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The evolution of dental adhesives: A critical review of the evidence from 4th to 8th generation systems

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Abstract
Introduction: Adhesive systems determine the longevity of restorations and the costs of retreatment; their selection and technique influence microleakage and sensitivity.
Objective: To analyze recent literature on 4th, 5th, 6th, 7th, and 8th generation bonding agents, describing their composition, representative brands, mechanism of action, and clinical evidence.
Methodology: Articles were searched in databases such as PubMed, Scopus, Google Scholar, using keywords: Dental Bonding, Etching, Composite Resins, Photopolymerization, dental adhesive, universal adhesive, 4th-8th generation, bond strength; clinical trial.
Results: 4th (total-etch, 3 steps): high adhesion and control, technique-sensitive. 5th (total-etch, 1 bottle): faster, but more hydrophilic; requires rigorous evaporation. 6th (self-etch 2 steps, 10-MDP): MDP-Ca chemical bond and consistent seal in dentin; selective etching improves enamel. 7th (all-in-one): maximum simplicity, but greater permeability; useful with active rubbing, multiple layers, and good aeration. 8th (universal multimode): favorable performance in NCCLs; possible need for activator with dual/self-curing materials; optimal with selective enamel etching and active application.
Conclusion: Universal adhesives (8th) offer the best versatility when applied with active rubbing, solvent evaporation, and selective etching; 2-step self-etch adhesives (6th) are highly predictable on dentin; 3-step adhesives (4th) remain the benchmark when durability is prioritized. The choice must be individualized according to the substrate, isolation, and light-curing parameters indicated by the manufacturer.

Keywords: Adhesion, dental adhesion, MDP, adhesion generation

1. Introduction

Dental adhesion is central to the longevity of direct and indirect restorations; marginal failures, sensitivity, and retention depend on the interaction between monomers, solvents, technique, and substrates [1].

Adhesive dentistry has evolved from total-etch systems to universal adhesives that allow for self-etch, selective etch, or total etch modes, seeking durability, especially in dentin [1].

In non-carious cervical lesions (NCCLs), universal adhesives show favorable clinical performance and, in general, comparable results between strategies (etch-and-rinse vs. self-etch) when selective enamel etching and active rubbing of the adhesive are applied [2, 3].

Light curing conditions the degree of conversion and sealing: what matters is the total energy (J/cm^2), the spectrum, and the homogeneity of the beam; "fast cures" are only safe if the irradiance and time guarantee it [4, 5].

Comparing adhesives is clinically relevant. Insufficient light curing can increase microleakage and reduce longevity, while shorter protocols would optimize clinical time if they maintain effectiveness. This study aims to synthesize current evidence to guide selection and technique through an analysis of the literature on dental adhesives organized by generations: 4th, 5th, 6th, 7th, and 8th. For each generation, evaluate its composition, commercial brands, mechanism, and disadvantages.

2. Methodology

A comprehensive and systematic literature search was conducted across three major electronic databases-PubMed, Scopus, and Google Scholar-to identify pertinent studies published on the topic. The search strategy utilized Boolean operators (AND, OR, NOT) to combine key terms, including but not limited to: MeSH terms ("Dental Bonding, " "Dentin-Bonding Agents, " "Etching, Dental, " "Composite Resins, " "Photopolymerization, " "Tooth Cervical Lesions") with keywords in Title/Abstract (dental adhesive, etch-and-rinse, self-etch, universal adhesive, three-step, two-step, one-step, 4th/5th/6th/7th/8th generation, 10-MDP, functional monomer, hybrid layer, smear layer, nano-layering, nanoleakage, microleakage, photopolymerization, radiant exposure, irradiance, curing time, light-curing unit, bond strength, microtensile, shear, clinical trial, randomized controlled trial, *in vitro*, non-carious cervical lesions (NCCLs), indirect restorations, resin cement, postoperative hypersensitivity.

The study selection process adhered to a structured multi-stage framework involving identification, screening, eligibility assessment, and final inclusion. All retrieved articles were rigorously evaluated against predefined methodological and relevance criteria. Furthermore, the quality of included studies was appraised using standardized assessment tools. To ensure the inclusion of high-caliber evidence, the review prioritized articles published in high-impact, peer-reviewed journals.

3. Results

3.1 Fourth-generation bonding agents

3.1.1 Composition

Three main components are used: acid, primer, and adhesive. According to the protocol, each component is packaged individually and applied sequentially. Compared to previous generations, the hybrid layer consists of the surface layer of dentin and enamel infiltrated with resin, which provides high bond strength and dentin sealing with a significant reduction in marginal leakage [6, 7].

3.1.2 Brand names

OptiBond FL (Kerr), Scotchbond Multi-Purpose (3M), All-Bond 3 (Bisco), among others [1, 8].

3.1.3 Light-curing time

H_3PO_4 removes the smear layer and opens the collagen mesh; a hydrophilic primer with solvents (acetone/ethanol/water) rehydrates and infiltrates monomers, and then a hydrophobic adhesive seals, forming a hybrid layer and tags in the enamel. Durability depends on thorough solvent evaporation and moisture control [9, 10].

3.1.4 Disadvantages

Sensitivity to technique (collagen collapse if dried out; excess moisture lowers conversion), postoperative sensitivity, need for rigorous solvent evaporation. Durable if performed correctly [11, 12].

It maintains the best control of each phase and forms stable hybrid layers if moisture is well managed and the solvent evaporates. It is very dependent, but it remains the benchmark when maximum predictability in dentin and enamel is sought.

3.2 Fifth Generation bonding agents

3.2.1 Composition

Single-component total-etch system that combines a hydrophilic primer and adhesive in a single bottle, using 37% phosphoric acid to condition enamel and dentin [13].

3.2.2 Brand names

ExciTE F, OptiBond Solo Plus, Prime & Bond NT, iBond Total Etch, among others [14].

3.2.3 Mechanism

Total etching of enamel and dentin followed by a single bottle combining primer+bond; solvents transport monomers to demineralized dentin and require active aeration to avoid residual water/solvent [15, 16]. Its greater hydrophilicity may increase sorption and nanofiltration if evaporation is insufficient [9, 13].

3.2.4 Disadvantages

Greater susceptibility to water degradation and possible interference with chemically cured composites due to acidic pH or inhibition of the amine initiator [17]. There may also be a possible collapse of dentin collagen if it is overdried, preventing proper hybrid layer formation. It was the system with the lowest microleakage [18, 19].

Simplification speeds up the procedure, but the more hydrophilic mixture increases the risk of sorption and nanofiltration if not aerated vigorously. It works well on enamel, and on dentin it depends greatly on moisture control and proper evaporation. Useful when speed is required, assuming discipline in drying.

3.3 Sixth Generation bonding agents

3.3.1 Composition

Two-component self-etching system (conditioner/primer + adhesive) in a single application unit. No etching, rinsing, or drying required, reducing the risk of cross-contamination [19].

3.3.2 Brand names

Clearfil SE Bond 2 and Adper Prompt L-Pop, among others [20].

3.3.3 Mechanism

The acid primer (superficially demineralizes and simultaneously infiltrates, incorporating the smear layer and forming MDP-Ca salts that provide chemical bonding and stability; the second step (hydrophobic adhesive) reduces permeability. Very consistent dentin seal; selective etching is recommended on enamel [21-23].

3.3.4 Disadvantages

Less dependence on dentin hydration, but greater post-polymerization hydrophilicity, which promotes water absorption, limited infiltration, and potential voids [8]. Adhesion is lower if selective etching is not performed; compatibility with dual/self-curing cements is usually better than in 1-step systems, but the manufacturer's activators must be verified [24-26].

Very consistent in dentin due to MDP-Ca chemical anchoring and simultaneous demineralization/infiltration. In enamel, selective etching usually improves margins. Its subsequent permeability may increase if the final adhesive is not sufficiently hydrophobic or is applied thinly.

3.4 Seventh Generation bonding agents

3.4.1 Composition

The seventh generation dental adhesion system represents all-in-one adhesives in a single package. It eliminates the uncertainty of mixing and multi-step processes, which could lead to technical sensitivity [13, 27].

3.4.2 Brand names
G-Bond/BeautiBond (GC), iBond (Self-Etch) (Kulzer), Adper Prompt L-Pop (3M), among others [28].

3.4.3 Mechanism
All-in-one: acid+primer+adhesive in one bottle; demineralizes and infiltrates at the same time, but the hydrophilic mixture and water in the system can leave a permeable membrane (water trees). Improved with active rubbing, multiple layers, and vigorous evaporation; verify compatibility with dual/self-curing materials [29- 31].

3.4.4 Disadvantages
High hydrophilicity after polymerization, susceptibility to hydrolysis, lower infiltration depth, and possible microvoids. Comparative studies observe less microleakage at coronal and apical margins versus 5th generation [29-32]. Simplifies, but requires compensatory strategies such as multiple layers, vigorous aeration, selective etching, and/or dual activator [32, 33].

It is extremely simple, but also extremely hydrophilic. It performs acceptably on slightly sclerotic dentin; on enamel, selective etching helps. It is practical for fast flows, although its durability depends on compensating for its hydrophilic nature.

3.5 8th Generation bonding agents
3.5.1 Composition
Universal all-in-one formulation that integrates etching, primer, and adhesive. Includes nano-fillers (~12 nm) that improve monomer penetration, hybrid layer thickness, and the mechanical properties of the system [34, 35].

3.5.2 Brand names
Futurabond DC (Voco, Germany) is an example with nano-fillers and excellent adhesive strength [36].

3.5.3 Mechanism
Universal multimode (self-etch, selective or total etching) with functional monomers that form MDP-Ca complexes; some incorporate nanofillers and/or silane to improve handling and adhesion to ceramics. There are “no-wait” and radiopaque variants; compatibility with dual cements may require an activator. Their performance depends on active application and etching strategy according to the substrate [37, 38, 39].

3.5.4 Disadvantages
Not specified in current sources, although previous studies mention the risk of increased hydrophilicity after curing. Recent evidence, however, highlights improvements in adhesion and long-term durability [40- 42]. Possible permeability and nanofiltration if solvent does not evaporate; effectiveness of incorporated silane is variable; incompatibility with dual/self-curing materials without activator; for enamel, selective etching improves edges [43, 44].

The best balance between performance and simplicity because they allow you to work in multimode: self-etch on dentin, selective etching on enamel, and total-etch when greater micro-retention is desired.

4. Conclusion
Universal systems offer the best combination of versatility and results, followed by 6th generation systems. 4th generation systems are the benchmark when greater complexity is acceptable. Success depends on technique (rubbing, solvent evaporation, selective enamel etching) and strict compliance with IFU and light-curing energy.

5. Conflict of Interest
Not available.

6. Financial Support
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