross-linked or hydrophilic domains of the adhesive. The hydrophilic domains exhibit limited monomer/polymer conversion because of adhesive phase separation [23] and lack of compatibility between the hydrophobic photoinitiator and the hydrophilic phase [24]. The poorly polymerized hydrophilic phase degrades rapidly in the aqueous environment. Resin elution continues to occur while water movement along the length of the hybrid layer becomes more rapid via transport pathways form relatively large water-filled channels [25]. The previously resin-infiltrated collagen matrix is exposed and becomes vulnerable to the attack by proteolytic enzymes [6,26]. The structure of methacrylate adhesives, presenting hydrolytically susceptible groups, such as ester and urethane, as well as hydroxyl, carboxyl, and phosphate groups [27], may be hydrolyzed by chemical and enzymatic degradation in the oral environment [28].

On prolonged exposure of the restoration to oral fluids, water begins to penetrate the resin. Water initially enters the matrix by diffusion into loosely cross-linked or hydrophilic

Please cite this article in press as: Frassetto A, et al. Mechanisms of degradation of the hybrid layer in adhesive dentistry and therapeutic agents to improve bond durability—A literature review. Dent Mater (2015), http://dx.doi.org/10.1016/j.dental.2015.11.007