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REVIEW

Concepts and techniques to improve resin/resin bonding. Literature Review.

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ABSTRACT

The availability of new scientific information about the etiology, diagnosis and treatment of carious lesions and the introduction of reliable adhesive restorative materials substantially reduced the need of extensive tooth preparations. In order to achieve a successful procedure, an adequate bonding interface between old and new composite is required. The aim of this article is to review the concepts and techniques described in the literature for the improvement of resin-resin bonding. Bonding to dentin has been quite difficult to achieve. The difficulties are that dentin's histological structure and chemical composition are very different from those of the enamel. Bonding to dentin requires, besides acid conditioning and the adhesive required for enamel, a primer or dentin bonding agent, which is a hydrophilic, able to penetrate by infiltrating the microscopic spaces of the collagen mesh. The repairing of faulty restorations is a treatment option that has proven to be quite effective and safe, since it presents excellent results over time. For this purpose, different methods for surface treatment have been developed, which has a great effect on the resistance of the reparation bonding. In order to achieve successful bonding between both resins, the following steps are recommended, including: surface roughening, acid etching, silane application, and bonding agent application.
Keywords: *adhesion, resin, bonding, dentin.*

INTRODUCTION

The classical concepts of tooth surface preparation were defended at the beginning of the XX century but these have changed drastically. This transformation in the philosophy has resulted in a more conservative approach for tooth surface preparation. This was not only applied to the basic concepts of retention shape but also to the resistance of the remaining tooth structure. The availability of new scientific information about the etiology, diagnosis and treatment of carious lesions and the introduction of reliable adhesive restorative materials substantially reduced the need of extensive tooth preparations. With the improvements in materials, the indications for resin-based materials have changed progressively from only the anterior segment to also performing resin-based restorations in posterior teeth *(Ritter et al., 2019).*

Despite the innovative improvements throughout the years and long-term stability *(Spyrou et al., 2014)*, composite resin restorations tend to have a limited lifespan and failures often appear because of diverse oral environment conditions *(Whitehouse et al., 2009).* This might lead to fractures, abrasions, discoloration, marginal leakage and lack of mimicry. Because of this, the clinician must decide whether to replace the restoration completely or simply repair it. In 2009, *Whitehouse* defined minimally invasive dentistry as the discipline based on scientific evidence that aims to preserve as much tissue as possible, in order to improve the patient's quality of life and oral health. The restoration of an affected dental piece weakens it, particularly if more tooth structure than necessary is retrieved *(Whitehouse et al., 2009)*.

Total replacement of a restoration might weaken healthy tooth structure due to attrition or even harm pulp tissue causing irreversible damage *(Koç-Vural et al., 2017)*.

A repairing procedure offers a minimally invasive alternative for completing the replacement of a restoration, since it reduces dental trauma on the pulp, avoids the removal of healthy tissue by expanding the preparation and has a significantly lower cost for the patient.

In order to achieve a successful procedure, an adequate bonding interface between old and new composite is required. The aim of this article is to review the concepts and techniques described in the literature for the improvement of resin-resin bonding.

BONDING OF COMPOSITE RESIN TO TOOTH STRUCTURES

Bonding to dentin has been quite difficult to achieve. The difficulties are that dentin's histological structure and chemical composition are very different from those of the enamel. Dentin is composed of 70% inorganic, 20% organic, and 10% water. Dentin morphology is tube-like. These tubules present a greater diameter near the pulp and their lumen contains the odontoblastic prolongation. Each tubule is surrounded by a hyper mineralized dentin zone named peritubular dentin and the less mineralized dentin, located between the tubules, is called intertubular dentin. The number of tubules decreases from 45,000 per mm^2 near the pulp to about 20,000 per mm^2 in the dentin-enamel junction *(Mella, 2006)*.

When caries appear, dentin is able to transform into another entity called "reparative dentin". The layer of dentinal mud, produced by cavity preparation, diminishes dentin permeability, occludes the holes of the dentinal tubules and avoids contact between adhesive and substrate, thus cancelling the key prerequisite for bonding. All of the previous factors cause that the application of adhesive techniques differs between enamel and dentin. Bonding to dentin requires, besides acid conditioning and the adhesive required for enamel, a primer or dentin bonding agent, which is a hydrophilic, able to penetrate by infiltrating the microscopic spaces of the collagen mesh *(Mella, 2006)*.

Resin tags, i.e., the portion of resin that is introduced into demineralized dentinal tubules, have an impressive appearance but provide little or none retention unless they are firmly bonded to the walls of the dentinal tubules, which is still in dispute. It is also argued that in vivo tags are shorter than in vitro ones because dentinal fluid reduces the penetration of the adhesive *(Mella, 2006*).

The bonding to dentin accomplished with resinous materials is due to the formation of a layer called "hybrid layer", which is composed of adhesive *(low-viscosity resinous material)* and collagen of the demineralized dentin matrix. Its integrity depends on an adequate polymerization and penetration of this adhesive. Therefore, micromechanical retention of the resin infiltrating the dentin's collagen structure is achieved *(Mella, 2006)*.

Thus, bond strength of composite resin to dentin depends on the individual sum of the adhesive strength provided by *(Mella, 2006)*:

a. Bonding Surface,

b. Formation of resin tags, provided that they are closely bonded to the walls of the dentinal tubules, and

c. Generation of hybrid layer at the expense of resin infiltration into the dentin's collagen matrix.

BONDING OF COMPOSITE RESIN TO COMPOSITE RESIN

The repairing of faulty restorations is a treatment option that has proven to be quite effective and safe, since it presents excellent results over time *(Fernández et al., 2015)*. For this purpose, different methods for surface treatment have been developed, which has a great effect on the resistance of the reparation bonding. Adhesive resistance of composite to composite restorations diminishes in 25% to 80% compared with its original resistance *(Koç-Vural et al., 2017)*. Some factors that are potentially significant in the creation of interfaces with great bond strength are: mechanical roughing of the substrate's surface, concentration and type of filler particles and resin composition. Bond strength between old and new composite can be improved by increasing superficial roughness of the resin to be repaired, thus improving mechanical bonding and using unfilled bonding resins for increasing surface moistening and chemical bonding *(Fernández et al., 2015)*.

The variations of this procedure depend on whether the restoration has been recently cured or if the restoration is too old. When the restoration has been recently placed and has already polymerized, it still might present an inhibited layer of resin on the surface. It is possible to add more resin directly, since it can essentially be an excellent bonding substrate. Moreover, after polishing the restoration, it is possible to repair a defect by adding more material. A polymerized and polished restoration has more than 50% of the non-reactive methacrylate groups, which is why it can polymerize again with other layers of material *(Philips, 2005)*.

Methacrylate groups that haven't reacted decrease in restorations over time. Consequently, the greater degree of intertwining reduces the fresh monomer's ability of penetrating the matrix. Bond resistance between the original material and the new one decreases in direct proportion to the time between polymerization and addition of new resin. This is also due to the fact that polished surfaces expose filler particles that aren't surrounded by silane. Therefore, the filler surface cannot be chemically bonded to the new layer of composite resin *(Philips, 2005)*.

When using incremental technique in bonding of composite resin to composite resin, it is usual to place thin layers of resin in incremental manner, thus polymerizing each one of them. By observing each polymerized layer, a superficial layer named "inhibited layer" can be viewed, which is a very thin partially polymerized layer that contains monomers that didn't polymerized due to oxygen *(Mella, 2006; Henostroza, 2006)*. The reason for this is that free radicals produced during polymerization appear more reactive with oxygen than with monomer, so oxygen acts as polymerization inhibitor *(Mella, 2006)*. By placing a second layer of resin and photopolymerizing it, the inhibited layer acts as a bond between both of them, creating a chemical bond between the different increments, thus integrating the whole as one body. At the end of the restoration, the inhibited layer is retrieved with polishing *(Mella, 2006)*.

BONDING OF COMPOSITE RESIN TO COMPOSITE RESIN IN RESTORATIONS REPAIR

This technique is based on achieving a bond between old and new composite resin, when the substrate is resin that has been exposed to oral environment or has been polished, thus losing a part of the polymerization-inhibited layer, responsible for chemical bonding *(Mella, 2006)*. Therefore, it is necessary to create an adequate bonding interface for which different methods have been created, in order to treat the surface to bond to *(Wahsh & Ghallab, 2015)*. However, there isn't a standard protocol or established material for treating the surface of an old resin before repair.

Even though surface treatment isn't the focus of clinical studies, there are many in vitro studies with different surface treatments, mechanical as well as chemical, to improve repairing, regardless of the type, it remains important to perform both *(Valente et al., 2016)*. Mechanical surface treatment seeks to increase the bonding area creating retentions. This is achieved by wearing away or cutting the surface of the primary resin, so that inorganic filler particles are exposed. This promotes mechanical bonding between both resins, increasing superficial roughness to boost bonding *(Lewis et al., 1998)*. Some options for mechanical treatment are the use of aluminum oxide, disk polishing, milling with diamond or tungsten tips, Er:YAG laser irradiation and acid etching with orto-phosphoric or hydrofluoric acid. Some options for chemical surface treatment, aimed at improving chemical bonding between resinous materials, are the use of bonding agents such as silane and different types of adhesives *(Wahsh & Ghallab, 2015; Amo & Botella, 2004)*. The best results for preparing the surface of a primary resin have emerged from the use of abrasive aluminum oxide stream with adhesive agents.

In order to achieve successful bonding between both resins, the following steps are recommended *(Mella, 2006)*:

1. Surface roughening

It can be achieved with sandpaper or diamond discs on the substrate. On the other hand, air abrasion is considered a viable technique that significantly increases bond strength in composite restoration *(Öztas et al., 2003)*. Other surface treatments included roughening of the composite resin with 500-grit sandpaper discs; abrasion, using 50 micron aluminum oxide; silica coating, which was also performed by abrasion with silica coated aluminum oxide air stream, all of which are used in contemporary restorative dentistry. It was proven that previous treatment with aluminum oxide and silica coated aluminum oxide provides better bonding values compared to the use of mechanical roughening methods such as diamond milling or sandpaper discs. The latter obtained better bonding values compared to not using any surface roughening method *(Kansow et al., 2004)*.

Some researchers, upon performing observations with scanning electron microscope and resistance measurements on the adhesive layer, concluded that mechanical interlocking is the key factor for improving the resistance of the restoration and bonding between two resin matrices *(Papacchini et al., 2007)*. Aluminum oxide is a metallic oxide that is produced from the reaction between a metal and oxygen. It is also known as basic oxide for its ability to form hydroxides when reacting to water. According to the instructions of Danville Materials' Microetcher, 90 micron brown aluminum oxide is suggested for the quick removal of cements in metals and for surface treatment of a metal when performing abrasion, while 50 micron white aluminum oxide is suggested for general procedures of metallic and non-metallic surface bonding, without discoloring ceramics or composite resin *(Kinyanjui, 2019)*.

2. Acid etching

Different modifications have been added to this technique, the types and concentrations of acids used to prepare the enamel and its preparation time have varied. New polymers have appeared, the form of polymerization of the material has changed radically and dentin acid etching has been introduced as a routine clinical procedure. Thus, the current "total etching" technique basically uses phosphoric acid *(H3PO4)* in variable concentrations, between 10% and 50%; the most used is 37% during 15 to 30 seconds *(Ceballos et al., 2002)*. Some authors mention up to 1 minute, following manufacturer's indications, because if that time is exceeded, an excessive denaturation of proteins is produced *(Sol et al., 2005)*. Afterwards, residue rinsing, quick drying and application of resin that will form a hybrid layer with the dentin collagen and tags into the microretentions produced by the enamel *(Aguilera et al., 2001)*. The core of the acid etching technique remains constant from its beginning: acid is applied to create a surface that is rich in microporosities on the enamel producing a dissolution of the top section or periphery of the prisms, in order to remove dentinal mud and opening the dentinal tubules, allowing the enamel microporosities, the exposed collagen and the outer portion of the dentinal tubules to act as retention to the adhesive resin, thus ensuring the sealing of the tubules and the obturation margins. On enamel, bonding is achieved by preparing the dry surface through the application of phosphoric acid for 15 seconds *(Sol et al., 2005)*. The flat surface of untreated enamel changes drastically when phosphoric acid etching is performed. The latter manages to dissolve and penetrate the inter- and intra-prismatic zones, so that an undermined area is created, producing demineralization patterns that are typical on the enamel.

3. Silane application

Silane is a chemical compound whose formula is SiH4 *(Mella, 2006)*. It is a hydrolizable monomer substance that competes with water on a glass surface. As a result, it forms a covalent bond between the bonding agent's silicon and the hydroxyl group's oxygen on ceramic cementations, thus providing chemical bonding. Silanes act as a bridge to bring organic and inorganic materials together. A general formula for the coupling agent of functional silane is Y-*(CH2)*, Si-*(OR)*3. Y is an organofunctional group that reacts to the organic matrix, CH2 is a ligand group and O is an alkoxy group. Silane functional coupling agents have to be activated by hydrolysis before bonding through OH groups to the substrate's surface *(Velezmoro, 2014)*.

Silanes are a good coupling agent since they promote bonding between composite resin and dental restorative materials. Nonetheless, they also have some limitations such as their application on non-silicon-based restorative materials, for example zirconia, aluminum oxide, metal and metal alloys. Currently, not only silane coupling agents are used for the promotion of composite resin bonding for dental restorative materials, but there are other coupling agents such as phosphate esters *(MDP)* added to self-adhesive and adhesive cements. Phosphate esters can bond directly to the hydroxyl groups of the non-silanized ceramic surface, such as zirconia. Additionally, the application of this coupling agent in bonding of composite resin to ceramic reflects better hydrolytic stability than the use of silane coupling agents *(Velezmoro, 2014)*.

4. Bonding agent application

When bonding is performed on the enamel surface, it is not necessary to have any different composition than the liquid of the composite paste, since the nature of the enamel and the little amount of water in its composition enable it to penetrate the irregularities created by the action of the acid on the enamel prism structure and produce the desired bonding. If the indicated precautions are followed and the technical steps are adequately performed, it is possible to generate enamel bonding that reaches values that surpass 15 MPa. Consequently, marginal sealing and mechanical integration of both structures are guaranteed *(Macchi, 2014)*. Dentin, on the other hand, is a dental tissue that is less calcified than enamel, there are hydroxyapatite crystals but in less amount and not oriented in rod shape but included in a weave of collagen fibers. If that surface is treated with an acid, only part of the hydroxyapatite is removed in search of an exposed collagen matrix, which is not an appropriate surface for bringing restorative material. Moreover, the dentin structure contains more humidity, especially a vital tooth, which makes it incompatible with a non-similar substance, such as the monomers that compose reinforced resin for restorations, hence needing a bifunctional molecule that contains a hydrophilic and hydrophobic component. Another factor that hinders interaction between adhesives and dentin is the presence of a detritus layer called smear layer, which results from the cutting procedure. This layer, along with the sectioned substrate remains, saliva, bacteria, fragments of the abrasive and oil, joins the intertubular dentin and penetrates the dentinal tubules forming smear plugs *(Christensen, 2002)*. This layer reduces dentin permeability, thus diminishing the flow of dentinal fluid *(Dourado & Reis, 2006)*.

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