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ORTHODONTIC BONDING AGENTS' EFFECTIVENESS AND SAFETY: REVIEW

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ABSTRACT: Orthodontic bonding agents play a crucial role in modern orthodontic treatment, enabling the attachment of brackets and other appliances to teeth. The effectiveness and safety of these bonding agents are of paramount importance to ensure successful orthodontic outcomes and patient satisfaction. This review article provides a comprehensive overview of the various types of bonding agents used in orthodontics, their effectiveness, and safety, while also addressing emerging trends and prospects in the field.

Keywords: Orthodontic bonding agents, orthodontic treatment, brackets, appliances, adhesive systems, bonding agent’s effectiveness

INTRODUCTION

Orthodontics focuses on the alignment and positioning of teeth to enhance both aesthetics and oral health. A key aspect of successful orthodontic treatment is the secure attachment of various appliances to the teeth. Orthodontic bonding agents, often referred to as adhesives, serve as the fundamental bridge that holds these appliances in place.[1] Their effectiveness and safety are pivotal to achieving the desired treatment outcomes while ensuring patient comfort and satisfaction. The world of orthodontic bonding agents has witnessed continuous advancements, driven by the pursuit of greater bonding strength, ease of application, and long-term durability.[2] At the same time, the safety of these agents is a critical concern, as their use can have a direct impact on oral health and patient well-being. Conventional etch and rinse, particularly 5th generation systems, have shown greater stability and longer bonding strength. Phosphoric acid treatment creates well-defined patterns for deep resin penetration, proving highly effective. Both etch and rinse and self-etch methods can achieve optimal bonding strength. The longevity of universal bond strength requires further clinical trials, and in the self-etch technique, its weaker chemical interaction with hydroxyapatite crystals in parallel enamel prisms may not withstand orthodontic forces. Applying two layers of Universal bond (HEMA-Free) with rubbing motion after phosphoric acid treatment can enhance the bond. Clean enamel surfaces and adherence to manufacturer instructions are critical. Thin, even layer thickness is crucial, as thicker or uneven layers may lead to fractures. Temperature control and avoiding adhesive evaporation are important. However, achieving optimal bond strength does not guarantee resistance to orthodontic forces during mastication and long-term treatment, and longevity is not solely determined by high bond strength. More in vitro and in vivo studies are needed to assess the effectiveness of new adhesives like universal bond and eighth-generation bond for long-term orthodontic treatments.[3] This comprehensive review explores the various types of orthodontic bonding agents, their effectiveness, and safety profiles, with a focus on established practices and emerging trends in the field.

ENAMEL STRUCTURE AND ADHESION MECHANISMS IN ORTHODONTICS

Enamel predominantly consists of enamel prisms, except for a thin outer layer that lacks prisms. These prisms extend from the dentin-enamel junction to the outer surface, and their orientation differs between teeth and various surfaces within the same tooth.[4] The response of enamel to acid etching agents is influenced by factors such as crystal orientation within prisms, compositional variations on the tooth's surface, morphological differences between teeth, the presence of prism-less enamel in specific areas, structural defects in the organic and inorganic components of enamel, and the presence of an acquired organic pellicle.[5] After etching, two surface changes occur: a shallow layer of enamel is removed, along with plaque and cuticles, and the remaining enamel surface becomes porous, enabling resin penetration and micromechanical bonding. Adhesion in the context of orthodontics refers to the force that attracts molecules of one substance to another when they are brought into close contact. Adhesion occurs when molecules of unlike substances are attracted to each other, while cohesion is the attraction of molecules of the same substance to each other.[6] The substance causing adhesion is called the adhesive, and the material it adheres to is called the adherend.[7] Two key factors influencing adhesion are wetting and contact angle. For effective adhesion to occur, the adhesive must sufficiently wet the adherend, and this wetting is characterized by the contact angle of a droplet placed on the surface. A smaller contact angle indicates better wetting ability, and a match between the adhesive and adhered surface, as well as a thin adhesive film, contribute to good wetting. The degree of contact angle plays a crucial role in surface wetting. A small contact angle suggests better wetting ability, while a large angle indicates poor wetting, where the liquid does not completely cover the surface. Resin penetrates the tooth surface, forming resin tags within the enamel. Adhesive molecules chemically bond to the inorganic (hydroxyapatite) or organic (collagen) components of the tooth structure. Substances on the tooth surface allow resin monomers to bond mechanically or chemically. Adhesion may result from a combination of the above mechanisms.[8]

ORTHODONTIC BONDING: SURFACE PREPARATION AND CONDITIONING

Achieving a successful orthodontic bond hinges on careful attention to three pivotal components: the condition of the tooth surface, the design of the bracket base, and the selection of an appropriate bonding agent. Orthodontic bonding success hinges on meticulous consideration of three fundamental components: the condition of the tooth surface, the design of the bracket base, and the choice of bonding agent. Orthodontic adhesives should exhibit suitable flow properties and the capacity to infiltrate tooth surfaces without excessive slumping or bracket displacement, often referred to as thixotropy.[9] Furthermore, they need to establish robust bonds with both enamel and dentin, offering immediate and durable adhesion. They should also have the ability to prevent bacterial infiltration and ensure safety and biocompatibility. User-friendliness, minimal setting shrinkage, and a low propensity to absorb water are essential qualities. Additionally, aesthetic appeal, color stability, and overall reliability are vital for orthodontic adhesive effectiveness. Bond strength measures the force per unit area required to separate two bonded surfaces near the adhesive interface and is typically expressed in Mega pascals (MPa). These tests can be either shear or tensile in nature. Tensile strength measures the force needed to stretch a material before it breaks, while shear strength evaluates the maximum shear stress a material can withstand before failing. Ideal orthodontic bond strength typically ranges between 8 and 9 MPa to withstand normal orthodontic forces. Before bonding brackets, it is essential to eliminate the natural organic pellicle that covers teeth.[10] This cleaning process is achieved through pumice, water, or prophylaxis paste using a rubber cup or polishing brush. It is known to double bond strength. Subsequently, the tooth is rinsed with water and thoroughly dried with oil-free air. Untreated enamel is inherently hydrophobic and requires conditioning for successful bonding. Typically, this is accomplished by etching the enamel with various acids, such as phosphoric acid, to create a micro-porous layer on the enamel surface. Phosphoric acid is the conventional choice for enamel etching. The recommended concentration is 37%, applied for about 15 seconds. This should be followed by a meticulous water lavage to remove any contaminant residue. While less popular, studies have suggested that 10% maleic acid can serve as an effective alternative to phosphoric acid for enamel conditioning. After the etching process, a liquid resin is applied to the tooth surface. This resin can penetrate the irregularities created during etching, forming a mechanical interlock between the tooth surface and the bonding material. Primers and coupling agents are substances designed to enhance the substrate's readiness to accept a bond. Primers consist of hydrophilic monomers carried in a solvent (Singh, 2007). Commonly employed monomers include HEMA, Di-methacrylates, 10-MDP, 4-META, Di-HEMA-phosphate, and HEMA-phosphate, as noted by Van Landuyt et al. (2007). The development of bonding primers has seen progress through various generations, enhancing their properties for restorative dentistry.[11] The solvents frequently used in primers are water, ethanol, and acetone. The addition of hydrophilic monomers, along with solvents, significantly improves the wetting characteristics of the primer. The adhesive comprises an unfilled or lightly filled resin, akin in composition to the resin found in composites. However, it incorporates hydrophilic molecules. Enamel conditioning is essential to prepare the enamel surface for effective cement bonding. Over time, the enamel can deteriorate due to exposure to various ions and particles in saliva. This necessitates enamel conditioning before applying cement. Orthophosphoric acid (OPhA) is a commonly used agent to condition enamel for bonding, and it's been employed in dentistry since 1955. However, the recommended concentration has decreased to 37% OPhA for 15 seconds to achieve optimal bonding. OPhA demineralizes enamel, creating microporosities that enhance mechanical adhesion.[12] Still, it's essential to note that OPhA makes enamel more susceptible to dental caries. Air abrasion, laser treatment, and maleic acid have also been explored as alternatives for enamel conditioning.[13]

BRACKET BASE DESIGN AND MATERIAL

The design of the bracket base comes in various forms, including beaded, large-round-pitted, irregular, and metal mesh bases. Different base designs influence bond strength to the attached surface. However, it's challenging to definitively determine which base design is superior because certain designs work well with specific cements but not as effectively with others. With the continuous introduction of new bracket base designs and bonding cements, testing all possible combinations is a complex task. More research is required to understand how different base designs interact with various cements. Another key factor affecting bond strength is the material from which the bracket is made. Ceramic brackets, introduced in the mid-1980s to offer a more esthetic orthodontic option, have gained popularity. Numerous studies have investigated ceramic brackets, but metal brackets remain the standard choice. While ceramic brackets often achieve higher bond strength than metal ones, this isn't always an advantage. Excessively high bond strength can lead to irreversible damage to the bonded surface during bracket removal.[14] Ceramic brackets pose a particular challenge due to their poor ductility, causing forces to transfer to underlying surfaces during debonding. This demands extra care in handling ceramic brackets to avoid complications. The material of the bracket isn't the sole factor in enamel damage during debonding. Tensile forces, although aiding in easier bracket removal, are more likely to result in cohesive failure. This type of failure occurs within the cement layer between the tooth surface and the bracket, often leaving cement remnants after debonding. Improper bracket removal can lead to enamel damage, manifesting as macroscopic or microscopic cracks or fractures. These complications can result in an unsightly appearance, hypersensitivity, and a heightened risk of pulp inflammation and cavities. Therefore, careful consideration of bracket material and debonding techniques is crucial in orthodontic practice.[15]

SCIENTIFIC CLASSIFICATION OF MODERN ADHESIVES

As an integral component of orthodontic treatment, the quest for optimizing bracket bonding has led to advancements in adhesive systems through various generations. First generation bonding agents: Developed in the 1960s, these agents used N-phenyl-glycine-glycidyl methacrylate (Npg-GMA) as a surface-active co-monomer to promote adhesion by chelating with surface calcium. Second generation bonding agents: These agents, primarily phenyl phosphorous esters, interacted with calcium through phosphate groups. Third generation bonding agents: Introduced in the late 1980s, they involved priming before applying the bonding agent, offering advantages such as higher bond strengths and reduced micro-leakage. Developed in the early '90s, they featured etching and priming with acetone or ethanol. Fifth generation bonding agents Emerged in the mid-1990s, these one-component systems combined primer and adhesive agents, exhibiting good adhesion to various surfaces. Sixth generation bonding agents: Introduced in the early 2000s, they featured a no-etch, no-rinse, no-cure approach. Seventh generation bonding agents: These "all-in-one adhesives" simplified the procedure by combining etching, priming, and bonding in a single step. Eighth generation bonding agents: Represented by Futura bond DC, they provided high bond strength, moisture tolerance, and fluoride content. Three-step etch and rinse adhesive systems. Two-steps etch and rinse adhesive systems simplified the procedure by combining primer and bonding agent into a single solution. Self-etching systems reduced the number of steps while considering factors like initial pH and hydrophilicity.[16,17]

UNIVERSAL ADHESIVE SYSTEMS

A significant breakthrough in adhesive dentistry emerged with the introduction of universal adhesives, a recent innovation adopted in clinical practice since 2011. These versatile products, often referred to as "multi-mode" or "multi-purpose" adhesives, exhibit remarkable flexibility. They can function both as self-etch (SE) and etch-and-rinse (ER) adhesives, enabling SE application on dentin and ER application on enamel, a technique commonly known as "selective enamel etching."[18] Universal adhesives possess the capability to bond various materials, including methacrylate-based restoratives, cements, and sealants, to a wide range of substrates, such as dentin, enamel, glass ionomer, metals, alumina, zirconia, and others. The mechanism behind universal adhesive systems is underpinned by several key principles. Notably, they contain 10-MDP (and/or other monomers) capable of forming ionic bonds with hydroxyapatite through Nano layering, setting them apart from traditional one-step self-etch adhesives. The stable calcium-phosphate salts formed by 10-MDP do not lead to significant decalcification and offer enhanced water stability. Active application of adhesives with 10-MDP intensifies Nano layering, increasing contact with hydroxyapatite crystals and bolstering bonding strength. It is important to note that there is reduced Nano layering in enamel due to the parallel orientation of hydroxyapatite crystals, making enamel less receptive to chemical interaction with 10-MDP. Studies have shown that phosphoric acid pre-etching and double-layer application of universal adhesives can enhance early-phase enamel bond strength. While conventional 'etch and rinse' and 'self-etch' adhesives exhibit higher shear bond strength, they also cause more enamel damage compared to universal adhesives. Applying universal adhesives in accordance with the manufacturer's recommendations ensures a satisfactory balance between bond strength and enamel preservation.[19,20]

OTHER TYPES OF BONDING

Bonding orthodontic brackets to ceramic surfaces presents challenges, as ceramics are resistant to acids. Hydrofluoric acid (HFA) has traditionally been used to etch ceramic surfaces, but its corrosive and toxic nature raises concerns.[21] Orthophosphoric acid (OPhA) and lasers have emerged as alternatives, with studies suggesting their effectiveness while causing less damage to ceramic. Air abrasion with specific conditions and certain chemical agents like Monobond Etch & Prime have also been explored. Bonding orthodontic appliances to resin composite restorations or laminate veneers presents its challenges. Various conditioning methods, such as acid etching, mechanical approaches, and chemical techniques, have been tested. The choice of conditioning method depends on the type of composite used. Roughening the composite surface with a bur is one effective method, especially for ceramic brackets. While silane application is commonly used, it might not always be necessary. Fewer studies have explored conditioning methods for amalgam and gold. For amalgam, air abrasion and laser treatment have shown promise. Gold surfaces are often prepared using air abrasion with specific conditions. Tin plating and the use of metal primers on gold surfaces have yielded mixed results. Adjusting the curing time for resin adhesive can enhance bond strength.[22,23]

REVIEW OF LITERATURE

Orthodontic treatment often involves bonding brackets to tooth surfaces, and the choice of surface conditioning method plays a crucial role in the success of this procedure. Various studies have explored different conditioning techniques to enhance the bond strength of orthodontic brackets and to minimize potential enamel demineralization. Paschos and colleagues conducted a study to assess the effectiveness of five bonding agents in preventing enamel demineralization during orthodontic treatment. They utilized artificial caries induction and quantification methods to evaluate lesion depth and mineral loss. The resin-modified glass ionomer cement, specifically Fuji Ortho LC, demonstrated the lowest lesion depth and mineral loss, suggesting its potential in minimizing the adverse effects of orthodontic treatment on enamel. This study also highlighted the utility of cone-beam microtomography for evaluating subsurface lesions.[24]
Orthodontic bond failure is a common problem, and the success of adhesive systems depends on several factors, including technique sensitivity and material-related factors. Both in vivo and in vitro studies face limitations in closely simulating the oral environment, where factors like saliva contamination, mastication-related stresses, decalcification, and adhesive degradation can affect bond longevity. Furthermore, storage conditions and shelf life can influence material properties, such as wettability and bond strength. Various surface conditioning techniques can be impacted differently by storage conditions. The choice of surface conditioning methods for different materials, including enamel, ceramic, composite, amalgam, and gold, is critical for achieving effective orthodontic bonding. The use of hydrofluoric acid (HFA) has traditionally

been common for ceramic surfaces but concerns about its corrosiveness and toxicity have prompted exploration of alternative methods. In some cases, the choice between 9.6% and 5% HFA may not significantly affect bond strength. While surface area is a consideration for bond strength, surface architecture may play a more crucial role in achieving effective bonding. Exposing hydroxyl ions within the ceramic surface is essential for chemical bonding to silane coupling agents. Therefore, the adequacy of conditioning methods may rely on their ability to expose these hydroxyl ions. It is crucial to consider how different materials and bonding agents interact when choosing a surface conditioning method. Determining the maximal bond strength for orthodontic brackets is essential, and previous figures such as 6–8 MPa may not be entirely accurate or reliable. Tensile and shear bond strengths should not be confused, and it's important to identify the forces brackets are subjected to during orthodontic treatment accurately. The value for the maximum intraoral shear bond strength of orthodontic brackets is still under investigation, and further research is needed to provide a more precise reference. While in vitro studies provide valuable insights into surface conditioning methods, they have limitations in replicating the complexity of the oral environment. Fewer studies are conducted in vivo, where clinical practices and environmental factors come into play. Clinical studies are essential to validate the findings from laboratory experiments.[1,17,24]

CONCLUSION

Orthodontic bonding agents have evolved significantly over the years, improving the effectiveness and safety of orthodontic treatment. Careful consideration of the type of bonding agent, their application techniques, and safety profiles is vital for successful outcomes and patient satisfaction. As advancements continue to shape the field of orthodontics, orthodontists should stay abreast of the latest developments to provide the best care for their patients.

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