wjpmr, 2025, 11(10), 193-200

SJIF Impact Factor: 6.842

WORLD JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH

www.wjpmr.com

Review Article

ISSN (O): 2455-3301

ISSN (P): 3051-2557

REDEFINING DENTIN BONDING INTERFACES: ADVANCES IN ETCHING TECHNIQUES, SURFACE MODIFIERS, AND MONOMER CHEMISTRY

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Article Received on 12/08/2025 **Article Revised on 01/09/2025** **Article Accepted on 22/09/2025**

ABSTRACT

Adhesive dentistry is rapidly expanding, with significant efforts to enhance the mechanical and bonding characteristics of adhesive materials. There has been significant research carried out worldwide to develop materials which are versatile, easy to use, and reliable. Recent Advancements include improvements in etching strategies and the incorporation of various monomers, nanoparticles, antibacterial agents, and biomolecules. These innovations are aimed to achieve simple, reliable bonding to the tooth substrate without compromising the properties of individual materials. Despite these advancements, there is a lack of comprehensive reviews that provide a narrative overview of the latest developments in dental adhesives. This review paper aims to bridge this gap by providing an overarching review of the latest advancements in the field of dentin bonding agents.

KEYWORDS: Adhesives, etching, bonding, monomers, bioactive materials, composite resins.

INTRODUCTION

In recent years, significant advancements have been made in adhesive dentistry, especially in improving the mechanical strength and bonding capabilities of resin-based dental adhesives. Researchers have explored various methods to increase versatility, such as incorporating functional monomers and silanes, modifying compositions to chemically bond to the tooth structures, and restorative materials, thereby facilitating multimode applications. These new materials are developed with the aim of being more user-friendly, requiring fewer steps, and being less technique sensitive. However, they must also ensure reliability and long-lasting bonds with various substrates. To meet these challenges, ongoing research and development focus on introducing new chemical components and techniques into dental adhesives.[1]

In contemporary adhesive dentistry, it is essential to achieve both optimal functional and aesthetic outcomes while minimizing the removal of tooth structure. A considerable amount of scientific research has demonstrated the excellent clinical results of composite restorations, which depend on the creation of hybrid layers (HLs) through either the traditional 3-step etch-and-rinse (ER) or the 2-step self-etch (SE) systems.[2] About a decade ago, single bottle/syringe systems were introduced to simplify, enhance reliability, and increase versatility in dental procedures. The chemical composition of these materials has undergone substantial changes with the incorporation of various new molecules. Furthermore, enhancements have been made at different stages of the adhesive process to improve their overall effectiveness.[1] Given the ongoing advancements in dentin bonding agents, dental clinicians may experience confusion and uncertainty regarding their true reliability and versatility. To address these concerns, this article will explore the properties of materials and techniques currently prevalent in the field of adhesive dentistry.

ADVANCEMENTS IN ETCHING STRATEGIES

Etching is essential in adhesive dentistry, as it creates micromechanical resin tags that help retain adhesive systems. While phosphoric acid etching has a long history of successful clinical use, it comes with several limitations. Erhardt M.C. and colleagues found that 37% phosphoric acid etching led to a statistically significant increase in shear bond strength, but on dentin, it had a negative impact on bond strength values.[3] To overcome the limitations of phosphoric acid (PA), new etching formulations and techniques have been developed. While an ideal etchant has yet to be found, various innovative formulations have shown promising results. Cadenaro M. et al have classified alternative etching methods on the basis of formulation of the conditioner and the etching strategy used.[1]

MATERIALS CAUSING PARTIAL DEMINARALISATION

PHOSPHORIC ACID ESTER MONOMER (PPM)

Chemically, phosphoric acid contains three hydroxyl groups, one of which is replaced by an ester in the phosphoric acid ester monomer (PPM). This monomer has the ability to simultaneously demineralize and bond to substrates. PPM-based materials are less aggressive than traditional phosphoric acid etching on dentin.[4] Wong J et al. compared various enamel etching strategies with reduced etching times to assess their impact on the bonding effectiveness of universal adhesives. They concluded that PPM etching was the least effective in enhancing bond strength.[2]

POLYALKENOIC ACID (PLA)

Polyalkenoic acids, which include polyacrylic, polyitaconic, and polymaleic acids, are a group of complex organic acids typically used for cavity conditioning in glass-ionomer cement restorations. These acids promote the formation of surface irregularities and form insoluble salts with calcium, facilitating a chemical bond between the glass ionomer cement and the carboxy groups of polyalkenoic acid. A study by Ling Zhang et al. showed that PLA etching resulted in more durable bonds for glass ionomer cements than phosphoric acid etching when both micromechanical and chemical bonding mechanisms were used.[5] However, based on various global research findings, it can be concluded that surface conditioning with PLA does not significantly increase bond strength values.

MULTI ETCHANT(YAMAKIN)

To overcome the shortcomings of the conventional materials, novel materials have been tried to achieve the desired demineralization of the tooth. These formulations primarily consist of phosphoric acid, the functional monomer M-TEG-P (methacryloiloxy tetraethylene glycol dihydrogen phosphate), thickening agents, a dye, and purified water. They are designed to bond effectively with enamel, dentin, and zirconia.[2] G.A.F. Silva et al. suggested that Multi Etchant (Yamakin) may be useful for bonding highly translucent zirconia by improving the cleaning efficiency of the intaglio surface, thus aiding in the formation of strong chemical bonds. However, there is insufficient evidence regarding the mechanical and optical properties of this new material, indicating the need for further research.[6]

SELF-LIMITING MATERIALS

Conditioning the tooth surface is a critical step in adhesive dentistry. They aid in creating a dentin surface that are ideal for receiving resin- based adhesive agent. The adhesion process involves conditioning dentin with an acid etchant, which demineralizes the collagen-rich organic matrix to facilitate the infiltration of adhesive resin. During this process, a denuded collagen layer may form at the base of the hybrid layer, making it vulnerable to degradation by matrix metalloproteinases (MMPs), which compromises bonding efficiency. To address this issue, various strategies have been explored. Earlier studies attempted to incorporate MMP inhibitors into phosphoric acid etchants. Although these approaches showed some promise, they did not fully meet expectations. As a result, the development of an etchant capable of dissolving the inorganic content of dentin, reducing nanoleakage, and inhibiting MMP activity is crucial for achieving improved dentin treatment outcomes. This has led to the introduction of the experimental Zirconium Oxynitrate (ZON) conditioner.[7]

Experimental Zirconiuim Oxynitrate (ZON) Conditioner (Ivoclar)

Zirconium oxynitrate, commonly utilized in applied chemistry and as a radiopacifying agent in endodontic cement, has recently gained attention for its potential as an enamel etchant. Studies indicate that when combined with different adhesive systems, $ZrO(NO_3)_2$ enhances bonding effectiveness.[8]

Chenmin Yao et al. examined the bonding effectiveness and durability to enamel using three new etchants. They used Enamel Conditioner (EC, Shofu), Multi Etchant (ME, Yamakin), and a metal salt-based ZON etchant (ZON, Ivoclar Vivadent: ZrO(NO3)2), as alternatives to traditional phosphoric acid etchants. The researchers found that ME did not achieve the same enamel bonding effectiveness as phosphoric acid, probably because it’s mildly acidic and has higher hydrophilicity. The effectiveness of EC and ZON was similar to that of phosphoric acid, indicating their potential as viable alternatives for enamel bonding.[9]

BIOMODIFYING AGENTS

Etch-37BAC (BISCO)

Antibacterial agents are chemicals that interact with bacteria to inhibit their growth. To improve the longevity of dental restorations, various antibacterial agents are being incorporated into restorative materials, with their effects on strength and durability being actively studied.

The main types of antibacterial agents used in dental materials include

- Leachable agents: Benzalkonium chloride (BAC) and chlorhexidine, which gradually release antibacterial substances.
- Polymerizable agents: 12-methacryloyloxydodecylpyridinium bromide (MDPB), which integrates into the resin matrix without leaching.
- Fillers: Nano-silver (Ag), copper iodide (CuI), and zinc oxide (ZnO), which are water-insoluble.

Among leachable agents, BAC and chlorhexidine are widely used. BAC's antibacterial effect stems from its amphiphilic nature, which allows it to disrupt bacterial membranes. However, a key drawback of leachable agents is the "burst effect"—a rapid initial release of antibacterial substances—leading to a decline in antimicrobial activity over time.

BAC is stable in acidic environments and is incorporated at a concentration of 1% into phosphoric acid. Products like EtCH-37a with BAC and UNI-ETCHa with BAC have shown bacterial inhibition without compromising bond strength. Additionally, BAC can inhibit matrix metalloproteinases (MMPs), helping to preserve the dentin-resin bonded interface.[10]

Santos, F.P. et al. studied the effects of 1% benzalkonium chloride-containing acid on the dentin-resin bond strength and nanoleakage of an etch-and-rinse adhesive, both immediately and after one year. (All Bond 3, Bisco). They concluded that adding 1% benzalkonium chloride to the acid conditioner could improve the long-term steadiness of collagen fibrils encompasses in the hybrid layer, without requiring additional steps in the bonding protocol.[11]

2% Chlorhexidine Digluconate

Etch-and-rinse (ER) and self-etch (SE) adhesive systems are the primary techniques used to create a hybrid layer (HL) at the resin-dentin interface, with HL thickness varying based on the etching approach. However, this layer remains prone to degradation due to resin hydrolysis and collagen demineralization.

Research by Shadman N. et al. found that chlorhexidine digluconate effectively prevented long-term bond strength loss without affecting immediate shear bond strength.[12] Similarly, Boaru M. et al. reported that applying a 2% chlorhexidine solution before a universal adhesive, whether using SE or ER methods, did not compromise the adhesive interface even under cariogenic conditions.[13]

2% Proanthocyanidins (PAC) From Grape Seed Extract

PAC, a plant-derived acidic cross-linking agent rich in polyphenolic compounds, has the ability to demineralize dentin surfaces. When dentinal collagen is treated with PAC, it shows significant improvements in mechanical and biological properties. Although PAC acts as an ultra-mild conditioner on root dentin, it does not significantly enhance bond strength. PAC has minimal effects on the crosslinking of dentinal collagen but can stabilize the partially demineralized organic matrix while preserving the original arrangement of the mineral phase. This stabilization promotes ion uptake and reactivity while strengthening collagen-mineral phase interactions, leading to increased mineral density and enhanced biomechanical properties.[14]

Chitosan

In dentistry, chitosan is extensively used in the treatment periodontal lesions, bone repair, endodontics, enamel remineralization, and enhancing adhesive infiltration and resin-dentin bond strength. Typically, 0.1 g of chitosan (75%-85% deacetylated, 50-190 kDa; MilliporeSigma) is dissolved in 0.2 wt% acetic acid for use. This biopolymer helps reduce collagen matrix degradation caused due to metalloproteinases. Chitosan is derived from chitin, a copolymer found in crustacean shells, fungi, and insects. It can crosslink with dentin collagen, strengthening fibrils against degradation and reducing matrix metalloproteinase (MMP) activity. Paschoini VL et al. investigated the effects of dentin pre-treatment with chitosan in combination with etch-and-rinse and self-etch adhesive systems. Their findings showed that chitosan improved the bond strength of the adhesive interface. Additionally, they reported no significant difference between immediate and long-term microtensile bond strength (μTBS) values.[15]

Zhou et al. studied the bonding effectiveness of EDTA-chitosan, phosphoric acid, and SE-Bond. They concluded that the EDTA-chitosan extrafibrillar demineralization strategy provides enhanced bonding strength and durability with reduced cytotoxicity by preserving intrafibrillar minerals.[16]

BCE: β-tricalcium phosphate (TCP)

TCP is resorbable and is extensively in the field of bone regeneration. They exist in two polymorphic phases: α and β. In dentistry, both α-TCP and β-TCP are widely used for various clinical applications. They are also utilized in toothpastes for enamel remineralization, in varnishes to prevent enamel demineralization, and are incorporated in adhesive agents to augment their properties.

α-TCP and β-TCP have shown promising results in vital pulp therapy, the treatment of periodontal defects, and the preservation of alveolar bone for implant placement. AlRefeai MH et al. discovered that adding β-TCP nanoparticles significantly enhanced the microtensile bond strength (μTBS) of adhesives. The incorporation of β-TCP filler particles facilitated effective dentin interaction, as demonstrated by the formation of a hybrid layer and resin tags.[17] Similarly, Al-Qahtani A.S et al. studied the effects of adding 5% and 10% tricalcium phosphate and found that incorporating these concentrations of β-TCP particles led to an increase in shear bond strength values.[18]

Lasers

Lasers have appeared as an alternate strategy in adhesive dentistry. They have played a key role in enamel etching. They cause minimum damage to tooth structure and have acceptable bond strength values. Lasers are painless, vibrationless and do not alter the surface temperature of the teeth. Among the various family of lasers used, Erbium family of lasers is the most recommended for adhesive dentistry. Erbium-doped yttrium-aluminum-garnet (Er:YAG) and erbium-chromium yttrium-scandium-gallium-garnet (Er,Cr:YSGG) lasers, operating at different wavelengths, are used for enamel etching. The Er:YAG laser emits at 2940 nm, while the Er, Cr:YSGG laser emits at 2780 nm—both wavelengths aligning with peak absorption in water and hydroxyapatite. This makes them effective as etching adhesives for enamel treatment. A meta-analysis by Jiang T et al. found no significant difference between Er:YAG laser etching and phosphoric acid etching in achieving optimal shear bond strength to enamel. When Er, Cr:YSGG was used there was a reduction in SBS values. They concluded that, when compared to conventional acid etch technique, erbium lasers showed no significant difference in the SBS values.[19]

Air Particle Abrasion (APA)

APA was introduced to dentistry in the 1940's. Their diverse application include cavity preparation, prophylaxis and removal of surface stains, selective caries removal and surface polishing or roughening. It uses a uses a high-pressure, focused particle stream, propelled by compressed air, to treat surfaces. Particles like sodium bicarbonate, glycine, or aluminum oxide are chosen based on the application.

Airborne particle abrasion (APA) increases the surface area available for micromechanical retention of adhesives and is commonly used for cleaning, pretreatment, and surface preparation before composite restorations. However, despite its benefits, APA can create surface porosities and microcracks, potentially weakening indirect restorations.

Lima V.P. et al. conducted a systematic review and meta-analysis on the effects of APA with aluminum oxide particles on the bond strength of composite resins. Their findings indicated that APA did not negatively impact the bond strength of resin-based materials to dentin. Notably, in some cases, immediate bond strength improved when 0.30 µm particles were applied at 0.5 bar air pressure. Furthermore, the duration of APA had no significant effect on bond strength values, reinforcing its safety and effectiveness for dentin bonding.[20]

PROGRESS IN THE COMPOSITION OF DENTIN BONDING AGENTS

PROGRESS IN MONOMERS

G-IEMA

Recently, novel hyper-branched dendrimers have emerged as promising candidates for dental materials. G-IEMA is a potential monomer for creating Bis-GMA-free adhesive systems, offering good solubility, reduced polymerization shrinkage, lower water sorption, and efficient double bond conversion (21). Vasconcelos e Cruz J et al. investigated dentin adhesion efficacy of two universal adhesives (UA) each mixed with conventional Bis-GMA, and another with G-IEMA. Their findings showed that G-IEMA significantly enhanced bond conversion rates, minimized polymerization shrinkage, and increased dentin bond strength. Current findings suggest that replacing Bis-GMA with G-IEMA could result in a Bis-GMA-free universal adhesive system with comparable dentin bond strength, regardless of the application protocol.[22]

Acryl Amide Based Monomers

2-Hydroxyethyl methacrylate (HEMA) is a hydrophilic monomer commonly used in adhesives. However, despite its versatility, HEMA has several drawbacks, including a lack of contribution to the polymerization process, increased water retention, and potential cytotoxicity. To overcome the drawbacks of HEMA, Hydroxyethyl Acrylamide (HEAA) has recently been proposed as a potential alternative to 2-hydroxyethyl methacrylate (HEMA). FAM-201 is a monomer used in photographic technology. It has unique properties such as light curable, water soluble, hydrophilic and is stable across a wide range of pH. This eliminates the need for HEMA as a co-solvent. M.H. Ahmad et al. studied the use of acrylamides in universal adhesives and found that FAM-201 can replace HEMA, whereas HEAA reduced the bonding ability of universal adhesives.[23]

10-methacryloyloxydecyl dihydrogen phosphate (10-MDP)

Incorporating functional monomers into dental adhesive systems enhances chemical interactions with dental substrates, resulting in stronger and more durable bonds compared to micromechanical adhesion alone. These monomers have a polar chemical structure that promotes adhesion while protecting collagen fibers by forming MDP-calcium salts, which contribute to a stable adhesive interface.

One such monomer, 10-MDP, establishes a strong and lasting interaction with hydroxyapatite by forming insoluble salts that prevent collagen fiber collapse. The superficial dissolution of hydroxyapatite occurs due to the reaction between MDP and hydroxyapatite, leading to MDP adsorption and the subsequent deposition of MDP-Ca salts. These salts exhibit lower solubility than those formed by other functional monomers, reinforcing adhesive stability.

10-MDP-containing adhesives have demonstrated exceptional stability, with a low dissolution rate of their calcium salts in water. However, cytotoxicity studies remain inconclusive regarding their effects on dental pulp, as replicating clinical conditions in laboratory settings poses challenges. Research by Kim E.C et al. indicated that at minimal toxic concentrations, 10-MDP triggered an exaggerated inflammatory response and suppressed odontoblastic differentiation in dental pulp cells.[24]

To maximize bonding effectiveness, the mode of application is critical. For optimal results, selective enamel etching combined with a scrubbing motion during application enhances monomer infiltration, ensuring a stable bond. Adhering to manufacturer guidelines facilitates penetration and hybridization, promoting MDP-Ca compound formation, securing collagen fibrils, and improving adhesive longevity.[25]

Dipentaerythritol Penta-Acrylate Phosphate (PENTA-P)

In recent years, extensive research has focused on incorporating phosphate ester monomers to enhance the bonding of methacrylate-based resin composites to yttria-stabilized tetragonal zirconia polycrystals (Y-TZP). This bonding mechanism relies on a silane-like coupling process driven by hydroxylation-based chemistry.

PENTA has been widely used in adhesives for bonding methacrylate resins to tooth substrates, showing promising results comparable to those achieved with MDP-containing adhesives. Ying Chen et al. investigated the potential of PENTA as an alternative for bonding methacrylate-based resins to Y-TZP and concluded that PENTA facilitates resin bonding through chemical interactions with zirconia. However, further studies indicated that while increasing PENTA concentration enhances its binding affinity with zirconia, it does not significantly affect overall bonding efficacy (26).

Glycero-Phosphate Dimethacrylate (GPDM)

GPDM was one of the first chemical compounds introduced for bonding to human dentin. Initially incorporated into etch-and-rinse adhesives like OptiBond FL, it has more recently been utilized as a functional monomer in self-etch adhesives, such as OptiBond XTR (Kerr). In vitro studies have demonstrated that GPDM provides strong bonding to both enamel and dentin.

Yoshihara et al. found that dentin treated with MDP was less hydrophilic compared to dentin treated with GPDM. Additionally, GPDM was easily rinsed off with water, whereas MDP remained bound to hydroxyapatite (HAp), highlighting differences in their adhesion mechanisms.[27]

MF8P

The novel fluoro-carbon functional monomer 6-methacryloxy-2,2,3,3,4,4,5,5-octafluorohexyl dihydrogen phosphate (MF8P; Kuraray Noritake Dental Inc., Tokyo, Japan) exhibits characteristics similar to those of 10-MDP, likely due to the strong chemical bond between fluorine and carbon. Because of its ability to achieve favourable bond strength, MF8P is a promising candidate as a functional monomer for bonding applications.[28]

Chlorhexidine

Restoration failure can result from both operator and material factors. The durability of composite restorations is often compromised by the collapse of the hybrid layer, which lies between the dentin collagen and adhesive resin. Khabadze et al. concluded that the hybrid layer is degraded due to the enzymatic activity of matrix metalloproteinases (MMPs).[29] Rayar et al. found that applying 2% chlorhexidine gluconate for 60 seconds significantly improved shear bond strength and enhanced the durability of the bonding agent interface in both total-etch and self-etch systems.[30] Similarly, Deniz et al. reported that a 30-second application of chlorhexidine during immediate dentin sealing with a universal adhesive system increased the shear bond strength of dentin to resin cement.[31]

Based on these findings, it can be concluded that applying chlorhexidine to the tooth surface before using a universal adhesive system does not negatively affect the adhesive interface, even under cariogenic attack conditions.[13]

Silver Nanoparticles

With the advent of nanotechnology in dentistry, various nanoparticles such as silica, zirconia, amorphous calcium phosphate, hydroxyapatite, titanium dioxide, zinc oxide, nano-clay, and silver have been incorporated which enhance the mechanical and antibacterial properties of dental adhesives. A study by Wang J et al. explored the effects of silver nanoparticles on dentin bond strength and their antibacterial activity against *Streptococcus mutans (S. mutans).* The researchers found that adhesive agents incorporating silver nanoparticles displayed significant antibacterial activity against *S. mutans*, while also preventing bond strength deterioration. Importantly, the incorporation of silver nanoparticles did not interfere with the bonding properties of universal self-etch adhesives.[32]

Magnetic Nanoparticle-Containing Adhesive

In an innovative approach, a nanoparticle-incorporated adhesive controlled by magnetic forces was developed to enhance material delivery to the pulp and improve adhesive penetration into dentin. While this material lacked bactericidal and remineralization properties, it was salinized with a monolayer of vinyl groups to form a covalent bond with the resin matrix. This advancement significantly improved bond strength, reduced biofilm metabolic activity and lactic acid production, and decreased biofilm colony-forming units (CFU) by four logs. Additionally, it raised the biofilm pH above 6.5, contributing to a more favourable environment for dental health. Consequently, this novel magnetic nanoparticle-containing adhesive offers multiple benefits and holds promises for various dental applications, enhancing bonded restorations and inhibiting secondary caries.[33]

Quaternary Ammonium (QA) Compounds

To improve the longevity of restorations, different antibacterial agents are being integrated into dental bonding agents. These agents inhibit bacterial growth by targeting residual bacteria in the tooth cavity and along the margins, thus reducing the risk of secondary caries. Efforts to develop adhesives with antibacterial properties have led to the incorporation of substances like chlorhexidine, glutaraldehyde, and nano-sized metallic particles such as silver, titanium, and copper. These additions aim to enhance the adhesive's ability to combat bacterial activity while maintaining effective bonding to dental substrates.

Antibacterial monomers, such as cationic quaternary ammonium compounds (QACs), exhibit antimicrobial activity against a diverse group of microbiological organisms. One notable quaternary ammonium compound (QAC) is 12-methacryloyloxydodecylpyridinium bromide (MDPB), which combines a polymerizable methacrylate group with an antibacterial quaternary ammonium group. An example is Clearfil SE Protect Bond primer, which contains 5% MDPB and demonstrates bacteriostatic activity and anti-adhesion properties against oral streptococci, particularly Streptococcus mutans. Additionally, 2-(Dimethylamino) ethyl methacrylate (DMAEMA) has shown promising antibacterial effects against Staphylococcus aureus and Escherichia coli, offering potential for broad-spectrum antimicrobial action in dental adhesives.[34]

Cetylpyridinium Chloride (CPC) Montmorillonite (Quarternary Ammonium Salt)

CPC is an effective broad-spectrum antibacterial agent that disrupts microbial cell membranes by creating an electric imbalance. This mode of action is not affected by mutations and is effective against various pathogens. CPC is commonly found in mouth rinses and toothpastes and has demonstrated inhibitory effects against Streptococcus mutans biofilm formation. When incorporated into hydrogels, CPC showed relatively short release and increased water sorption.

To overcome this limitation, a novel strategy was developed by Kenya Matsuo et al., who loaded CPC into Montmorillonite clay (CPC-Mont). They found that CPC release from CPC-Mont adhesives was greater and more prolonged than from CPC adhesives alone. Additionally, CPC-Mont adhesives could be replenished with CPC by soaking them in a 2 wt% CPC solution.This technology provides adhesives with antibacterial properties and rechargeability without compromising their bonding potential or increasing cytotoxicity.[35]

Bioactive Glasses (BAGs)

Bioactive glass (BAG), developed by Dr. Larry Hench, has been a focal point for researchers aiming to integrate it into different dental materials. When used as a filler, they release calcium and silica ions, exhibits antibacterial properties, inhibits matrix metalloproteinase (MMP) activity, and also aids in the remineralization of enamel and dentin. It reduces the action of MMP1 and MMP2 on the collagen, which is vital for the remineralization of dentin. A study conducted by Kim HJ et al. assessed the impact of a novel BAG-incorporated dentin adhesive on the permeability of demineralized dentin. The study indicated that the novel adhesive reduced the permeability of demineralized dentin through its remineralization capabilities while also maintaining strong bonding to dentin. This research supports the use of BAG in dentin adhesives as a multifunctional component.[36]

Riboflavin Modified Universal Dentine Adhesive

Collagen crosslinking was introduced to reinforce dentin collagen and improve bonding durability. This crosslinking facilitates inter-diffusion of solvents, hydrophilic monomers. Riboflavin and UVA were used by Cova et al. inside the dentin adhesives. Eusufzai SZ et al. in their systematic review evaluated the effects of riboflavin collagen crosslinkers on bonding efficiency of dental adhesives. The findings revealed a significant improvement in the micro tensile bond strength of dentin when riboflavin-induced cross-linkers were used compared to those without riboflavin.[37]

CONCLUSION

While significant progress has been made in simplifying and enhancing the versatility of dental adhesive materials, their long-term reliability remains uncertain. This uncertainty stems from the lack of extensive randomized clinical trials and real-world data on the performance of these materials. Additionally, there is a noticeable gap between the adhesion improvements observed in laboratory tests and the actual clinical performance of restorations. The field of dental adhesion is transitioning towards developing multifunctional adhesives that integrate desired bond strength, bioactivity, antibacterial properties, and durability. The ongoing research is focused on overcoming hydrolytic degradation and clinical validation of novel formulations.

Conflict of Interest Statement

The authors declare no conflicts of interest.

Acknowledgments

None.

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