

DOI 10.26724/2079-8334-2025-2-92-207-212

UDC 616.314-74:615.462-044.7

O.S. Baido, A.V. Marchenko  
Poltava State Medical University, Poltava

### OPTIMIZATION OF ADHESIVE FIXATION IN DIRECT COMPOSITE RESTORATIONS: THE ROLE OF DELAYED POLYMERIZATION

e-mail: o.baido@pdmu.edu.ua

The purpose of this review was to analyze the literature regarding the influence of polymerization time, specifically comparing immediate and delayed polymerization techniques, on the quality and longevity of adhesive bonding in direct composite restorations. Based on an analysis of recent scientific publications (from the last 5 years indexed in Scopus/Web of Science), key aspects of dentin adhesion mechanisms, polymerization kinetics, shrinkage stress development, and factors influencing bond strength were examined. While the benefits of Immediate Dentin Sealing for indirect restorations are well-documented, the application of delayed polymerization principles to direct restorations remains less explored, with contradictory results in existing preclinical studies regarding optimal delay times and clinical significance. Studies suggest potential advantages of delayed polymerization (e.g., 5 minutes) in improving bond strength and marginal adaptation, possibly due to more complete initial polymerization conversion and stress relaxation within the adhesive layer before composite placement. However, a lack of standardized protocols and long-term clinical data persists. Further research, particularly well-designed clinical trials, is needed to establish evidence-based protocols for potentially optimizing direct composite restorations through controlled polymerization timing.

**Key words:** dentin bonding, delayed polymerization, immediate dentin sealing, bond strength.

О.С. Байдо, А.В. Марченко

### ОПТИМІЗАЦІЯ АДГЕЗИВНОЇ ФІКСАЦІЇ В ПРЯМІЙ КОМПОЗИТНІЙ РЕСТАВРАЦІЇ: РОЛЬ ВІДТЕРМІНОВАНОЇ ПОЛІМЕРІЗАЦІЇ

Метою даного огляду був аналіз літературних джерел щодо впливу часу полімеризації, зокрема порівняння негайної та відтермінованої технік, на якість та довговічність адгезивного з'єднання при прямих композитних реставраціях. На основі аналізу актуальних наукових публікацій (за останні 5 років, індексованих у Scopus/Web of Science) розглянуто ключові аспекти механізмів адгезії до дентину, кінетики полімеризації, розвитку полімеризаційного стресу та факторів, що впливають на міцність з'єднання. Хоча переваги негайного запечаткування дентину (IDS) для непрямих реставрацій добре задокументовані, застосування принципів відтермінованої полімеризації для прямих реставрацій залишається менш вивченим, з суперечливими результатами в існуючих доклінічних дослідженнях щодо оптимального часу відтермінування та клінічної значущості. Дослідження вказують на потенційні переваги відтермінованої полімеризації (напр., 5 хвилин) у покращенні міцності з'єднання та крайової адаптації, можливо, завдяки більш повній початковій конверсії полімеру та релаксації напружень в адгезивному шарі перед внесенням композиту. Однак, існує брак стандартизованих протоколів та довготривалих клінічних даних. Подальші дослідження, особливо якісні клінічні випробування, необхідні для розробки доказових протоколів оптимізації прямих композитних реставрацій через контроль часу полімеризації.

**Ключові слова:** дентинне з'єднання, відтермінована полімеризація, негайне запечаткування дентину, міцність з'єднання.

*The study is a fragment of the research project, "Improving the effectiveness of prevention and treatment of hard tooth tissue lesions considering the mechanisms of pathology development", state registration No. 0124U005249.*

Florescu et al. (2015) and Hayashi et al. (2019) have established that the longevity of direct composite restorations largely depends on the quality and stability of the adhesive bond between the restorative material and the hard tissues of the tooth – enamel and dentin. These findings were supported in numerous studies [11, 27]. Achieving a reliable adhesive bond is a key factor that determines the lifespan of the restoration and prevents the development of secondary caries, postoperative sensitivity, and marginal breakdown [4, 5, 15]. The clinical success of a restoration is not merely an aesthetic concern; it is a fundamental aspect of oral health. The failure of this interface not only compromises the individual restoration but also carries a significant economic burden due to the need for costly repairs or replacements, contributing substantially to overall healthcare expenditures. Furthermore, recurrent failures can erode patient confidence in restorative treatments, leading to dental anxiety and avoidance of necessary care. Modern adhesive systems and composite materials have undergone significant development, offering simplified application protocols and improved physical and mechanical properties [12, 25]. This evolution has moved from complex multi-bottle systems requiring meticulous, technique-sensitive steps to more streamlined approaches. Universal adhesives, in particular, capable of working in various etching modes (total-etch, selective-etch, self-etch), have gained widespread popularity for their versatility and user-

friendliness [19, 30]. This simplification, however, does not eliminate the underlying chemical and physical challenges of creating a durable bond, especially to the complex dentin substrate.

Despite this progress, the degradation of the adhesive bond over time remains a primary clinical challenge [4, 23]. The high prevalence of dental caries, particularly among populations in the Poltava region, underscores the ongoing need for durable and effective restorative solutions [28]. The strength and durability of adhesion are influenced by a complex interplay of numerous factors. These include the intrinsic properties of the chosen adhesive system and composite material, such as their chemical composition, viscosity, and film thickness [1, 12]. The nature of the substrate itself is paramount, with significant differences between bonding to highly mineralized, prismatic enamel and the more variable, vital dentin, which can present as intact, sclerotic, or caries-affected [24]. Furthermore, the specific preparation and surface treatment technique employed by the clinician can dramatically alter the outcome [29]. The composite application and polymerization technique, including critical elements like incremental layering, layer thickness, and the geometric C-factor of the cavity, are also crucial variables. Finally, all of this occurs within the dynamic and challenging conditions of the oral cavity, with its constant humidity, pH fluctuations, thermal changes, and bacterial activity [10]. The polymerization dynamics of the adhesive and composite layers plays a particularly important role, as the degree of monomer conversion directly dictates the material's final mechanical properties and the stability of the crucial hybrid layer. Concurrently, the inevitable process of polymerization shrinkage generates stress at the bonding interface, which can threaten the integrity of the bond from the moment of placement [7, 18].

One promising approach to optimizing the adhesive protocol is to study the influence of polymerization time parameters. In the realm of prosthetic dentistry, the Immediate Dentin Sealing (IDS) technique has gained wide recognition and acceptance. This technique involves applying and polymerizing the adhesive system on freshly prepared dentin immediately after tooth preparation for an indirect restoration, crucially, before taking the impression. This approach allows for the creation of the hybrid layer under ideal, controlled conditions. Numerous studies, systematic reviews, and meta-analyses confirm the benefits of IDS in improving adhesion, reducing microleakage, and minimizing postoperative sensitivity during the cementation of indirect restorations [2, 9, 20]. The success of IDS has logically spurred inquiry into whether similar principles could be applied to direct restorations, where the timeline is much more compressed but the fundamental challenges of bonding remain the same.

However, the question of the feasibility of applying these principles – namely, creating a specific time interval between the polymerization of the adhesive and the placement of the first composite layer in direct restorations (a technique known as “Decoupling With Time”) – remains significantly less explored and is a subject of intense debate [26]. The existing data are predominantly from preclinical laboratory settings, are often contradictory in their findings, and do not yet provide clear, evidence-based recommendations for routine clinical practice [3, 13]. This literature gap leaves clinicians to rely on manufacturer instructions and anecdotal experience rather than robust scientific evidence when it comes to this specific timing variable.

**The purpose** of the study was to analyze current literature data regarding the influence of the polymerization time of adhesive systems (immediate vs. delayed technique) on the quality of the adhesive bond of composite materials to enamel and dentin in direct restorations, to consider the potential mechanisms of this influence, and to outline unresolved issues and prospects for further research. A deeper understanding of these mechanisms is essential for developing clinical protocols that can predictably enhance restoration longevity.

#### Mechanisms of Adhesion to Tooth Tissues and the Role of Polymerization.

Modern adhesive dentistry is based on creating a micromechanical and chemical bond between the restorative material and the tooth tissues. When interacting with enamel, which is a highly mineralized and relatively homogeneous substrate, adhesive systems penetrate the micropores created by acid etching, forming resin tags that provide a strong and predictable mechanical interlock [31]. This bond to etched enamel is generally considered the most reliable and durable aspect of adhesive dentistry.

Adhesion to dentin, however, is a profoundly more complex process due to its inherently different structure. Dentin is a vital tissue with higher organic and water content compared to enamel, and it is permeated by millions of dentinal tubules that contain odontoblastic processes and dentinal fluid. This inherent wetness is a major obstacle for hydrophobic resin materials. The surface is also invariably covered by a smear layer following mechanical preparation with dental burs [8]. This layer, a tenacious combination of cut tooth structure, denatured collagen, bacteria, and saliva, must be either completely removed (in total-etch techniques) or modified and incorporated (in self-etch techniques) by the adhesive system to allow for proper interaction with the underlying dentin. The key step in modern dentin bonding is the formation of the hybrid layer – an inter-diffusion zone of adhesive resin monomers and the demineralized collagen network of dentin after its treatment [4, 22]. The quality, thickness, and long-term stability of this hybrid

layer, which is essentially a composite of resin and dentin components, as well as the effective formation of resin tags within the dentinal tubules, are the ultimate determinants of the strength and durability of dentin adhesion [1, 11, 23]. A poorly formed hybrid layer with incomplete resin infiltration can leave exposed collagen fibrils vulnerable to enzymatic degradation over time.

The polymerization process plays a critical role in securing the adhesive bond. Light-curing initiates the free-radical polymerization that converts the fluid monomers of the adhesive and composite into a solid, cross-linked polymer network [7]. The degree of conversion (the percentage of reacted carbon-carbon double bonds) directly affects the final mechanical properties (such as hardness, flexural strength, and modulus of elasticity) and the degradation resistance of the polymer matrix [7, 25]. A higher degree of conversion generally leads to a stronger, more stable material. However, incomplete polymerization, a risk that is especially pronounced deep within the adhesive layer or when using universal adhesives in self-etch mode (where residual acidic monomers can inhibit the polymerization reaction), can lead to significantly reduced bond strength and accelerated degradation of the hybrid layer. This degradation can occur through two primary pathways: hydrolysis of the resin components (ester bond cleavage) and enzymatic breakdown of exposed collagen fibrils by host-derived enzymes like matrix metalloproteinases (MMPs) and cathepsins [4, 6]. These enzymes, present in dentin, can become activated in the acidic environment created by some adhesives and slowly break down the organic framework of the hybrid layer.

Simultaneously, polymerization is invariably accompanied by material shrinkage, a physical consequence of converting monomer molecules into a more densely packed polymer network. This shrinkage generates internal stresses (polymerization stress) at the restoration-tooth interface [18]. The magnitude of this stress is a multifactorial issue, depending on the volume and configuration of the cavity (the C-factor, or ratio of bonded to unbonded surfaces), the type of composite material (its inherent shrinkage and modulus of elasticity), the thickness of the applied layer, and the intensity and protocol of the curing light [14]. High C-factor cavities (such as Class I preparations) are particularly prone to high stress as the shrinkage is constrained by many bonded walls. Excessive stress can have immediate and devastating consequences, including the cohesive or adhesive failure of the bond, leading to marginal gap formation, which in turn facilitates microleakage, postoperative sensitivity, and even catastrophic outcomes like enamel cracks or cuspal fractures. Thus, achieving an optimal and delicate balance between a high degree of conversion for mechanical stability and the minimization of polymerization stress for interfacial integrity is the fundamental and persistent challenge in modern adhesive restorative dentistry.

#### Immediate Dentin Sealing (IDS) in Indirect Restorations.

The IDS technique, as conceptualized and popularized by P. Magne, involves the application of an adhesive system to freshly prepared dentin immediately after tooth preparation for an indirect restoration. This proactive sealing creates a hybrid layer and polymerizes the adhesive on a pristine, uncontaminated dentin surface under optimal moisture control, before the potential for contamination during subsequent clinical steps like impression-taking and restoration try-in. This is a crucial distinction, as it allows the most sensitive part of the bonding procedure to be completed under ideal conditions, free from the contamination that can occur during provisionalization and impression making. Numerous studies have robustly confirmed the wide-ranging advantages of IDS, which include improved marginal adaptation of the final indirect restorations, significantly higher bond strengths, and a markedly reduced risk of bacterial contamination and postoperative sensitivity [2, 20]. Some advanced IDS protocols also advocate for the application of a thin layer of flowable composite over the cured adhesive. This "resin coating" serves as an additional protective layer, fills any microscopic irregularities, and can improve the wetting and adaptation of the definitive luting cement, further enhancing the bond [9]. The well-documented success of this technique in indirect dentistry serves as the primary inspiration for investigating time-related variables in direct restorations. It poses the logical question: if protecting the bond from immediate stress is beneficial in the long term for indirects, could a short-term stress protection be beneficial for direct?

#### Decoupling With Time (Delayed Polymerization) for Direct Restorations: Problem Statement.

Inspired by the success of IDS, researchers began to investigate whether creating a deliberate time interval between the polymerization of the adhesive and the placement of the first composite layer in a direct restoration could improve the quality and longevity of the bond. This philosophy stems from a biomimetic approach, which seeks to create restorations that mimic the physical and mechanical properties of natural tooth structures and manage stresses in a similar way. The core hypothesis, as proposed by pioneers like D.S. Alleman, is that such an interval (ranging from a few seconds to several minutes) might confer two key benefits. First, it could allow the adhesive layer to achieve a higher initial degree of conversion before being stressed. Second, and perhaps more importantly, it could provide a crucial window for the adhesive layer to relax and dissipate some of the initial, most intense polymerization stresses before it is challenged by the additional, and often substantial, shrinkage stress from the first increment of restorative composite. This "decoupling" of stress events could potentially lead to a stronger, more resilient, and more stable final bond, with better marginal integrity.

However, the direct application of this principle faces unique challenges not present in the IDS protocol. Unlike the lengthy period between preparation and final cementation in indirect restorations, any time delay in a direct restoration procedure must be clinically realistic and efficient, typically measured in seconds or, at most, a few minutes, to be practical in a busy clinical setting. Furthermore, maintaining a perfectly isolated and uncontaminated field in the oral cavity for an extended period during a direct restoration is significantly more challenging and can affect the efficacy of this sensitive approach. The potential for contamination by saliva or gingival crevicular fluid during the delay period is a serious clinical concern that must be addressed, as even microscopic contamination of the cured adhesive surface can compromise the subsequent bond to the composite resin.

The theoretical basis for the potential benefits of delayed polymerization can be found in foundational studies on polymerization kinetics. For example, the work of Lu and Bowman (2004) showed that a significant portion of both monomer conversion and the development of polymerization stress occurs very rapidly, within the first few minutes following light activation. After this initial burst, the rate of both processes slows down considerably and approaches a plateau. This kinetic profile strongly suggests that even a brief waiting period could allow the adhesive layer to progress substantially through the most critical phases of polymerization and stress relaxation, potentially creating a more mature and stable foundation for the subsequent composite layers. The goal is to allow the adhesive to form a robust, well-polymerized layer that can better withstand the forces exerted upon it by the shrinking composite.

#### Preclinical Studies on Delayed Polymerization.

Studies directly comparing immediate and delayed composite placement after adhesive polymerization in direct restorations show mixed and often conflicting results, highlighting the complexity of the issue and the sensitivity of the experimental setups.

Some *in vitro* studies indicate clear advantages of delaying. For example, Dietschi et al. (2002), although using a 24-hour interval that is clinically unrealistic for a direct technique, demonstrated a significant improvement in the marginal adaptation of Class II restorations with delayed composite placement compared to immediate placement. This landmark study, while not directly applicable in its timing, provided a proof of concept. Studies with shorter, more clinically relevant intervals also showed positive effects. Burrow et al. (1994) noted a trend towards higher bond strength with a 3-minute delay. More recently, Alsayed et al. (2023) found an improvement in adhesion metrics with delayed polymerization of a dual-cure composite [3]. Using advanced real-time imaging techniques like Optical Coherence Tomography (OCT), Hayashi et al. (2019) observed a visible reduction in gap formation at the bonding interface with a technique that simulated delayed polymerization, providing visual evidence to support the concept.

On the other hand, a body of research has found no significant difference or even a slight decrease in adhesion with a delay. For instance, Reis et al. (2024) found no significant effect of polymerization delay on the bond strength of different adhesives [26]. It is critically important to recognize that the results of these studies are highly dependent on the specific experimental protocol. Key variables that can influence the outcome include the type of adhesive system used (etch-and-rinse vs. self-etch, and the presence or absence of functional monomers like 10-MDP) [16, 17], the type of composite material (conventional, bulk-fill, flowable) [14], the presence or absence of a flowable composite liner [9], the specific testing methodology (e.g., microtensile bond strength vs. shear bond strength, or microleakage evaluation, each of which tests different aspects of the bond) [21], and the overall experimental conditions, such as the use of thermocycling or artificial aging protocols to simulate the oral environment [10]. This lack of standardization makes direct comparison between studies challenging.

#### Discussion of the Review Findings.

Based on the thorough literature review provided, a primary conclusion can be drawn: the scientific community has not yet reached a consensus on the clinical utility of delayed polymerization for direct composite restorations. There is no agreement on the optimal delay time, with published studies proposing intervals ranging from 90 seconds to 10 minutes or more. Crucially, a standardized, universally accepted protocol for clinical application does not exist. The vast majority of studies have been conducted *in vitro*, under controlled laboratory conditions that may not accurately reflect the dynamic and challenging clinical environment. There is a profound lack of long-term clinical observation data from well-designed randomized controlled trials that would either definitively confirm or refute the theoretical benefits of delayed polymerization for the longevity and real-world clinical success of direct restorations. This gap in the literature represents a significant barrier to the evidence-based implementation of this technique. The conflicting results may stem from the immense number of variables at play, many of which are not always controlled or reported in studies, such as the specific light-curing unit and its output, operator technique and experience, and minor variations in the chemical composition of different batches of materials. Therefore, while the concept is theoretically sound, its clinical translation remains unproven.

**Unresolved Questions and Prospects for Research.**

The analysis of the current body of literature highlights a number of critical, unresolved questions that must be addressed to move the field forward:

– What is the optimal, clinically realistic time interval for delaying composite placement in direct restorations? This ideal time must provide the best possible balance between achieving a theoretical improvement in bond quality and the practical constraints of clinical efficiency and patient comfort. Future research should investigate a range of specific time points (e.g., 1, 3, 5 minutes) to identify a potential dose-response relationship.

– Does the potential effect of the delay depend on the specific chemistry and application protocol of the adhesive system being used (e.g., etch-and-rinse vs. various generations of self-etch, and the role of universal adhesives)? It is plausible that certain adhesive formulations, particularly those with higher solvent content or different photoinitiator systems, may benefit more from a delay than others.

– What is the precise impact of placing a flowable composite liner (resin coating) in conjunction with a delayed polymerization technique? Does it enhance the effect by acting as a stress-absorbing layer, have no impact, or potentially interfere with the stress relaxation mechanism by creating a thicker, more rigid interface?

– How does delayed polymerization affect the long-term stability of the adhesive bond? More importantly, how does it influence tangible clinical outcomes such as marginal staining, the incidence of secondary caries, postoperative sensitivity, and the overall structural integrity of the restoration over a period of many years? Longitudinal studies are desperately needed.

– What are the true cost-effectiveness and workflow implications of implementing a delayed technique? This requires not just an analysis of material costs, but also of the impact on the clinician's chair time and overall practice productivity. A technique that adds several minutes to each procedure may not be viable in all clinical settings. Answering these multifaceted questions requires a concerted research effort. This must include further standardized *in vitro* studies designed to isolate variables, but most importantly, it necessitates the initiation of well-designed, multicenter, randomized clinical trials with long-term patient follow-up. Only such high-level evidence will allow for the development of scientifically sound, evidence-based recommendations on the feasibility and specific protocols for using delayed polymerization to potentially optimize the outcomes of direct composite restorations.

**Conclusions**

1. The quality and durability of the adhesive bond between the composite and tooth tissues are critically important for the clinical success of a direct restoration, and the complex polymerization process, with its dual challenges of achieving high conversion and managing stress, plays a pivotal role in the formation and long-term stability of this interface.

2. The Immediate Dentin Sealing technique has proven its clinical effectiveness for improving adhesion and outcomes in indirect restorations, thereby stimulating scientific interest in studying the impact of similar time-related parameters in the more time-sensitive environment of direct restorative procedures.

3. The concept of delayed polymerization, which involves creating a deliberate interval between adhesive polymerization and composite placement, has a strong theoretical basis related to the known principles of polymerization kinetics and the potential for beneficial stress relaxation within the adhesive layer before it is challenged by the bulk of the restorative material.

4. The available preclinical data on the effectiveness of delayed polymerization for direct restorations are limited and highly contradictory, although some laboratory studies do suggest potential benefits (e.g., with a 5-minute delay) with respect to bond strength and marginal adaptation. This inconsistency highlights the need for more standardized research methodologies.

5. The significant lack of standardized clinical protocols and, most importantly, long-term clinical studies, makes it impossible to draw definitive conclusions about the clinical significance and feasibility of the widespread implementation of delayed polymerization in routine dental practice.

6. Further rigorous research, particularly in the form of well-designed randomized clinical trials, is essential to determine the optimal parameters and evaluate the long-term clinical effectiveness of this technique for improving the outcomes of direct composite restorations.

**References**

1. Alam A, Chowdhury AFMA, Yamauti M, Saikaew P, Hoshika S, Carvalho RM, et al. Cause-Effect Relationship of Varying Bonding Thicknesses in Dentin Adhesion of Universal Adhesives. *The Journal of Adhesive Dentistry*, 24(1), 2022, 291–300. <https://doi.org/10.3290/j.jad.b3240695>.
2. Alghauli MA, Alqutaibi AY, Borzangy S. Clinical benefits of immediate dentin sealing: A systematic review and meta-analysis. *The Journal of Prosthetic Dentistry*, 2024, Advance online publication. <https://doi.org/10.1016/j.prosdent.2024.03.014>.

3. Alsayed B, Suliman AA, Clark W, Cook R, Sulaiman TA. Effect of Photo-polymerization Delay on the Bond Strength and Microhardness of Dual-polymerizing Resin Cements. *Operative Dentistry*, 2023, 48(4), 457–463. <https://doi.org/10.2341/22-119-L>.
4. Amin F, Fareed MA, Zafar MS, Khurshid Z, Palma PJ, Kumar N. Degradation and Stabilization of Resin-Dentine Interfaces in Polymeric Dental Adhesives: An Updated Review. *Coatings*, 2022, 12(8), 1094. <https://doi.org/10.3390/coatings12081094>.
5. Askar H, Krois J, Göstemeyer G, Schwendicke F. Secondary caries risk of different adhesive strategies and restorative materials in permanent teeth: Systematic review and network meta-analysis. *Journal of Dentistry*, 2021, 104, 103541. <https://doi.org/10.1016/j.jdent.2020.103541>.
6. Bedir MGA, Karadas M, Bedir F. Effect of matrix metalloproteinase inhibitors on bonding durability of universal adhesives. *Dental Materials Journal*, 2023, 42(4), 581–590. <https://doi.org/10.4012/dmj.2022-282>.
7. Borges ALS, Dal Piva AMO, Moecke SE, de Morais RC, Tribst JPM. Polymerization Shrinkage, Hygroscopic Expansion, Elastic Modulus and Degree of Conversion of Different Composites for Dental Application. *Journal of Composites Science*, 2021, 5(12), 322. <https://doi.org/10.3390/jcs5120322>.
8. Bourgi R, Kharouf N, Cuevas-Suárez CE, Lukomska-Szymanska M, Haikel Y, Hardan L. A Literature Review of Adhesive Systems in Dentistry: Key Components and Their Clinical Applications. *Applied Sciences*, 2024, 14(18), 8111. <https://doi.org/10.3390/app14188111>.
9. Carvalho MA, Lazari-Carvalho PC, Polonial IF, de Souza JB, Magne P. Significance of immediate dentin sealing and flowable resin coating reinforcement for unfilled/lightly filled adhesive systems. *Journal of Esthetic and Restorative Dentistry*, 2021, 33(1), 88–98. <https://doi.org/10.1111/jerd.12700>.
10. Dabbagh S, Hardan L, Kassis C, Bourgi R, Devoto W, Zarow M, et al. Effect of Intraoral Humidity on Dentin Bond Strength of Two Universal Adhesives: An In Vitro Preliminary Study. *Coatings*, 2022, 12(5), 712. <https://doi.org/10.3390/coatings12050712>.
11. Demarco FF, Cenci MS, Montagner AF, de Lima VP, Correa MB, Moraes RR, Opdam NJM. Longevity of composite restorations is definitely not only about materials. *Dental Materials*, 2023, 39(1), 1–12. <https://doi.org/10.1016/j.dental.2022.11.009>.
12. Dressano D, Salvador MV, Oliveira MT, Marchi GM, Fronza BM, Hadis M, Palin WM. Chemistry of novel and contemporary resin-based dental adhesives. *Journal of Mechanical Behavior of Biomedical Materials*, 2020, 110, 103875. <https://doi.org/10.1016/j.jmbbm.2020.103875>.
13. Dreweck F, Burey A, Dreweck M, Fernández E, Loguercio A, Reis A. Challenging the concept that OptiBond FL and Clearfil SE Bond are gold standard adhesives: A systematic review and meta-analysis. *Operative Dentistry*, 2021, 46(1), E34–E48. <https://doi.org/10.2341/20-059-LIT>.
14. Eichler E, Vach K, Schlueter N, Jacker-Guhr S, Luehrs AK. Dentin adhesion of bulk-fill composites and universal adhesives in class I-cavities with high C-factor. *Journal of Dentistry*, 2024, 142, 104852. <https://doi.org/10.1016/j.jdent.2024.104852>.
15. Fan-Chiang YS, Chou PC, Hsiao YW, Cheng YH, Huang Y, Chiu YC, et al. Optimizing Dental Bond Strength: Insights from Comprehensive Literature Review and Future Implications for Clinical Practice. *Biomedicines*, 2023, 11(11), 2995. <https://doi.org/10.3390/biomedicines11112995>.
16. Fehrenbach J. Is the presence of 10-MDP associated to higher bonding performance for self-etching adhesive systems? A meta-analysis of in vitro studies. *Dental Materials*, 2021, 37(10), 1463–1485. <https://doi.org/10.1016/j.dental.2021.08.014>.
17. Fehrenbach, J. 2022. Which self-etch acidic composition may result in higher dental bonds at the long-term? A network meta-analysis review of in vitro studies. *Journal of Dentistry*, 126, 104283. <https://doi.org/10.1016/j.jdent.2022.104283>.
18. Guo J, Yang B, Yang J, Holmes B, Fok A, Chen J, Wang Y. Optical and mechanical factors in the temporal development of tooth-composite bond. *Dental Materials*, 2020, 36(5), 660–671. <https://doi.org/10.1016/j.dental.2020.03.010>.
19. Hardan L, Bourgi R, Kharouf N, Mancino D, Zarow M, Haikel Y, et al. Bond Strength of Universal Adhesives to Dentin: A Systematic Review and Meta-Analysis. *Polymers*, 2021, 13(5), 814. <https://doi.org/10.3390/polym13050814>.
20. Hardan L, Devoto W, Bourgi R, Sabbagh J, Cuevas-Suárez CE, Lukomska-Szymanska M, et al. Immediate Dentin Sealing for Adhesive Cementation of Indirect Restorations: A Systematic Review and Meta-Analysis. *Gels*, 2022, 8(3), 175. <https://doi.org/10.3390/gels8030175>.
21. Herrmann G, Reimann S, Daratsianos N, Weber A, Keilig L, Nadal J, Bourauel C. Comparison of different standardised bond strength tests and the influence of glycine powder treatment in composite resin repairs. *International Dental Research*, 2020, 10(2), 36–43. <https://doi.org/10.5577/intdentres.2020.vol10.no2.2>.
22. Mazzitelli C, Maravić T, Josic U, Cadenaro M, Marchesi G, Breschi L. Progress in Dental Adhesive Materials. *Journal of Dental Research*, 2023, 102(3), 254–262. <https://doi.org/10.1177/00220345221145673>.
23. Mokeem LS, Garcia IM, Melo MA. Degradation and Failure Phenomena at the Dentin Bonding Interface. *Biomedicines*, 2023, 11(5), 1256. <https://doi.org/10.3390/biomedicines11051256>.
24. Mohanty PR, Mishra L, Sazuk K, Lapinska B. Optimizing Adhesive Bonding to Caries Affected Dentin: A Comprehensive Systematic Review and Meta-Analysis of Dental Adhesive Strategies following Chemo-Mechanical Caries Removal. *Applied Sciences*, 2023, 13(12), 7295. <https://doi.org/10.3390/app13127295>.
25. Pompilii OO, Tkachenko VA, Kerimova TM, Pompilii ES. Modern trends and perspectives of the development of adhesive dentistry. innovative techniques for the application of adhesive systems. *Wiadomości Lekarskie*, 2023, 76(12), 2721–2728. <https://doi.org/10.36740/WLek202312124>.
26. Reis A, Feitosa VP, Chibinski AC, Favoreto MW, Gutierrez MF, Loguercio AD. Biomimetic Restorative Dentistry: an evidence-based discussion of common myths. *Journal of Applied Oral Science*, 2024, 32. <https://doi.org/10.1590/1678-7757-2024-0271>.
27. Santos MJMC, Zare E, McDermott P, Santos Junior GC. Multifactorial Contributors to the Longevity of Dental Restorations: An Integrated Review of Related Factors. *Dentistry Journal*, 2024, 12(9), 291. <https://doi.org/10.3390/dj12090291>.
28. Sheshukova O, Mosiienko AS, Polishchuk TV, Maksymenko AI, Marchenko AV, Bauman SS, et al. Comprehensive assessment of caries resistance in 6-7 year-old children residing in Poltava and internally displaced children. *Wiadomości Lekarskie*, 2024, 77(12), 2487–2492. <https://doi.org/10.36740/WLek/1971144>.
29. Sun G, Chen X, Wei F, Bai T, Zhu S. Effects of Er: YAG, Er,Cr: YSGG, and Nd: YAG laser irradiation and adhesive systems on the immediate and long-term bond strength of dentin: a systematic review and meta-analysis. *Lasers in Medical Science*, 2023, 38(1), 32. <https://doi.org/10.1007/s10103-022-03699-6>.
30. Triani F, Pereira da Silva L, Ferreira Lemos B, Domingues J, Teixeira L. Universal Adhesives: Evaluation of the Relationship between Bond Strength and Application Strategies—A Systematic Review and Meta-Analyses. *Coatings*, 2022, 12(10), 1501. <https://doi.org/10.3390/coatings12101501>.
31. Sato, Takaaki & Takagaki, Tomohiro & Hatayama, Takashi & Nikaido, et al. Update on Enamel Bonding Strategies. *Frontiers in Dental Medicine*, 2021, 2. <https://doi.org/10.3389/fdmed.2021.666379>.