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MODERN ADHESIVE SYSTEMS IN DENTISTRY: CHEMISTRY, CLINICAL STRATEGIES, AND ADHESIVE BOND DURABILITY

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Annotation. Adhesive technologies are a key factor in the success of direct restorations, sealing fissures, fixing indirect structures, and treating non-carious lesions. In recent years, universal (multi-mode) adhesives have been most noticeably developed, allowing them to work in total-etch (etch-and-rinse), self-etch and selective etching of enamel. Their effectiveness is determined by a combination of functional monomers (in particular, 10-MDP), the composition of solvents, the presence / absence of HEMA, the water balance, as well as the application protocol and substrate features (enamel/dentin, degree of sclerosis, humidity). The purpose of this work is to systematize modern ideas about the structure and mechanisms of adhesive systems, compare clinical strategies for the use of universal adhesives and identify the factors determining the durability of the adhesive interface. The degradation processes of the hybrid layer, the role of the collagen matrix and enzymes, as well as practical approaches to reducing the sensitivity of technology and increasing the stability of the bond over time are considered. The review's conclusions emphasize that clinical success is determined not only by the "generation" of the adhesive, but also by compliance with the protocol: surface preparation, humidity control, rubbing time, correct polymerization, and a reasonable choice of adhesion regimen.

Keywords: adhesive systems; universal adhesives; 10-MDP; HEMA; hybrid layer; selective etching of enamel; durability of adhesion; sensitivity of technology.

Introduction. The transition from mechanical retention to an adhesive concept has radically changed restorative dentistry: more gentle preparation has become possible, the tightness of the edge has improved, indications for composite materials and minimally invasive techniques have expanded. However, the adhesive interface remains the "weak link": even with high initial joint strength, durability may be limited by resin hydrolysis, collagen degradation, nanofluidization, and accumulation of defects at the "tooth tissue—adhesive—composite" interface. Modern universal adhesives are positioned as solutions that simplify the choice of protocol and reduce the risk of errors, but clinical stability still depends on the fine details of the application. The purpose of the review is to analyze modern adhesive systems and universal adhesives in terms of composition, mechanisms of interaction with enamel and dentin, clinical application strategies and durability factors.

Tasks:

1. to present the classification and evolution of adhesive systems;
2. Describe the key components and the role of functional monomers;
3. compare the modes of total-etch, self-etch and selective etching of enamel for universal adhesives;
4. Discuss the causes of degradation of the adhesive interface and ways to increase stability;
5. Formulate practical recommendations for the clinician.

Materials and methods (work design)

A narrative review of publications on the topic of adhesive systems and universal adhesives has been performed, including clinical studies, meta-analyses, experimental work on adhesion

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chemistry, and documents on adhesive strength tests. For the methodological context of adhesion testing, the provisions of the international standard for testing adhesion to tooth structures were taken into account.

1. Classification of adhesive systems: from "generations" to clinical logic

Historically, adhesives have been described through "generations," but in modern clinical practice, classification by the number of stages and protocol is more useful.:

1. Etch-and-rinse (total-etch):
o 3-step systems (etching → primer → bond)
o 2-step systems (etching → "primer+bond")
2. Self-etch:
o 2-step (self-etch primer → bond)
o 1-stepper (all-in-one)
3. Universal adhesives (multi-mode):
o total-etch, self-etch and selective etching of enamel are allowed, depending on the clinical situation.

The key difference between universal adhesives is the desire to combine simplicity (fewer steps) and flexibility (choice of strategy) without significant loss of reliability. At the same time, in practice, universal systems demonstrate variability of properties, depending on the composition and clinical protocol.

2. The composition of adhesives and the role of the main components

A modern adhesive is a multifactorial composition, where each component affects the kinetics of infiltration, polymerization and stability.

2.1. Functional monomers and 10-MDP

One of the most discussed functional monomers is 10-MDP (10-methacryloyloxydecyl dihydrogen phosphate). It is capable of forming a chemical interaction with hydroxyapatite calcium (including the formation of MDP-Ca complexes), which is considered as one of the mechanisms for increasing bond stability on dentin and some restoration materials.

Experimental and review data indicate that 10-MDP-based adhesives often exhibit higher adhesion rates compared to a number of alternative monomers, although direct comparison depends on the test method and aging conditions.

2.2. Solvents (ethanol/acetone/water) and "water balance"

Solvents ensure the transport of monomers into the demineralized substrate and the displacement of moisture. Insufficient evaporation of the solvent leads to a decrease in the degree of conversion and increased water permeability of the interface. Universal adhesives often contain water as a component necessary for the ionization of acidic monomers; hence the requirements for correct rubbing time and active air blowing.

2.3. HEMA: advantages and limitations

HEMA increases the wettability and compatibility of components, facilitating infiltration, but may increase water absorption and promote degradation during aging. Studies analyzing universal adhesives with different HEMA contents note the connection of HEMA with water absorption and a decrease in the micro-strength of adhesion after aging, which stimulates the development of HEMA-free systems.

3. Mechanisms of adhesion to enamel and dentin

3.1. Enamel

Enamel is a highly mineralized substrate, for which the creation of microretence after etching is critical. In the self-etch mode, enamel etching may be insufficient for a number of universal adhesives, so selective etching of the enamel with phosphoric acid is often considered as a compromise: improving the edge tightness on the enamel while maintaining the advantages of self-etch on dentine.

3.2. Dentin

Dentin is a moist, organo-mineral substrate with a system of dentinal tubules. With total-etch, a zone of demineralized collagen appears, which must be completely infiltrated by monomers to form a full-fledged hybrid layer. Errors (over-drying/over-wetting, insufficient rubbing, residual solvent) lead to incomplete infiltration, nano-flow, and reduced durability.

4. Clinical strategies for the use of universal adhesives

4.1. Total-etch vs self-etch vs selective etching of enamel

Systematic reviews and meta-analyses of clinical trials on universal adhesives generally show comparable clinical efficacy of various strategies (total-etch, self-etch, selective-etch) for follow-up periods up to 18-36 months, provided the protocol is correct.

In the restoration of non-carious cervical lesions (NCCL), a number of randomized trials also demonstrate satisfactory clinical efficacy using the selective-etch approach and analyze the effect of HEMA/solvents/monomers on long-term outcomes.

4.2. "Active rubbing" and contact time

For universal adhesives, active scrubbing is critically important, increasing penetration into the substrate and improving the interaction of functional monomers with hydroxyapatite. In the clinic, this is reflected in strict adherence to the application time recommended by the manufacturer and control of solvent evaporation.

4.3. Contamination and clinical reality

Saliva and blood reduce adhesion, especially on dentine. Experimental studies consider protocols for restoring adhesion on contaminated surfaces, while the presence of 10-MDP may be an important factor in maintaining efficiency under adverse conditions, but this does not negate the strict isolation of the working field.

5. Durability of the adhesive interface: why the bond "ages"

Even with perfect initial adhesion, degradation can occur in several ways:

1. Hydrolysis of resin components and reduction of conversion rate with residual solvent.
2. Enzymatic degradation of collagen (including by matrix metalloproteinases), activated by etching and moisture.
3. Nanoflow and water permeability of the hybrid layer, especially in case of insufficient infiltration.
4. Substrate factor: sclerosed dentin, hypermineralization, NCCL features.

Modern reviews emphasize that the transition from "micromechanics only" to a combination of micromechanical and chemical adhesion, as well as strategies for biomodification of dentin and moisture control, are central areas for improving durability.

6. Practical recommendations (protocol-based approach)

Below are universal, clinically applicable points that increase predictability.:

1. Insulation: cofferdam or maximum possible insulation for direct restorations; avoid saliva contamination.
2. Enamel: with universal adhesives, it is often advisable to selectively etch the enamel for 15-30 seconds, then thoroughly rinse and dry the enamel without drying the dentin.
3. Dentin: In total-etch mode, maintain "wet dentin" (without shiny water) and avoid overdrying.
4. Scrubbing: active application according to the manufacturer's instructions; do not shorten the time.
5. Air blowing: sufficient and directed to evaporate the solvent (but without "blowing" the material off the surface).

6. Polymerization: observing the illumination power and time, controlling the light guide and distance.

7. Deep cavities: consider guided tactics (including lining materials according to indications) to reduce the risks of postoperative sensitivity and stress.

Conclusion. Modern adhesive systems, especially universal adhesives, provide high clinical flexibility and in most cases demonstrate satisfactory effectiveness with the correct protocol. However, the durability of an adhesive compound is determined not by the "generation name", but by a combination of factors: the chemistry of the adhesive (functional monomers, HEMA, solvents), the selected mode (total-etch/self-etch/selective-etch), insulation quality, humidity control, and application/evaporation/polymerization time. The current development trend includes optimizing HEMA-free formulas, increasing the resistance of the hybrid layer to water aging, and deepening understanding of the mechanisms of interface degradation.

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