WEP Warwick Evans Publishing

International Journal of Materials Science and Technology Studies

ISSN: 3006-7693 (Print), ISSN: 3006-3744 (Online) | Volume 4, Number 2, Year 2025
DOI: https://doi.org/10.62051/ijmsts.v4n2.05
Journal homepage: https://wepub.org/index.php/IJMSTS/index

A Review of the Development and Clinical Application Progress of Dental Adhesive Materials

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ABSTRACT

Dental adhesive materials are one of the core technologies in modern restorative dentistry. Their development has evolved from mechanical retention to chemical bonding, and from single function to multi-functional composites. This article reviews the development history of dental adhesive materials, including advancements in etch-and-rinse techniques, self-etch adhesive systems, and universal adhesives. It also explores their clinical application progress in various fields such as caries restoration, aesthetic restoration, and implant restoration. Furthermore, the article analyzes the current limitations of adhesive materials and future development trends, providing references for clinical selection and research.

KEYWORDS

Dental adhesive materials; Etch-and-rinse techniques; Restoration

1. INTRODUCTION

Dental adhesive materials are functional materials capable of firmly bonding restorations such as composite resin, ceramics, metals, etc. to tooth structures. Since Buonocore introduced the acid-etch technique in the 1950s, adhesive materials have undergone multiple innovations, evolving from early mechanical bonding to today's combined chemical-mechanical bonding, significantly improving the long-term success rate of restorations. [1] This article systematically reviews their development history and discusses the latest progress in clinical applications.

2. THE CHARACTERISTICS OF HYALURONIC ACID DEVELOPMENT HISTORY OF DENTAL ADHESIVE MATERIALS

2.1. Chemical structure First-Generation Adhesive Systems (1950s-1970s)

Buonocore (1955) first proposed using phosphoric acid to Buonocore, in his groundbreaking work published in 1955, was the first to propose the innovative technique of utilizing phosphoric acid to etch the surface of tooth enamel. This method was aimed at significantly enhancing the bond strength between the resin material and the tooth structure, thereby laying a solid and foundational cornerstone for the development of modern adhesive dental technology. During this initial stage, the adhesive materials developed were specifically designed and effective only for use on enamel surfaces. Unfortunately, their performance was notably subpar when applied to dentin, the inner layer of the tooth, which posed significant limitations in their broader clinical applications. This initial phase, despite its limitations, marked a pivotal step forward in the evolution of dental adhesive systems. etch tooth enamel to enhance the bond strength of resin, laying the foundation for modern adhesive technology. Adhesives in this stage were only applicable to enamel and performed poorly on dentin.

2.2. Second- to Fourth-Generation Adhesive Systems (1980s-1990s)

Second Generation: This phase marked the introduction of hydrophobic resins, such as Bis-GMA, into dental adhesive systems. However, despite this advancement, the bonding effectiveness to dentin remained significantly unsatisfactory, failing to meet the desired clinical standards as reported by Nakabayashi et al. in their 1982 study. [2] The limitations in achieving a robust dentin bond highlighted the need for further innovations in adhesive technology.

Third Generation: A significant leap was made with the adoption of the "Total-Etch" technique, which involved the simultaneous treatment of both enamel and dentin surfaces. This method was complemented by the incorporation of hydrophilic monomers, such as HEMA, aimed at enhancing the wettability of dentin. The improved wettability facilitated better infiltration of the adhesive into the dentinal tubules, thereby enhancing the bond strength. This approach was notably detailed by anca in his 1992 research, [3] marking a pivotal improvement in dental adhesive strategies.

Fourth Generation: The fourth generation represented a cornerstone in dental adhesive technology with the establishment of the "Hybrid Layer" concept. This innovative approach achieved high-strength bonding through a meticulously designed three-step process. The first step involved etching the tooth surface to create a micro-retentive pattern. The second step was the application of a primer, which penetrated the etched surfaces and facilitated the bonding process. The final step was the application of adhesive resin, which bonded securely to both the primer-treated enamel and dentin, creating a robust hybrid layer. This comprehensive method was extensively elaborated by Fusayama in 1993, setting a new standard for dental bonding procedures and significantly improving clinical outcomes.

2.3. Self-Etch Adhesive Systems (2000s-Present)

Self-Etch Adhesives combine etching and priming into one step,simplifying the application procedure and reducing post-operative sensitivity (Van Meerbeek et al., 2003). They are classified into one-step and two-step systems and are now widely used clinically [4].

2.4. Universal Adhesives (2010s-Present)

Universal Adhesives are compatible with various restorative materials (e.g., resin, ceramics, metals) and support different curing modes (light-cure/self-cure), making them a current research hotspot (Münchow et al., 2016).

3. CLINICAL APPLICATION PROGRESS

3.1. Caries Restoration

The introduction of adhesive materials has brought about a transformative shift in the realm of dental restoration, fundamentally altering traditional approaches by facilitating minimally invasive (MI) techniques. These state-of-the-art materials, especially flowable composites, have emerged as a cornerstone in modern dental practices. When these flowable composites are utilized in tandem with self-etch adhesives, they exhibit an exceptional ability to effectively seal pits and fissures within the tooth structure. This sealing prowess is of paramount importance, as it plays a critical role in substantially diminishing the likelihood of secondary caries ormation. By mitigating this risk, the longevity and structural integrity of the dental restoration are significantly enhanced, ensuring that the treatment remains durable and effective over an extended period.

According to a comprehensive study conducted by Perdigão in 2020, the synergistic combination of flowable composites and self-etch adhesives stands out as a major leap forward in the management of dental caries. This innovative approach not only streamlines clinical procedures, thereby boosting

efficiency within dental practices, but also translates into markedly improved outcomes for patients. The enhanced sealing capabilities and reduced invasiveness of these materials contribute to a more comfortable and successful treatment experience, underscoring their pivotal role in advancing the field of dental restoration.

3.2. Aesthetic Restoration

In the realm of aesthetic dentistry, all-ceramic veneers and high-strength ceramic restorations have become increasingly popular due to their superior aesthetic properties and durability. The success of these restorations heavily relies on the use of high-bond-strength materials, which ensure a robust and long-lasting bond between the ceramic and the tooth structure. The application of silane coupling agents plays a pivotal role in this process, as it significantly enhances the durability and stability of the ceramic-resin interface. (attabanasuk et al. 2019) have highlighted that the use of silane coupling agents not only improves the mechanical properties of the restoration but also contributes to its overall aesthetic appeal.

3.3. Implant Restoration

Adhesive materials are indispensable in the retention of superstructures on dental implants. These adhesives provide the necessary bond strength to ensure the stability and functionality of the implant-supported restorations. However, it is imperative to exercise caution during the application process, as residual adhesive material can pose a significant risk. Specifically, any leftover adhesive has the potential to cause peri-implantitis, a condition characterized by inflammation around the implant, which can compromise the long-term success of the implant. Linkevicius et al. [5] emphasize the importance of meticulous adhesive application and removal techniques to mitigate this risk and ensure optimal implant health.

3.4. Dentin Hypersensitivity Treatment

Dentin hypersensitivity is a common dental issue that can cause significant discomfort for patients. The use of desensitizers, such as GLUMA, in combination with adhesive materials, has proven to be an effective treatment strategy. These desensitizers work by occluding the dentinal tubules, thereby reducing the flow of fluid within the tubules and alleviating hypersensitivity symptoms. (ei et al. 2021) have demonstrated that the integration of desensitizers with adhesives not only provides immediate relief but also offers a sustainable solution for managing dentin hypersensitivity, enhancing the overall comfort and quality of life for patients.

4. CHALLENGES AND FUTURE PROSPECTS

Insufficient Durability Concerns: The adhesive interface may undergo substantial degradation over an extended period when exposed to the intricate and demanding long-term oral environment, a concern that has been prominently highlighted by Tay et al. in their comprehensive 2019 study. [6] This progressive degradation can significantly compromise the overall effectiveness and sustained longevity of the adhesive bond, thereby increasing the likelihood of potential failures. Such failures could necessitate repeated interventions, thereby imposing additional burdens on both patients and healthcare providers, and ultimately affecting the reliability and trustworthiness of the adhesive system in clinical practice.

Technique Sensitivity Issues: The success of clinical outcomes is profoundly influenced by the precision and accuracy of the application procedures employed. Even minor deviations or inconsistencies in technique can have a substantial impact on the final result, underscoring the critical need for meticulous attention to detail and adherence to established protocols during the application

process. This sensitivity to technique underscores the importance of skilled practitioners and standardized procedures to achieve optimal outcomes.

5. CONCLUSION

The evolution and advancement of dental adhesive materials have significantly propelled the forward momentum of minimally invasive dentistry, a field that prioritizes preserving as much natural tooth structure as possible. Starting with the groundbreaking introduction of the acid-etch technique, which revolutionized the way dental restorations adhere to tooth surfaces, the journey has progressed through various stages of innovation leading up to the development of universal adhesives. These universal adhesives represent a pinnacle of versatility and efficiency, capable of bonding to a wide array of dental substrates with remarkable effectiveness. Throughout this trajectory, the performance characteristics of these adhesive materials have undergone continuous enhancement, marked by improvements in bond strength, durability, and user-friendliness. Consequently, the clinical application scope of these materials has broadened substantially, enabling dental practitioners to address a more diverse range of dental conditions with greater precision and less invasive procedures. Looking ahead, ongoing research and development efforts are imperative to further refine and optimize the material properties of dental adhesives. The goal is to achieve even higher levels of performance, particularly in terms of long-term stability and resistance to degradation over time. By doing so, the dental profession can strive to meet and exceed the ever-rising clinical standards, ultimately leading to better patient outcomes and enhanced oral health care.

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