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Methods to Establish a Reliable Bond with Dentin: A Narrative Review

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ABSTRACT

Developing a durable, strong bond with dentin remains a significant challenge due to the complex structure of dentin and the physiological and pathological modifications undergoes over time. This narrative review examines the causes of bond failure and explores methods to enhance bond durability. Relevant articles were obtained from electronic databases such as PubMed, ScienceDirect and Google Scholar. The search used MeSH terms/keywords such as Dentin Bonding, Longevity, Bond strength, Bond Failure and bond durability. The inclusion criteria were articles published in English between the years 2012 and April 2024. This review examines dentin boning, the main causes of bonding failure and suggested methods to enhance bonding to dentin. The aim of this article is to provide a comprehensive overview of problems associated with dentin bonding and the suggested methods to overcome those problems in everyday dental practice.

KEYWORDS: Dentin Bonding, Longevity, Bond strength, Bond Failure, Bond durability

1. INTRODUCTION

Developing a durable strong bond with dentin has been always challenging to obtain. This may be attributed to the complex structure of dentin. The complexity is related to the great variations in biochemistry, morphology and mechanical properties of different dentin types, ages, different depths and between crown and root dentin. In addition, there are physiologic or pathologic modifications affecting dentin over time [1, 2]. Many morphological and structural differences between superficial and deep dentin exist affecting the quality of the formed hybrid layer which affects the bonding ability of adhesive systems. Deep dentin bonding is limited due to less intertubular dentin and collagen fibrils and tubules number that increases toward the pulp chamber. Moreover, there is an increase of the intrinsic wetness and moisture affecting the final bond strength. In addition, it has been reported that bonding to deep dentin is more susceptible to degradation compared to superficial dentin after aging [3].

Hybrid layer degradation is the main cause affecting durability of the formed bond. Degradation may occur due to hydrolysis of resin components caused by sorption and usage of hydrophilic adhesives which acts as semi permeable membranes allowing water movement over the bonded interface even after polymerization [4]. Improving dentin bonding can be achieved through modifications to the physical properties of the bonding agent or enhancing the dentin surface to facilitate the application of the adhesive agent [5]. This narrative review analyses the causes of bond failure and methods to enhance bond durability aiming to have a stable durable bond.

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2. METHODOLOGY

To conduct this narrative review on methods to enhance bond durability a search strategy was conducted in May 2024 across many electronic databases including PubMed, Science Direct and Google Scholar. Papers and articles were searched from 2012 to 2024 using MeSH term/keywords such as 'Dentin Bonding', 'Longevity', 'Bond strength', 'Bond Failure' and 'Bond durability'. Only articles published in English were selected. Initially, 100 articles were selected based on their titles and abstracts. Only full-text articles were selected to conduct this review. After full text evaluation, removing duplicates, conducting a quality assessment of selected articles based on PRISMA checklist and application of the eligibility criteria, 20 articles were selected to conduct the review (see Fig. 1.)

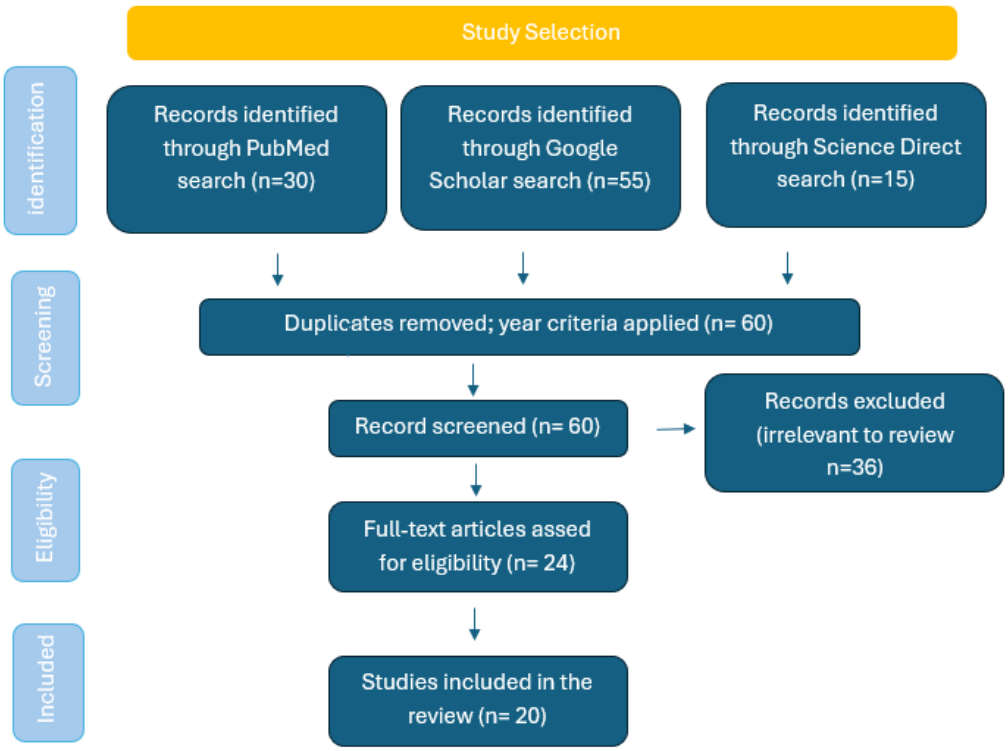

Fig. 1: Flowchart showing the articles selection process to conduct this review.

3. BONDING ABILITY OF DENTIN TISSUE

Histologically, dentin is composed of approximately 50% of dentin is inorganic minerals, 30% is organic portion composed of type I collagen and non-collagenous proteins and approximately 20% water.6 Intertubular dentin is composed of well-organized mineralized collagen matrix. Dentinal tubules, have an inverted cone shape, narrow from dentin-pulp toward dentin-enamel junction (DEJ). Dentinal tubules are filled with a highly mineralized peritubular dentin which increase toward the DEJ. The amount of tubular and intertubular dentin differs according to cavity depth. Size and patency of dentinal tubules also varies according to cavity depth affecting dentin permeability and overall intrinsic wetness. Increased moisture leads to a lower bond strength especially in deep dentin. There is an agreement that

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immediate dentin bond strength in deep dentin is generally lower 30-50% that superficial dentin [4, 6].

Dentin nature whether sound or carious dentin also affects the bond strength of dentin. Immediate bond strength of caries-affected dentin and caries-infected dentin is less than sound dentin. This is attributed to the decrease in mineral content associated with caries progression leading to increased porosity and changes in organic structure of dentin affecting the final bond strength [7]. Caries demineralization increase wetness of dentin. Moreover, lower mineral content leads to deeper matrix demineralization during usage of phosphoric acid or acidic monomers. Thus, more water resides in exposed collagen matrix affecting the strength and durability at dentin-resin interface [7, 8].

4. IDEAL DENTIN BONDING REQUIREMENTS

The ideal dentin bonding system should form a strong, durable bond between the restorative material and the dentin surface, mimicking the natural bond of dentin-enamel junctions (See Fig. 2).

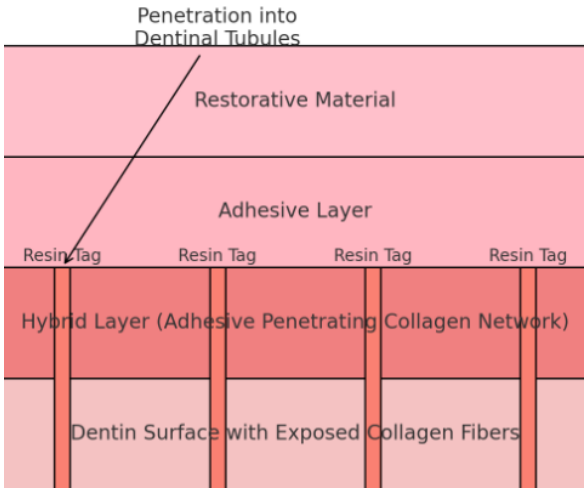

Fig. 2: Diagram describe the ideal situation of bonding to dentin.

This bond should resist mechanical stresses, provide a good seal to prevent microleakage, and be biocompatible with the surrounding tissues [1]. Bonding to dentin is achieved through:

4.1 Hybrid Layer Formation: The ideal bond involves the formation of a hybrid layer where the adhesive resin penetrates the collagen network of demineralized dentin. This results in a strong mechanical interlocking and resin infiltration.

4.2 Resin Tag Formation: They are formed when the adhesive flows into the dentinal tubules. These tags contribute to the micromechanical retention of the bond.

4.3 Good Wetting and Penetration: The adhesive system must effectively wet the dentin surface and penetrate deeply into the demineralized collagen matrix to ensure a strong bond.

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4.4 Chemical Bonding: Ideal dentin bonding may also involve chemical bonds between functional groups in the adhesive and the components of the dentin (e.g., calcium in hydroxyapatite).

4.5 Minimal Technique Sensitivity: The bonding process should have minimal technique sensitivity, ensuring consistent results even with slight variations in the clinical procedure.

4.6 Durable and Stable Bond: The bond should remain stable over time, resisting hydrolytic degradation and maintaining its strength in the moist oral environment.

5. CAUSES OF BOND FAILURE

One of the principle causes of decrease dentin bond strength is hydrolytic degradation affecting organic collagen, adhesive system, or both. It should be noted that water is required to maintain collagen matrix to allow proper infiltration of resin monomer. However, increased moisture leads to separation between hydrophobic and hydrophilic monomers. This separation results in irregular resin infiltration of resin monomer leaving voids or water blisters at resin-collagen interface [9]. Moreover, increased moisture decreases monomer conversion. Reduced longevity of the interface, increased enzymatic degradation of the exposed collagen, and hydrolysis of the weakly polymerized adhesive are the results of inadequate resin infiltration and conversion [10].

5.1. Adhesive Resin Degradation

Hydrophilic adhesives are required to achieve dentin wet bonding to ensure adequate hybridization of exposed collagen. However, degradation occurs over time due to constant exposure to water in the mouth. This water weakens the adhesive bond between the filling and the tooth by dissolving the adhesive material and creating friction. The situation is worsened by limitations in the bonding materials themselves [11]. Dental adhesives are made of a combination of components that attract water (hydrophilic) and repel water (hydrophobic). Unfortunately, these components don't always mix evenly and fully cure, leaving behind weak spots that water can easily exploit. Even the initiators used to cure the adhesive can hinder the process, as they may struggle to fully harden the water-loving parts of the adhesive. On top of this, everyday wear and tear from temperature changes, chewing, and enzymes can further accelerate the breakdown of the filling [12].

5.2. Collagen Degradation

Several studies have documented the presence of collagenolytic activity within dentin. Even in sterile environments, dentin's collagen can degrade over time due to intrinsic matrix proteases [12, 13]. Pashley *et al.*, confirmed this by finding a significant decrease in gelatinolytic and collagenolytic activity when dentin specimens were treated with enzyme inhibitors. As a result, researchers have focused on understanding the role of these enzymes in the degradation of the hybrid layer (HL), identifying the specific enzymes involved, their location within the dentin, and potential methods to reduce or eliminate their activity. Among these endogenous enzymes, matrix metalloproteinases and cysteine cathepsins are particularly noteworthy [13].

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6. METHODS TO ENHANCE BOND DURABILITY

6.1. Caries-Infected Dentin Removal

Generally, bonding to caries affected dentin shows lower bond strength compared to sound dentin. The decrease in bond strength with carious dentin is attributed to the decreased in mineral content and reduced crystallinity in the mineral phase compared to normal dentin affecting hybridization due to increased moisture. Carious dentin also shows less hardness and reduced number of MDP-dentin bonding sites affecting chemical bonding with dental adhesives. Carious dentin is composed of two layers, outer layer termed infected dentin and inner layer termed affected dentin. Caries infected dentin is composed of irreversible denatured collagen fibers that cannot be remineralized. While, caries-affected dentin is minimally loaded with bacteria, partially demineralized and physiologically mineralizable. Therefore, many researchers advocate utilization of partial caries removal to avoid pulp exposure. (ref) Caries infected dentin removal in addition to proper marginal sealing are required to arrest caries progression and provide a minimum required bond strength [14].

6.2. Chemical Bonding

One of the methods to maintain collagen hybrid layer is usage of functional adhesive monomers that forms chemical bond with hydroxyapatite calcium ions. These functional monomers such as 10-MDP stabilize part of the hydroxyapatite around collagen keeping the collagenic enzymes inactive and minimize collagen degradation. However, this bond strength shows reduction in bond strength overtime. This may be related to incomplete penetration of resin monomers in the deepest part of the hybrid layer [15].

6.3. Enzyme Inhibitors

Many enzymatic inhibitors were used to slow or eliminate collagen degradation maintaining bond strength. Matrix Metalloproteinases (MMPs) shows ability in the degradation process affecting hybrid layer and subsequent the longevity of resin-dentin bond. Different mechanisms are available to inhibit the action of MMPs such as chelating cations, collagen crosslinking and competitive inhibition for active sites of the collagen molecule. One of the most popular enzyme inhibitors is chlorohexidine due to its ability to inhibit collagenases located in dentin. However, usage of chlorhexidine requires a separate priming step before adhesive application. Other MMPs inhibitors include Benzalkonium chloride (BAC), tetracyclines and Polymerizable quaternary ammonium methacrylates (QAMs) [16, 17].

6.4. Deproteinization

Dentin deproteinization is a process that aims to remove the organic part of the dentin smear layer aiming to increase mineral/organic ratio and altering its chemical composition, to be nearly like etched enamel, and changing surface energy of dentin resulting in a more stable interface [18]. Some authors termed this process a “reverse hybrid layer” where the collagen is not infiltrated with resin monomers, but the resin monomers occupy the original spaces of collagen. This showed an increase in infiltration of resin monomer with subsequent increase in the dentin bond strength [19]. Sodium hypochlorite has been considered the gold standard for dentin deproteinization by many researchers. Sodium hypochlorite has the ability to increase the surface roughness which in turn shows better mechanical retention of resin tags. It can also

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increase dentin surface energy which improves the penetration and compatibility of hydrophobic monomers to etched dentin [20]. However, Sodium hypochlorite has several drawbacks such as the formation of a fragility zone as well as its cytotoxic effect, bad taste and odor. It was also reported that using NaOCl may affect the bonding procedure negatively as it may remove some of the dentin mineral content making dentin much weaker than normal. Therefore, other deproteinizing agents were investigated such as papain and bromelain. Both materials showed an ability to breakdown proteins including collagen improving dentin surface for adhesion.

6.5. Biomodification of Hybrid Layer

The goal of modern restorative therapy is to replace damaged tissue in order to restore tooth form and function, as pulpal cells are unable to reconstruct, or repair destroyed dental tissue. Nonetheless, the emergence of biomodification techniques—such as enhanced collagen cross-linking and biomimetic remineralization—offers a new approach to adhesive dentistry by chemically altering the tissue to improve its stability and characteristics [21].

6.5.1 Cross linking

Intermolecular and intermicro-fibrillar cross-linking can provide a solution to improve stability and strength of dentin collagen matrix. Quantity and cross-linking type determine the ability to resist biodegradation. By changing the collagen molecule's enzyme binding site or by allosterically silencing collagenolytic enzymes, cross-linking can also have an impact on enzymatic destruction. The cross-linkers tested include natural and synthetic cross-linkers. Natural cross-linkers include glutaraldehyde, genipin and chitosan. While synthetic cross-linkers include such as formaldehyde, epoxy compounds, synthetic glutaraldehyde and silane coupling agents. Synthetic cross-linkers offer precision and controlled properties, natural cross-linkers often provide superior biocompatibility, reduced toxicity, and better mimicry of natural processes, which can be particularly advantageous in dentin adhesion applications [22, 23].

6.5.2 Biomimetic Remineralization

Polyanions, such as polyacrylic acid or polyaspartic acid, attach to collagen during biomimetic remineralization of the hybrid layer. They function as analogues of dentin phosphoproteins, which control physiological mineralization by permitting calcium binding and encouraging apatite nucleation. A "therapeutic" composite covering the hybrid layer uses amorphous calcium phosphate as an apatite source. Biomimetic remineralization shows considerable promise in remineralizing hybrid layers or dentin that resembles caries, according to in vitro research. Additionally, these experiments have shown that the hybrid layer's mechanical characteristics and bond strength are preserved over time [24, 25].

6.5.3 Limiting Hydrophilic Adhesives

Hydrophilic monomers are used in dental adhesives to enhance the bonding to moist dentin surfaces. However, they come with certain disadvantages that can impact the durability of dental adhesives. One commonly used hydrophilic monomer is Hydroxyethyl Methacrylate (HEMA). HEMA suffer from their high sensitivity to water that led to increased porosity in the adhesive layer compromising bond durability. This high affinity to water leads to increase hydration affecting the polymerization process with subsequent decrease in mechanical strength of resin composite restoration. To overcome the disadvantages of hydrophilic

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monomers, less hydrophilic HEMA-Free adhesives have been introduced. HEMA-free adhesives represent an innovative approach to overcome degradation. By eliminating the HEMA component, these novel adhesives aim to improve the durability of the bond between the filling and the tooth, potentially reducing post-operative sensitivity and extending the lifespan of the restoration. However, ongoing research is crucial to definitively determine whether HEMA-free alternatives offer equivalent or superior performance compared to traditional HEMA-containing adhesives. Long-term clinical trials are needed to assess their effectiveness in real-world scenarios and ensure they provide a reliable and long-lasting solution for patients [26, 27].

6.6. Ethanol Wet Bonding

Resin-dentin bonds will remain stable for as long as hybrid layer degradation is prevented by MMP-inhibitors or MMP-inhibitor-conjugated resin monomers, unless a more proactive alternative becomes clinically available. Along the resin-dentin interface, there is still an issue with a water-rich zone that is rich in hydrophilic monomers that are either polymerized or unpolymerized. The loss of integrity resulting from the adhesive component's breakdown will persist even if the collagen matrix is retained. This could be the cause of the gradual reduction of link strength even in cases where enzyme inhibition is effective [28].

The goal of ethanol-wet bonding is to employ ethanol to let more hydrophobic monomers penetrate dentin by dehydrating demineralized dentin matrices. Hydrophobic monomer infiltration reduces resin plasticization, water sorption, solubility, and plasticization; it may also stop or lessen collagen's enzymatic hydrolysis. When combined, these would increase the bond's endurance [29]. However, ethanol-wet bonding is currently not possible in clinical settings due to technique sensitivity and typically lengthy treatment times; hence, more accessible and repeatable methods or materials must be created for daily use [30].

7. CONCLUSION

Resin composite restoration clinical effectiveness is complex to evaluate. Carious dentin is not always the best substrate for the development of long-lasting hybrid layers, as was previously mentioned. Thus, the minimal needs are the meticulous removal of carious dentin along the cavity borders and the removal of at least caries-infected (soft) dentin.

Collagenolytic enzymes may be inhibited with chlorhexidine. While long-term clinical performance trials are still missing and chlorhexidine may not be flawless, no side effects have been recorded either. Chlorhexidine treatment is already advised by several manufacturers as an optional step following acid etching or prior to applying SE primer. It is reasonable to infer that chlorhexidine (applied separately or integrated into adhesive systems) can and should be used until other methods are demonstrated to be safe and at least as effective.

Another appealing option is provided by employing hydrophobic adhesives, an easier method would be to combine cross-linkers with ethanol-wet bonding, or a related chemical. Hydrophobic monomers should be able to permeate the collagen matrix if cross-linkers are able to stiffen the exposed collagen matrix enough to prevent shrinkage after rapid and complete evacuation of water. Collagen matrix degradation should be effectively prevented by increased resistance and enzyme inhibition with cross-linkers. The adhesive component of the hybrid layer should also be preserved with little to no hydrophilic monomers. But the ultimate

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objective should still be biomimetic remineralization, which brings the hybrid layer collagen back to its initial mineralized condition or very near to it.

8. RECOMMENDATIONS

The aim of adhesive dentistry is to enhance the durability of bond with dentin through:

- Finding more methods to Address chemical and physical challenges.
- Conducting more long-term clinical trials to enhance and evaluate the suggested methods to increase bond durability.

CONFLICT OF INTEREST

There was no conflict of interest

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None declared

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