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THE LATEST ADHESIVE TECHNOLOGIES IN DENTISTRY

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Abstract: Over the past decade, adhesive dentistry has undergone a fundamental transformation, shifting from complex multi-step procedures to highly efficient and simplified techniques. The durability of the resin–dentin interface, considered the weakest link in restorative dentistry, plays a critical role in the long-term success of composite restorations and indirect prosthetic treatments. This study focuses on recent advances in dental adhesive technologies, with particular emphasis on eighth-generation universal adhesives, bioactive bonding agents, and the chemical integration of functional monomers such as 10-MDP. Previous clinical trials and laboratory studies were comprehensively reviewed to evaluate hybrid layer durability, technique sensitivity, and bond strength. The study compares total-etch, self-etch, and selective-etch modes implemented through modern universal adhesive systems. The introduction of 10-MDP (10-methacryloyloxydecyl dihydrogen phosphate) has become the “gold standard” for providing chemical adhesion to dental tissues as well as restorative materials such as zirconium dioxide and non-precious alloys. In addition, the “No-Wait” application technique significantly reduces technique sensitivity by enabling immediate penetration into dentinal tubules without prolonged rubbing. Recent developments in bioactive adhesives have demonstrated promising results in inhibiting matrix metalloproteinases (MMPs), thereby preventing enzymatic degradation of collagen fibers and breakdown of the hybrid layer. Modern adhesive technologies not only simplify clinical workflows but also effectively enhance bond durability. Universal adhesives offer clinicians greater flexibility without compromising fixation strength. Future prospects include the widespread use of biomimetic materials capable of stimulating secondary dentin formation and providing long-term antimicrobial protection at restoration margins.

Key words: dentin bonding, bioactive materials, hybrid layer, universal adhesives, 10-MDP, eighth-generation adhesives.

Annotatsiya: Oxirgi o'n yil ichida adgeziv stomatologiya tubdan o'zgardi — murakkab ko'p bosqichli muolajalardan yuqori samarali va soddallashtirilgan usullarga o'tdi. Restavratsion stomatologiyaning eng zaif bo'g'ini hisoblangan smola–dentin kontaktining chidamliligi kompozit restavratsiyalar va bilvosita protezlashning uzoq muddatli samaradorligi uchun muhim ahamiyatga ega. Ushbu tadqiqot stomatologik adgeziv texnologiyalar sohasidagi so'nggi yutuqlarni, ayniqsa 8-avlod universal adgezivlarini, bioaktiv bog'lovchi agentlarni va 10-MDP kabi funksional monomerlarning kimyoviy integratsiyasini o'rganishga qaratilgan. Gibrid qatlamning chidamliligi, usullarning sezgirligi va yopishish kuchini baholash uchun avvalgi klinik sinovlar va laboratoriya tadqiqotlari atroflicha ko'rib chiqildi. Ishda zamonaviy universal tizimlar orqali amalga oshiriladigan “total-etch” (to'liq o'yish), “self-etch” (o'zi o'yish) va “selective-etch” (selektiv o'yish) rejimlari o'zaro solishtirildi. 10-MDP (10-metakriloiloksidetsil digidrofosfat) moddasining joriy etilishi tish tuzilmalari hamda sirkoniy dioksidi va nometall qotishmalar kabi restavratsion materiallarga kimyoviy adgeziyani ta'minlashda “oltin standart”ga aylandi. Bundan tashqari, “No-Wait” (kutmasdan qo'llash) texnologiyasi dentin kanalchalariga uzoq vaqt ishqalamasdan darhol kirib borish orqali muolaja sezgirligini sezilarli darajada kamaytirdi. Bioaktiv adgezivlar sohasidagi so'nggi ishlanmalar matritsi metalloproteinazalarini (MMP) bloklashda istiqbolli natijalarni ko'rsatdi, bu esa kollagen tolalarining fermentativ parchalanishini va gibrid qatlamning buzilishini oldini oladi. Zamonaviy adgeziv texnologiyalar ish jarayonlarini soddallashtirish bilan birga, birikmaning chidamliligini samarali oshirdi. Universal adgezivlar shifokorga fiksatsiya soddahamligiga zarar yetkazmagan holda kerakli moslashuvchanlikni ta'minlaydi. Kelajakda ikkilamchi dentin hosil bo'lishini rag'batlantiradigan va restavratsiya chekkalarida uzoq muddatli mikroblarga qarshi himoyani ta'minlaydigan biomimetik materiallardan keng foydalanish kutilmoqda.

Kalit so'zlar: dentin bondingi, bioaktiv materiallar, gibrid qatlam, universal adgezivlar, 10-MDP, sakkizinchi avlod adgezivlari.

Аннотация: За последние десять лет адгезивная стоматология претерпела существенные изменения, перейдя от сложных многоэтапных процедур к высокоэффективным и упрощённым методикам. Долговечность смола-дентинного соединения, являющегося самым уязвимым звеном реставрационной стоматологии, имеет решающее значение для долгосрочной эффективности композитных реставраций и непрямого протезирования.

Настоящее исследование направлено на анализ последних достижений в области стоматологических адгезивных технологий, с особым акцентом на универсальные адгезивы восьмого поколения, биоактивные связывающие агенты и химическую интеграцию функциональных мономеров, таких как 10-MDP. Для оценки прочности гибридного слоя, чувствительности методик и силы адгезии были детально рассмотрены предыдущие клинические испытания и лабораторные исследования. В работе сопоставлены режимы total-etch, self-etch и selective-etch, реализуемые с использованием современных универсальных адгезивных систем. Введение 10-MDP (10-метакрилоилосидецил дигидрофосфата) стало «золотым стандартом» обеспечения химической адгезии к тканям зуба, а также к реставрационным материалам, таким как диоксид циркония и недорогие сплавы. Кроме того, технология «No-Wait» (нанесение без ожидания) значительно снижает чувствительность процедуры за счёт немедленного проникновения в дентинные каналы без длительного втирания. Современные разработки в области биоактивных адгезивов демонстрируют перспективные результаты в ингибировании матриксных металлопротеиназ (MMP), предотвращая ферментативное разрушение коллагеновых волокон и деградацию гибридного слоя. Современные адгезивные технологии не только упрощают клинические протоколы, но и эффективно повышают долговечность соединения. Универсальные адгезивы обеспечивают врачу необходимую гибкость без снижения прочности фиксации. В перспективе ожидается широкое применение биомиметических материалов, способных стимулировать образование вторичного дентина и обеспечивать длительную антимикробную защиту краёв реставраций.

Ключевые слова: дентинный бондинг, биоактивные материалы, гибридный слой, универсальные адгезивы, 10-MDP, адгезивы восьмого поколения.

INTRODUCTION

Prosthetic dentistry is undergoing a profound technological transformation driven by rising clinical demands for functional precision, long-term reliability, and high aesthetic outcomes. Modern dental rehabilitation no longer focuses solely on restoring the anatomical integrity of individual teeth or dentitions; instead, it prioritizes the comprehensive restoration of masticatory efficiency, speech function, and facial harmony in close integration with patients' aesthetic expectations. This shift has necessitated the adoption of advanced materials, digital workflows, and highly automated manufacturing technologies capable of delivering predictable and reproducible results.

Over recent decades, computer-based technologies have become a cornerstone of prosthetic dentistry. The integration of computer-aided design and manufacturing has significantly altered traditional approaches to the fabrication of dental restorations, replacing labor-intensive and technique-sensitive methods with digitally controlled processes. Conventional casting techniques based on cobalt–chromium and nickel–chromium alloys, while clinically proven, are increasingly challenged by digital alternatives that offer superior accuracy, standardization, and efficiency. As a result, CAD/CAM systems have emerged as a dominant paradigm in contemporary prosthetic workflows, enabling precise digital modeling, virtual treatment planning, and automated fabrication of a wide range of orthopedic structures.

Within the CAD/CAM framework, additive manufacturing technologies—commonly referred to as 3D printing—have attracted particular attention due to their ability to fabricate complex geometries directly from digital models with minimal material waste and high production flexibility. Among these technologies, selective laser sintering and related laser-based methods stand out as especially promising for dental applications, as they allow for the processing of high-strength metal alloys suitable for definitive prosthetic frameworks. Laser sintering offers advantages in terms of dimensional accuracy, mechanical performance, and process automation, positioning it as a viable alternative to both conventional casting and subtractive milling techniques.

Despite the rapid expansion of additive technologies in dentistry, their clinical implementation still raises important questions regarding the long-term performance and quality of prosthetic restorations. In particular, the precision of marginal fit, internal adaptation, surface characteristics, and compatibility with aesthetic veneering materials remain critical factors influencing the longevity and clinical success of orthopedic structures. While existing studies demonstrate that laser-sintered frameworks can achieve marginal fit values within clinically acceptable limits, comprehensive evaluations of their interaction with veneering ceramics and composites are still limited.

In this context, the present study addresses the growing need for a systematic assessment of modern CAD/CAM and additive manufacturing technologies in prosthetic dentistry, with particular emphasis on laser sintering

methods. By analyzing current technological capabilities, manufacturing accuracy, and clinical implications, the article aims to contribute to the evidence base supporting the rational selection of fabrication techniques for contemporary dental prostheses.

REVIEW OF LITERATURE ON THE SUBJECT

The scientific literature demonstrates a steady evolution of dental adhesive systems, driven by the need to improve bonding durability, reduce technique sensitivity, and enhance clinical reliability. Van Meerbeek et al. (2011) provided a foundational classification of self-etch adhesive systems, establishing a conceptual framework that distinguishes adhesives based on their interaction depth with dentin and enamel. Their work highlighted the balance between simplified clinical protocols and long-term bond stability, which remains a central issue in adhesive dentistry.

Subsequent studies have focused on the chemical mechanisms underlying effective dentin bonding. Yoshihara et al. (2019) emphasized the critical role of functional monomers, particularly 10-MDP, in achieving stable chemical bonding with hydroxyapatite. This chemical interaction has been shown to contribute significantly to bond durability and resistance to hydrolytic degradation. Supporting this view, Cardoso et al. (2017) demonstrated that 10-MDP-based adhesives exhibit lower technique sensitivity compared to conventional systems, making them more predictable in clinical practice.

Clinical performance over time has also been extensively investigated. Loguercio et al. (2015), through a 36-month randomized controlled clinical trial, confirmed that simplified universal adhesives can maintain satisfactory bonding effectiveness under clinical conditions, reinforcing their suitability for routine use. Similarly, Sofan et al. (2017) summarized current adhesive systems and underlined the trend toward universal formulations capable of functioning in both self-etch and etch-and-rinse modes.

Recent research has further refined application protocols to optimize bond strength. Mazzitelli et al. (2020) reported that the "No-Wait" technique does not compromise dentin bond strength, offering additional simplification without sacrificing performance. At the same time, Tjäderhane et al. (2013) highlighted the biological factors influencing bond degradation, particularly the role of matrix metalloproteinases in collagen breakdown. This finding underscores the importance of adhesive formulations that provide both chemical bonding and biological stability.

Overall, the reviewed studies confirm that modern universal adhesive systems represent a significant advancement in adhesive dentistry, combining chemical efficacy, simplified application, and clinically proven durability, while ongoing research continues to address biological and long-term performance challenges.

RESEARCH METHODOLOGY

The research methodology is based on a systematic review and comparative analysis of contemporary scientific publications devoted to CAD/CAM and additive manufacturing technologies in prosthetic dentistry. Data were obtained from peer-reviewed articles, experimental studies, and clinical reports. The collected information was analyzed using descriptive and comparative methods, focusing on manufacturing accuracy, marginal fit indicators, and material performance characteristics.

ANALYSIS AND RESULTS

At this point in the development of prosthetic dentistry, physicians must not only restore the integrity of teeth and dentitions but also guarantee the restoration of the dental-maxillary apparatus's masticatory and speech functions, particularly in conjunction with the restorations' high aesthetic performance [22].

The adoption of cutting-edge materials and technologies is a major factor in the advancements made in prosthetic dentistry today. Orthopedic therapy is becoming more efficient in a number of ways: new materials are being created, fixed prosthesis manufacturing procedures are being improved, and prosthesis production concepts are evolving. Cobalt–chromium and nickel–chromium alloys veneered with ceramic materials were the main building blocks for permanent dental prostheses for a long period [11].

Defects in hard dental tissues and dentitions are now being replaced more and more by automated production management and advanced computer data processing technologies [10]. To achieve this, software modules with intuitive graphical user interfaces are used to automate communication between manufacturing complexes and design activities.

The term Computer-Aided Design Systems (CAD systems) refers to the interrelated technologies of Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), and Computer-Aided Engineering (CAE) [23]. As a result, the process of creating prosthetic devices using a variety of special hardware and software planning complexes is being increasingly applied in contemporary dentistry.

Mörmann V. and Brandestini M. (Switzerland), Duret F. (France), and Altschuler B. (USA) made the first efforts to use CAD/CAM technology in dentistry [4, 5, 18].

Laser scanners and optical cameras are used in contemporary CAD/CAM systems to digitize a three-dimensional image of the prepared tooth. Any contemporary CAD/CAM system is composed of three functional modules:

- a laser and/or optical system for image acquisition;
- a computer system for prosthesis modeling and information processing (CAD system);
- a computer-aided manufacturing facility for prosthetics (CAM system).

As a result, there are three primary stages in the CAD/CAM production of dental prostheses: scanning, design, and manufacturing [3, 5, 6, 7].

Every year, the number and diversity of CAD/CAM systems increase, featuring different technical approaches and material selections. As dental computer systems advanced, it became necessary to provide materials with high strength indicators and ease of processing so that they could be used to manufacture standard milling blanks (Duret F.).

Dental prosthesis frameworks with exceptional biocompatibility, high accuracy, and excellent aesthetics can be produced under conditions of high labor automation through CAD/CAM technology. It allows for proper organization of the treatment process, eliminates errors, and provides a full-scale model of the dental prosthesis in advance [14]. Computer modeling makes it possible to visualize the patient's future appearance with new teeth and to select the optimal option before treatment begins.

Single crowns, bridges of various lengths, telescopic crowns, individual implant abutments, complete anatomical forms for press-ceramic models (overpress), temporary crowns, and other casting models can all be fabricated using CAD/CAM systems. Materials include zirconium dioxide, titanium, cobalt–chromium alloys, plastic, and wax [4].

CAD/CAM technology saves time and financial resources and does not require the same level of technical expertise or highly qualified technicians as casting, which is the conventional method of framework fabrication. In addition, workplace pollution is significantly lower compared to casting. One clear advantage is that a CAD/CAM complex can be operated by a single operator.

Higher manufacturing precision (dimensional deviation of 15–20 μm compared to 50–70 μm in casting), high labor automation (reducing technician time by more than five times), high productivity (up to 120 units per day), and the ability to perform modeling while manufacturing is carried out at a remote milling center are among the specific advantages of CAD/CAM technology.

A form of CAD/CAM manufacturing known as additive technologies, or 3D printing, involves constructing a three-dimensional object by adding successive layers of material based on a digital model. Printing is performed by a 3D printer, which uses a virtual three-dimensional model to guide the successive layering of material to create a physical object. Compared to other additive manufacturing methods, 3D printers are generally faster, less expensive, and easier to operate. They provide engineers with the ability to manufacture components from multiple materials with different mechanical and physical properties within a single process.

Extrusion (forcing molten material through a nozzle), photopolymerization (curing polymers using ultraviolet or laser radiation), granulation (bonding or sintering material particles), and lamination (bonding layers of material followed by cutting) are the four fundamental material processing methods underlying all 3D printing technologies.

Based on the analysis and evaluation of the relevant literature [1, 2, 4], it can be concluded that laser and inkjet rapid prototyping technologies—which are further subdivided into the following—are widely applied:

- laser technologies: stereolithography (SLA), selective laser sintering (SLS), and laminated object manufacturing (LOM);
- inkjet technology: fused deposition modeling (FDM).

Among these, SLS (Selective Laser Sintering) is considered the most promising technology for dentistry, as it enables the use of a wide range of metal alloys in powder form. Due to its excellent mechanical properties and metal content of up to 99.99%, the fabricated product is suitable for use as a final prosthetic component.

SLS is based on liquid-phase sintering. During this process, a capillary system consisting of solid, liquid, and gaseous phases is formed within the powder body. Laser sintering of prostheses relies on the capillary-driven flow of the resulting melt-binder into the interparticle spaces. Materials used include aluminum alloys, titanium, cobalt–chromium alloys, and stainless steel.

The SLS process employs a laser beam and a platform that descends in predetermined steps. A specialized roller distributes a thin layer of sintering powder over the platform. The laser beam first outlines the contour of the layer and then scans the entire surface within it. Under thermal exposure, the powder particles melt and solidify, forming a solid mass corresponding to the layer of the three-dimensional model. Layer by layer, the product is built from the bottom up while remaining embedded in an initial powder bed that serves as a support structure [1, 17, 20, 29].

Process productivity is a key determinant of layer-by-layer synthesis efficiency. Analysis reveals that radiation power, laser beam travel speed, and scanning step are the primary factors influencing surface roughness [9, 12]. The natural surface roughness may eventually save time by eliminating the requirement for sandblasting.

The internal accuracy and marginal fit of orthopedic devices are crucial factors in their longevity. The American Dental Association (ADA) now recommends that there should be a gap of no more than 25 μm between the tooth and the internal surface of the structure. In practice, however, this is difficult to achieve. While Hung et al. suggest 50–75 μm [21], Assif et al. report that the typical gap along the margin is closer to 140 μm [13]. According to Gulker, a gap of 200 μm could be acceptable [19]. For laser-sintered structures, Quante K. and Ucar Y. demonstrate marginal fit values within the range of 76–93 μm [26, 29]. A gap of 120 μm , as proposed by McLean and von Fraunhofer, is regarded as a clinically acceptable threshold in several studies [25].

One study found that the marginal fit for direct metal laser sintering (DMLS) structures was 70.98 μm , for milled structures 63.21 μm , and for cast structures 36.96 μm . The corresponding cervical fits were 45.66 μm , 70.05 μm , and 87.71 μm , respectively. Overall, all groups examined demonstrated marginal fit quality superior to the clinically accepted criterion of 120 μm [26].

Modern technologies, particularly laser sintering, have the potential to replace traditional casting and milling techniques for orthopedic frameworks. However, insufficient research has been conducted on the quality and specificity of bonding aesthetic veneering materials (composite or porcelain) to metal frameworks fabricated using additive technologies.

CONCLUSIONS AND SUGGESTIONS

Based on the analysis of contemporary scientific literature, it can be concluded that modern dental adhesive systems have reached a high level of technological and clinical maturity. The transition from conventional multi-step adhesives to simplified and universal systems has significantly improved clinical efficiency while maintaining reliable bonding performance. Functional monomers, particularly 10-MDP, play a key role in achieving stable chemical interaction with dental hard tissues and ensuring long-term bond durability.

Experimental and clinical evidence confirms that universal adhesives demonstrate acceptable bond strength, reduced technique sensitivity, and satisfactory clinical outcomes over extended observation periods. At the same time, biological factors such as enzymatic degradation of dentin collagen remain important challenges influencing bond longevity. Overall, current adhesive technologies provide a solid foundation for predictable restorative outcomes, while further research should focus on optimizing biological stability and long-term performance under complex oral conditions.

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