REVIEW ARTICLE

CONTENTS

# Comparative analysis of the clinical application of modern adhesive protocols for ceramic restorations (literature review)

**Anatoliy Potapchuk, Vasyl Almashi, Viktoria Demidowa, Nazar Basarab**
UZHHOROD NATIONAL UNIVERSITY, UZHHOROD, UKRAINE

## ABSTRACT

**Aim:** To analyze the well-known physicomechanical and clinical properties of modern adhesive systems, explore the latest trends and approaches to their improvement, and assess the prospects for the further development of restorative dentistry.

**Materials and Methods:** A comprehensive search for relevant publications related to the topic was conducted using scientific databases such as Scopus, PubMed, BVS, and Scielo.

**Conclusions:** The standardization of knowledge regarding tooth tissue preparation, adhesive application techniques, as well as potential errors and complications, will contribute to enhancing the quality of dental care and elevating it to a new level.

**KEY WORDS:** tooth hard tissues, ceramic restorations, dental adhesive system, «ethanol wet bonding,» dental adhesives

Wiad Lek. 2025;78(4):921-929. doi: 10.36740/WLek/203905 DOI

## INTRODUCTION

The true revolution in global aesthetic dentistry is associated with the development and implementation of adhesive restorative materials in practice [1-4]. Achieving effective fixation through micromechanical retention has made it possible to perform minimally invasive preparation while maximizing the preservation of the tooth's hard tissues [3,5]. The capabilities of adhesive techniques have allowed for the creation of ceramic structures with a range of advantages that, according to both domestic and international specialized literature, positively affect the quality of treatment, ensuring a longer service life [2,5,6]. The widespread application of this technology has revealed complications in adhesive treatments due to insufficient theoretical knowledge and the unjustified expansion of indications for their use [5,7]. Mistakes during adhesive fixation reduce the strength of the bond between ceramics and the tooth's hard tissues, which often leads to complications such as debonding, cracking of the structure, margin displacement, recurrence of caries, and other unfavorable outcomes [4,6]. According to several authors, this is linked to a lack of theoretical understanding regarding the mechanisms of adhesion and the impact of enamel, dentin, and ceramic surface preparation processes on adhesive fixation [1,2,5,8,9]. A search of scientific works by foreign authors in the «US National Library of Medicine National Institutes of Health» revealed 699 papers on the query «dental adhesive system» and 186 papers on «ethanol wet bonding.» To date, adhesion to enamel and the interaction of existing adhesive systems with dentin have been studied in detail. Specialized literature provides data confirming the degradation of the adhesive bond, the role of chemical components, the main application techniques, and the influence of the dentin's enzymatic system on the degradation speed of the hybrid layer. A number of studies have been conducted to optimize the adhesive bond using inhibitors of metalloproteinases and ethanol solution. In the field of ceramic preparation, questions regarding the permissibility of sandblasting, as well as the clarification of etching and cleaning algorithms for ceramic surfaces, remain relevant [2,4].

Currently, there is no unified methodological approach to the adhesive fixation protocol and its algorithm [1,9-11]. The lack of knowledge about the factors that contribute to the weakening of the adhesive bond and its mechanisms requires not only theoretical justification but also experimental research [7,8,11]. Therefore, this issue is not only an important scientific direction but also a practical challenge, making it both timely and necessary.

## AIM

Analysis of the known physicochemical and clinical properties of modern adhesive systems, emerging trends and approaches to their improvement, and prospects for the further development of restorative dentistry.

## MATERIALS AND METHODS

The search for relevant publications related to the objective topic was conducted using scientific databases such as Scopus, PubMed, BVS, and Scielo. The following keywords were used: dental hard tissues, ceramic restorations, dental adhesive system, «ethanol wet bonding,» and dental adhesives. The review included original articles, research studies, and official recommendations from medical associations. All collected articles were processed following the principles of content analysis, with subsequent systematization and categorization of the obtained data using CADIMA software.

## REVIEW AND DISCUSSION

The evolution of adhesive systems has progressed through the gradual simplification of procedures and the reduction of the number of application steps [2,3]. Self-etch adhesives were developed to eliminate the need for separate dentin etching; however, their effectiveness in removing the enamel smear layer and etching prismatic enamel was found to be insufficient [3]. Consequently, a combined technique emerged, integrating acid etching of enamel with dentin conditioning using a self-etching primer [7,11].

Contemporary research in the field of adhesion focuses on studying a new method of dentin adhesion—ethanol wet bonding. Recent experimental data indicate that the use of ethanol promotes deeper infiltration of dimethacrylates into inter- and intraprismatic spaces, prevents phase separation between hydrophilic and hydrophobic monomers, and strengthens the enamel-adhesive interface [1,11].

According to studies by Ayar M. K. et al. (2019), the application of Single Bond 2 3M ESPE in wet and ethanol bonding techniques on enamel demonstrated a significant difference in bond strength, ranging from 17.4 MPa to 28.7 MPa, respectively [4,8,11]. The traditional dry bonding method involved drying both enamel and dentin, causing collagen fiber collapse and reducing adhesive strength to 5 MPa, which, in turn, did not allow the material to withstand polymerization stress of 24 MPa [2,5,10,11].

Despite the high effectiveness of the wet bonding method, its clinical application remains complex and requires a high level of professional training [9,11]. Further development of adhesive technologies and research into dentin adhesion have led to the simplification of the adhesive application process and the emergence of self-etching systems, which contribute to increased efficiency and predictability of dental treatment.

In modern dental practice, most clinicians successfully apply the dentin self-etching method in combination with enamel etching [4]. An important discovery for the further development of adhesive technologies was the fact of hybrid layer degradation and destruction over time [5].

Further improvement of dentin adhesion has two goals:

I — slowing down the degradation of the adhesive bond by introducing new application techniques and modifying the structure of adhesive systems [4].

II — creating universal adhesives that are less dependent on operator skills and easier to use [4].

The first classification of adhesive systems is based on their order of development and is divided into generations [4,6,8,11-13]. The earliest clinically relevant generation in dentistry is the fourth, which introduced the total-etch technique for enamel and dentin, where orthophosphoric acid, primer, and adhesive were contained in separate containers [5,6,8,13]. The next generation combined the hydrophilic primer and hydrophobic adhesive in one container, which negatively affected their ability to wet the dentin and enamel surfaces. The sixth generation of adhesive systems introduced the concept of self-etching for the first time [10,11,13,14]. The acidic monomers in the primer etch and infiltrate the smear layer of dentin and enamel, followed by the application of the adhesive [2,8,9].

The seventh generation was developed to maximize ease of use for dentists. A single container combining functional and structural monomers can be used in total-etch, selective-etch, and self-etch concepts [1,2,5,9,11,14]. Although combining components with different properties in one container may lead to phase separation of hydrophilic and hydrophobic phases, weakening the adhesive layer's strength, and some researchers indicate the possibility of worsening adhesion in the long term, the seventh generation has gained popularity due to its simplicity and versatility [14].

Selective adhesive systems of the eighth generation are one-step complexes that combine a conditioner, primer, and self-etch adhesive. These formulations also contain nanoparticles that can deeply penetrate dentinal tubules into the formed hybrid layer, preventing its expansion. This mechanism allows for a faster tooth restoration procedure and ensures excellent adhesion of the restorative material to dental tissues [8,9].

In specialized international literature, adhesive systems are classified based on the etching concept and the number of steps in the adhesive protocol [3,4,6,8,10,14,15]. Based on the first criterion, systems are divided into total-etch, selective-etch, and self-etch systems [7,9,11,14-16]. Based on the second criterion, adhesives can be three-step, two-step, and one-step [7].

In three-step adhesives of the fourth and sixth generations: etching, priming, bonding; in two-step adhesives of the fifth and sixth generations: etching, primer and bond combined, or primer bond.

One-step adhesives include those of the seventh and eighth generations, provided they are used in the self-etching technique [5,7,11,12,15,16].

The chemical composition of adhesive systems consists of an acidic component, primer, bond, initiators, stabilizers, fillers, and a solvent [3]. Monomers are organic molecules capable of polymerization. During polymerization, they form a single structure that ensures the strength of the adhesive layer, its retention, and connection with tooth tissues.

There are two main types of monomers:

- Functional monomers contain a functional group and a polymerization group. They are primarily responsible for etching and are used to prime the hydrophilic dentin surface [4,5].
- Structural monomers are generally hydrophobic and form a polymer network during polymerization, significantly improving the adhesive's strength properties [8,12,14,16,17].

Over time, more specialized monomers have been developed that perform functions such as fluoride ion release, antibacterial activity, or enhanced polymerization [16,17]. In adhesive systems of the fifth, seventh, and eighth generations, functional and structural monomers are contained in a single container, while in the fourth and sixth generations, hydrophilic functional monomers are included in the primer, and hydrophobic monomers are in the adhesive [3,5,8,9,11,17,18].

Initiators are substances that activate the polymerization reaction in the adhesive system. The choice between initiation types depends on the intended application of the adhesive system. Systems with chemical initiation of polymerization are used for bonding indirect restorations, while systems with photo-initiators are applied for direct restorations [3,13].

Solvents are included in adhesive systems to improve the wetting of the tooth surface and the diffusion of monomers into the microporous structure of enamel and dentin. According to several studies, partial retention of the solvent deteriorates the mechanical properties of the hybrid layer and increases its degradation rate [3,7,11,14]. Ethanol is a polar solvent, and its low dielectric constant enhances its ability to dissolve less polar substances, such as adhesive system monomers [6]. Another property of ethanol is its ability to form hydrogen bonds with water, facilitating water evaporation from the tooth surface [2,4,6,8,11,18]. Acetone evaporates four times more easily than ethanol, which contributes to improving the structure of the polymerized hybrid layer. However, the evaporation of the solvent from the adhesive container can reduce the material's shelf life [10,11,13,15].

Inorganic fillers are rarely included in adhesive systems due to the increased viscosity of the adhesive caused by filler addition [15,17]. The film thickness increases, which limits the application of adhesive for pre-polymerization before fixing ceramic adhesive restorations [7,8,11,17]. However, greater resistance to polymerization stress due to increased elasticity, higher resistance to degradation, and better load distribution have made such adhesive systems among the most effective [16,18,19].

The surface layer of enamel, composed of randomly arranged hydroxyapatite crystals, is called aprismatic enamel. Aprismatic enamel is significantly more resistant to etching, making it a poor substrate for adhesion. This must be considered when fabricating no-prep ceramic or composite restorations [7,11,15,18-20]. The presence of an aprismatic enamel layer necessitates longer etching, pre-treatment of the tooth surface with rotating diamond instruments, or air abrasion. The enamel smear layer is easily removed using 38% orthophosphoric acid but may act as a barrier to certain self-etch adhesives [4,5,8,9,11].

Most dentists limit tooth tissue preparation to diamond burs of high and low abrasiveness. However, according to specialized national and international literature, the best method for final preparation of enamel and dentin is air abrasion, which achieves a uniformly rough surface while preserving the integrity of enamel prisms [11,12,17,19]. Scanning electron microscopy has revealed the absence of cup-shaped depressions and fractured hydroxyapatite crystals. Furthermore, in cases of delayed cavity filling or bonding of laboratory-fabricated restorations, air-abrasive treatment most reliably removes biofilm and residues of temporary filling materials from tooth tissues [2,6,8,11,15]. Healthy dentin consists of 50% mineral phase, 30% collagen fibers, and 20% water.

As a rule, dentists work with teeth that have previously undergone a carious process and must consider that the structure of caries-infected dentin, caries-demineralized dentin, and sclerotic dentin differs significantly. A minimally invasive approach to cavity preparation requires the preservation of as much of the natural tooth tissue as possible; therefore, specialists must be knowledgeable about the effectiveness of adhesion to each type of altered dentin [2,4,8,10,19,21].

Infected dentin has undergone destruction of both mineral components and the organic matrix, and the cohesive forces between layers of infected carious dentin are too weak for it to serve as a reliable substrate for adhesion [18,20]. In the structure of demineralized dentin, partial destruction of the organic matrix and disruption of the crystalline structure of the mineral phase occur, leading to the formation of a deeper hybrid layer [2,4,8]. However, the altered structure and depth of demineralization prevent adhesive monomers from properly distributing within the adhesive interface [5,6,11,12,18,19]. Monomers only partially fill the free spaces, making the dentin bond prone to degradation and less durable [6,7,11].

Adhesion to sclerotic dentin is compromised due to dentin's response to external factors, resulting in the formation of acid-resistant tricalcium phosphate crystals in the dentinal tubules. These impede the penetration of adhesive monomers into the dentinal tubules and the depth of the demineralized zone [12,14,16,21,22]. Thus, all caries-affected tissues serve as inferior substrates for adhesion compared to healthy dentin. This is attributed to the exposure of fresh acid molecules to the surface and the washing away of weakened crystals from the aprismatic layer.

Dynamic enamel etching may also have a positive effect when applied to prepared enamel; however, this process requires further investigation. The use of self-etch adhesives on enamel still lacks a consensus within the scientific community. E. Can Say, E. Özel, H. Yurdagüven et al. (2020) reported in their studies that one-step self-etch adhesives exhibit lower bond strength to prepared enamel than two-step and three-step adhesives used in the phosphoric acid etching technique [17,19,26,27]. Conversely, several national and international authors report identical adhesion strength between self-etching and separate etching techniques [24,25,27].

Beyond the immediate adhesion strength following fixation, an important factor is the bond's resistance to masticatory forces. The hybrid layer formed by a self-etch adhesive is significantly thinner and more linear in structure, and its durability under chewing forces requires further investigation [8,14,16,19,20,26].

Two main approaches exist for dentin etching: the first involves using orthophosphoric acid gel [20,25-27]. In this case, complete dissolution of the smear layer occurs, regardless of its thickness (ranging from 1 to 2.4 microns), along with the dissolution of smear layer fragments filling dentinal tubule entrances to a depth of up to 10 microns, as well as complete dissolution of 50% of the inorganic dentin components to a depth of 3–5 microns [17,23,24,27]. Interfibrillar spaces contain a negatively charged proteoglycan hydrogel, which, under prolonged exposure to the enzyme chondroitinase ABC, increases the adhesion strength of Scotch Bond Multi-Purpose and Prime&Bond NT by 49% and 63%, respectively [18].

The second approach involves the use of self-etch adhesives. In this case, the acidic monomers in the adhesive simultaneously etch and prime the dentin surface, and since there is no rinsing phase, the etching by-products remain on the surface [15,25]. Modern self-etch adhesives are classified as weak-acid (pH $\geq$ 2), medium-acid (pH = 1.5), and strong-acid (pH $\leq$ 1). Weak-acid adhesives superficially etch dentin, leaving hydroxyapatite crystals between collagen fibers, so dentinal tubules are only partially freed from the smear layer, forming a hybrid layer thinner than one micron [14,15,19,22,25]. Medium-acid adhesives cause deeper demineralization of dentin and partially penetrate the dentinal tubules, while strong-acid adhesives penetrate dentinal tubules entirely, forming a hybrid layer comparable to that of three-step adhesives in the total-etch technique.

Aside from the chemical composition of the adhesive, the etching technique significantly influences its effectiveness. Static etching involves applying acid for a set time without additional actions, whereas dynamic etching involves acid application followed by activation with a brush inside the cavity. According to Meerbeek BV et al. (2020), etching activation can increase the aggressiveness of the self-etching primer, positively affecting adhesion to dentin with a thick smear layer [17,21].

The original enamel bonding technique, proposed by Buonocore, was dry bonding [27]. This technique continued to be used even after the introduction of fourth- and fifth-generation adhesive systems in the total-etch technique. Researchers initially assumed that a dry cavity was necessary for effective adhesion, and etched enamel was expected to have a characteristic chalky appearance. At the time, it was not yet known that drying etched dentin led to collagen fiber collapse and a reduction in interfibrillar spaces, which are essential channels for adhesive monomer infiltration [10,24,26-28].

The adhesion strength to collapsed dentin is only 5 MPa and cannot withstand polymerization stress of 24 MPa, leading to debonding of one of the cavity walls, microleakage, and various complications such as postoperative sensitivity, secondary caries, and restoration failure [24,28,29].

As a solution to dentin adhesion issues, J. Kanca (1992) proposed the wet bonding technique [13,20,25]. The liquid remaining in the cavity is gently dispersed or dried using an aspirator, sponge, or paper points, maintaining the dentin and enamel in a slightly moist condition [5,7,11].

Differences in drying methods were analyzed by Magne P. et al. (2008), who found no statistically significant difference between cavity drying with an air stream or an aspirator when using the fourth-generation adhesive system OptiBond FL [11].

Thus, collagen fibers released during etching remain extended, maximizing the dentin surface area and opening access to dentinal tubules. The hydrophobic monomers of older adhesive systems cannot penetrate deep into moist demineralized dentin; therefore, more hydrophilic monomers, which are part of fourth-generation primers and fifth- and seventh-generation adhesives, are used for this purpose [18,22,29,30]. The wet bonding technique significantly increases the hybridization area of dentin; however, moisture control remains one of the most technique-sensitive processes in adhesive dentistry.

The primer (fourth generation) or adhesives (fifth and seventh generations) contain a solvent that must fully evaporate, as residual solvent creates voids and water channels in the polymerized hybrid layer. This phenomenon reduces the adhesive's mechanical properties and resistance to hydrolysis [24,25,30]. According to research by M. Toledano et al. (2022), the immediate tensile strength of fourth- and sixth-generation adhesives significantly decreases under conditions of incomplete solvent evaporation [18,22,26,29]. When using a fourth-generation adhesive, the next step is applying a bond consisting of large hydrophobic molecules without a solvent, which is then air-blown to form a uniform thin film [8,11,21,26,29].

Diego Spreafico et al. (2018) studied the effect of strong (0.68 MPa) and weak (0.12 MPa) air-blowing on self-etch adhesives and found minimal impact on the adhesion strength of Clearfill SE and G-Bond adhesives. However, they noted a thinner adhesive layer when weak air-blowing was used.

In a study of samples prepared with one-step adhesives G-Bond and Prompt L-Pop, where strong air-blowing was used, scanning electron microscopy revealed areas of dentin with exposed collagen but without a hybrid layer. This phenomenon is likely associated with excessive removal of the adhesive layer from the dentin surface [25,26,29,30]. The observed effects are explained by monomer separation from water as the solvent evaporates, leaving water droplets trapped in the polymerized adhesive layer, significantly weakening its mechanical properties [11,19,21,25].

These issues were not observed when using the two-step adhesive Clearfill SE, which features separate application of hydrophilic and hydrophobic components, leading to better compatibility with the dentin surface primed by the primer. The final stage of adhesive preparation—polymerization—depends on the functional and structural monomers in the adhesive system, the photo-initiator, environmental moisture, and the type and intensity of the curing light [26,27,30,31].

Apart from potential errors in applying adhesive systems, the quality of bonding is also affected by enzyme-induced hydrolysis and degradation of the polymer and collagen fibers in the hybrid layer [13,16,17,22,26,31]. Matrix metalloproteinases (MMPs) play a crucial role in both physiological and pathological metabolism of collagen-based tissues. They participate in tooth tissue formation, but after mineralization, the enzyme becomes covered with a layer of hydroxyapatite crystals, which prevents its movement and renders it inactive [17,19,22,26,31].

According to C. Sabatini et al. (2022), acid etching followed by adhesive application increases MMP activity and triggers the degradation process of demineralized and weakly hybridized collagen [8,13,19,25,31]. The degradation rate can be reduced by using proteolytic activity inhibitors such as chlorhexidine, benzalkonium chloride, ethanol, and other substances, as well as by ensuring more complete infiltration of demineralized dentin with polymer [5,6,16,22,29,31].

One of the modern methods for improving dentin hybridization is the use of a 95% ethanol solution for treatment before primer application [12,14,18,22,26,30,31]. D. Pashley et al. (2017) demonstrated the positive effect of ethanol in their studies, describing the process of breaking down the proteoglycan gel between collagen fibers, which facilitates deeper penetration of hydrophobic monomers [29,31]. However, several other studies found no significant differences compared to conventional bonding techniques, and the ethanol-based adhesive protocol still requires further investigation [23,25,28,30].

Recent studies on traditional methods of dentin preparation using diamond and carbide burs have shown differences in smear layer thickness, ranging from 2.4 microns when using coarse-grain diamond burs to 1 micron with fine-grain diamond burs and carbide burs [22]. The method of preparation plays a significant role in the use of self-etch adhesive systems, as a thinner smear layer dissolves more easily under the influence of acidic monomers [1,3,7,15,18,21,23].

Currently, laser preparation techniques exist, with the undeniable advantage of virtually eliminating the smear layer. However, damage to the microstructure of dentin, associated with the destruction of organic molecules and the formation of microcracks, actually weakens adhesion to the laser-treated surface [19,20-24]. Air abrasion, ultrasonic, and sonic preparation methods create a thinner smear layer on the dentin surface compared to treatment with medium-grit burs and leave the surface more intact and uniform. The margins of cavities formed using air-abrasion and sonic instruments demonstrate better long-term adhesion stability [17,19].

For indirect adhesive ceramic restorations, adhesion to both the hard dental tissues and the ceramic surface is equally crucial [16-18,27]. Today, three primary methods are used for ceramic surface preparation before bonding: sandblasting, etching, and silanization [18,26].

Air abrasion with aluminum oxide particles under controlled pressure is used in traditional ceramic restoration techniques, such as pressed ceramics and refractory die fabrication, to remove investment residues [24,25,27,28]. Several scientific studies have confirmed the effectiveness of air abrasion in enhancing adhesive bond strength. However, some ceramic manufacturers still prohibit sandblasting in their material usage instructions [6,14,16,26].

Another method, etching ceramics with hydrofluoric acid of varying concentrations, is a widely accepted technique for preparing surfaces for adhesive bonding. Among clinicians, there is ongoing debate regarding dynamic etching, where hydrofluoric acid gel is actively distributed across the internal surface of the restoration throughout the exposure time. However, no studies have yet demonstrated a significant advantage of this technique [7,28].

The third method, silanization, involves applying a substance that bonds to ceramic on one side and to dental polymers on the other. This technique has evolved with the introduction of a new material, Monobond Etch & Prime, which combines etching and silanization. The specific features of its application require further study [22,24,26,28].

Analysis of publication trends indicates a sustained interest in the problem of bonding zirconia restorations, which remains an active area of research. In addition to strengthening the bond between polymers and ceramics, studies have also focused on the longevity of this adhesion. The durability of the bond between zirconia-based ceramics and polymer has been investigated in numerous studies, with findings indicating that it largely depends on the surface treatment method of zirconia.

All chemical methods for improving zirconia adhesion can be broadly classified into two groups:

1. Application of a silicate coating using various techniques (selective infiltration etching, pyrochemical methods, and magnetron sputtering deposition).
2. Application of chemical cross-linking agents, such as bicon – methacryloxydecyl dihydrogen phosphate (MDP) and other monomers or silanes [7,11,17,22,24,25].

According to the literature, adhesive systems containing phosphate monomers provide more reliable adhesion than silica-based or silane coatings on zirconia. Studies have confirmed that the MDP monomer enhances the adhesion strength of polymer cement to zirconia due to the formation of chemical bonds (P=O, OH=Zr), and even ionic bonds. MDP monomer is considered the most effective agent for reliable fixation of zirconia-based prostheses.

Despite extensive research, the challenge of improving the adhesion of polymer cement to zirconia and extending the longevity of bonded restorations remains unresolved. New methods for zirconia ceramic surface preparation offer the potential to enhance the bond strength between polymers and zirconia. However, these techniques remain expensive and inaccessible to most practitioners. None of the innovative bonding techniques function effectively without the use of an MDP primer [8,9,11,13,20,22].

One type of etching of zirconium ceramics is laser impregnation with a high-energy laser to melt and re-harden the surface by creating small holes to increase the mechanical strength of the zirconium. and resin. Lasers that are often tested are the Er:YAG laser, the Nd:YAG laser, and the carbon dioxide (CO2) laser [17,18].

Ma Yonggang and other studies confirmed that the performance value of the three laser-treated ceramics was significantly lower than that of the control group, and there was no difference between the three statistically significant. Laser etching has a significant impact on improving the bond between ceramic and resin. However, this technique does not interfere with the flow of energy to enhance the value of communication. The adhesion of laser-etched zirconium dioxide ceramics and resin-based paints is significantly reduced after staining for 6 months. Also, I'm dreaming technology for processing the surface of NobelBond ceramics, which was used to bond the surface with zirconium at the end of the day [25,26]. The principle is that the surface of the previously sintered or the surface of the sintered zirconium frame, after cutting, is coated with a suspension, where the zirconium dioxide powder is placed and cured, and after sintering, The solution then unfolds, creating pores on the surface with zirconium. Phark et al. The value of zirconium dioxide after NobelBond and sand blasting was determined. The results show that the first one has a high vitality immediately after the old one and the rest, and the last one has a high value after the one-piece thermal cycle of the old one. At the same time, the surface of the zirconium porcelain is coated with NobelBond and does not require sandblasting. Since the technology is still new, the assessment of effects will require further verification [22,25].

According to current research, 15 seconds of perforation of the prepared enamel surface produces adhesive fixation similar to that of 60 seconds. F. R. Tay and D. H. Pashley et al., 2019, provide evidence that activation of the mordant gel with a pencil leads to more uniform and uniform penetration of aprismatic enamel [11,18,20,22,25].

Clinical adhesion studies are carried out on the basis of previously established light practice criteria, the United States Public Health Service (USPHS) sees five evaluation criteria: 1) Retention of the restoration. (indicated by the presence or loss of restoration; 2) Damage to the marginal fit, which is indicated by the use of a dental probe and a probe; 3) Maybe change the color between the restorations; 4) Visible carious boundary defect; 5) post-operative sensitivity (visible with a spray from a distance of 2-3 cm while the other teeth are covered with cotton rolls) [13,26,30].

Nathaniel C. Lawson et al., 2019, examined the effectiveness of restorations in non-carious lesions according to Black class 5, with the use of Scotch Bond Multi-Purpose adhesives, Scotch Bond Universal self-protrusion, Scotch Bond Universal total protrusion2 136]. After 24 months, the final restoration was assessed according to the criteria of Cvar and Ryge 1) Regional jurisdiction. 2) Farbuvannya cordon. 3) Secondary caries. 4) Sensitivity, and a statistically significant difference was found between the three adhesive techniques [18,26,29,31].

Van Meerbeek B. et al., 2020, indicate that laboratory studies of the adhesive interface give us the ability to accurately measure the strength of the bond, however, the weakest adhesive bonding forces can clinically effectively eliminate the function of a worn-out restoration in an empty tooth in patients with low risk [9,11,18,30,32,33]. The clinical effectiveness of adhesive restoration lies not only in the solidification of the correct adhesive and adhesive protocol, but also in the mechanical preparation of tooth tissue and the surface of ceramics, empty form, Isolation of the working field from the line, forms of restoration and occlusal interactions with antagonist teeth [29,32,34,35]. An equally important factor is the choice of dental cement and the method of preparing the restoration material before fixation [28,30,36].

## CONCLUSIONS

The content analysis of scientific publications conducted in this study highlights the presence of numerous unresolved issues in the field of adhesive dental technologies, necessitating further scientific inquiry and experimental research. Current investigations focus on optimizing the composition and structural properties of adhesive systems, integrating experimental functional monomers with antibacterial activity and enhanced chemical interactions with dental tissues, as well as developing substances capable of prolonging the inhibition of hybrid layer degradation.

An important area of ongoing research involves the refinement of adhesive protocols to facilitate deeper and more effective infiltration of demineralized dentin. This aspect is considered a critical determinant of adhesive bond longevity and, therefore, warrants prioritized study.

The systematization and standardization of knowledge regarding tooth tissue preparation, adhesive application techniques, and potential procedural errors and complications are essential for advancing the quality of dental care. Within the scope of the findings obtained and in accordance with the objectives of departmental research, it is feasible to establish optimal parameters for air-abrasive treatment of ceramic surfaces and dental hard tissues, assess their impact on adhesive bond strength, and investigate the influence of etching gel application methods and exposure duration on the micro-roughness of ceramic and dental tissue surfaces.

Furthermore, the study aims to evaluate the effects of various factors on adhesive bond strength within the ceramic/composite material system and to refine adhesive surface preparation protocols for both dental and ceramic substrates. The implementation of these advancements is expected to substantially reduce the risk of treatment-related complications, enhance the reliability of adhesive bonding, and improve the long-term success of ceramic restorations for the rehabilitation of dental hard tissue defects.

## REFERENCES

1. Udod OA, Moroz IO. Pryami fotokompozytsiini vidnovlenya zubiv: stan ta porushenya [Direct Photocomposite Restorations of Teeth: State and Disorders]. Inovatsii v stomatolohii. 2022;1:19–24. (Ukrainian)
2. Schärer BM, Peutzfeldt A. Impact of adhesive application errors on dentin bond strength of resin composite. Biomater Investig Dent. 2022;9(1):101–109. doi:10.1080/26415275.2022.2138405. DOI

3. Oike K, Takamizawa T, Aoki R et al. Comparison of dentin bond durability in different adhesive systems containing glycerol-phosphate dimethacrylate (GPDM) functional monomers under long-term water storage. Int J Adhes Adhes. 2023;124:103366. doi: 10.1016/j.ijadhadh.2023.103366. DOI
4. Hardan L, Bourgi R, Cuevas-Suárez CE et al. Effect of different application modalities on the bonding performance of adhesive systems to dentin: A systematic review and meta-analysis. Cells. 2023;12(1):190. doi:10.3390/cells12010190. DOI
5. Tavares FV, Maciel CM, Watanabe MU et al. Influence of adhesive systems containing different functional monomers on the longevity of bond strength at different dentin depths. Int J Adhes Adhes. 2024;132:103723. doi:10.1016/j.ijadhadh.2024.103723. DOI
6. Vilde T, Stewart CA, Finer Y. Simulating the intraoral aging of dental bonding agents: A narrative review. Dent J (Basel). 2022;10(1):13. doi:10.3390/dj10010013. DOI
7. Daher R, Krejci I, Mekki M et al. Effect of multiple enamel surface treatments on micro-shear bond strength. Polymers (Basel). 2021;13(20):3589. doi:10.3390/polym13203589. DOI
8. Gupta A, Tavane P, Gupta PK et al. Evaluation of microleakage with total etch, self-etch and universal adhesive systems in Class V restorations: An in vitro study. J Clin Diagn Res. 2017;11(4):53–56. doi:10.7860/JCDR/2017/24907.9680. DOI
9. Van Meerbeek B, Yoshihara K, Van Landuyt K et al. From Buonocore's pioneering acid-etch technique to self-adhering restoratives: A status perspective of rapidly advancing dental adhesive technology. J Adhes Dent. 2020;22(1):7–34. doi:10.3290/j.jad.a43994. DOI
10. Raji Z, Hosseini M, Kazemian M. Micro-shear bond strength of composite to deep dentin by using mild and ultra-mild universal adhesives. Dent Res J (Isfahan). 2022;19:44. doi:10.4103/1735-3327.35915717. DOI
11. Potapchuk AM, Krulyk VV. Suchasni metody restavratsii skoliv keramichnoho pokryttya metalokeramichnykh zubnykh proteziv [Modern Methods of Restoration of Ceramic Chipping in Metal-Ceramic Dental Prostheses]. Naukovyi visnyk Uzhhorodskoho universytetu. 2015;1(51):239–245. (Ukrainian)
12. Jafarnia S, Zeinaddini MJ, Zandkarimi F et al. Comparative evaluation of microtensile bond strength of three adhesive systems. Front Dent. 2022;19:8. doi:10.18502/fid.v19i8.8725. DOI
13. Almeida RAM, Lima SNL, Nassif MV et al. Eighteen-month clinical evaluation of a new universal adhesive applied in the «no-waiting» technique: A randomized clinical trial. Clin Oral Investig. 2023;27(1):151–163. doi:10.1007/s00784-022-04703-7. DOI
14. Borysenko OM. Udoskonalennya pidkhodiv do zastosuvannya adhezyvnykh system dlya vidnovlennya zubiv fotokompozytsiinymy materialamy [Improving Approaches to the Use of Adhesive Systems for Tooth Restoration with Photocomposite Materials] [Dissertation Abstract]. Lyman: Donetsk National Medical University. 2020,14 p. (Ukrainian)
15. Hiers RD, Huebner P, Khajotia SS et al. Characterization of experimental nanoparticulated dental adhesive resins with long-term antibacterial properties. Nanomaterials. 2022;12(21):3732. doi:10.3390/nano12213732. DOI
16. Yamanaka A, Mine A, Matsumoto M et al. Back to the multi-step adhesive system: A next-generation two-step system with hydrophobic bonding agent improves bonding effectiveness. Dent Mater J. 2021;40(4):928–933. doi: 10.4012/dmj.2020-272. DOI
17. Wang L, Bai X, Liu Y et al. The effect of an extra hydrophobic resin layer on the bond strength and durability of one-step universal adhesives used as a primer. J Dent. 2023;135:104568. doi: 10.1016/j.jdent.2023.104568. DOI
18. Meerbeek BV, Yoshihara K, Landuyt KV et al. From Buonocore's pioneering acid-etch technique to self-adhering restoratives: A status perspective of rapidly advancing dental adhesive technology. J Adhes Dent. 2020;22(1):7–34. doi:10.3290/j.jad.a43994. DOI
19. Hardan L, Bourgi R, Cuevas-Suárez CE et al. Effect of different application modalities on the bonding performance of adhesive systems to dentin: A systematic review and meta-analysis. Cells. 2023;12(1):190. doi:10.3390/cells12010190. DOI
20. Vilde T, Stewart CA, Finer Y. Simulating the intraoral aging of dental bonding agents: A narrative review. Dent J. 2022;10(1):13. doi:10.3390/dj10010013. DOI
21. Ziotti IR, Paschoini VL, Corona SA et al. Chitosan-induced biomodification on demineralized dentin to improve the adhesive interface. Restor Dent Endod. 2022;47(3):e28. doi:10.5395/rde.2022.47.e28. DOI
22. Moradian M, Saadat M, Sohrabniya F, Afifian M. The comparative evaluation of the effects of quercetin, α-tocopherol, and chlorhexidine dentin pretreatments on the durability of universal adhesives. Clin Exp Dent Res. 2022;8(6):1638–1644. doi:10.1002/cre2.667. DOI
23. Attia AM, Abo-Elezz AF, Safy RK. Effect of phytic acid on bond strength and interfacial integrity of universal adhesive to deep dentin. Braz Dent J. 2022;33(5):116–125. doi:10.1590/0103-6440202204810. DOI
24. Bielikov OB, Sorokhan MM. Porivnyalna kharakterystyka mostopodibnykh proteziv z miniinvazyvnym preparuvannyam opornykh zubiv [Comparative characteristics of bridge prostheses with minimally invasive preparation of abutment teeth]. Bukovynskyi medychnyi visnyk. 2017;1(81):224–229. doi:10.24061/2413-0737.XXI.1.81.2017.48. (Ukrainian) DOI
25. Mocharko V, Mascarenhas P, Azul AM et al. In search of novel degradation-resistant monomers for adhesive dentistry: A systematic review and meta-analysis. Biomedicines. 2022;10(12):3104. doi:10.3390/biomedicines10123104. DOI
26. Toledano M, Toledano-Osorio M, Hannig M et al. Zn-containing adhesives facilitate collagen protection and remineralization at the resin-dentin interface: A narrative review. Polymers. 2022;14(3):642. doi:10.3390/polym14030642. DOI

27. Valenti M, Valenti A, Schmitz JH et al. Survival analysis up to 7 years of 621 zirconia monolithic single crowns with feather-edge margins fabricated with a cast-free workflow starting from intraoral scans: A multicentric retrospective study. J Prosthet Dent. 2023;129(1):76–82. doi: 10.1016/j.prosdent.2022.05.029. DOI
28. Hardan L, Devoto W, Bourgi R et al. Immediate dentin sealing for adhesive cementation of indirect restorations: A systematic review and meta-analysis. Gels. 2022;8(3):175. doi: 10.3390/gels8030175. DOI
29. Ozer F, Batu Eken Z, Hao J et al. Effect of immediate dentin sealing on the bonding performance of indirect restorations: A systematic review. Biomimetics. 2024;9(3):182. doi: 10.3390/biomimetics9030182. DOI
30. Delgado A, Belmar Da Costa M, Polido MC et al. Collagen-depletion strategies in dentin as alternatives to the hybrid layer concept and their effect on bond strength: A systematic review. Sci Rep. 2022;12(1):13028. doi:10.1038/s41598-022-17371-0. DOI
31. Guo X, Yu Y, Gao S et al. Biodegradation of dental resin-based composite – A potential factor affecting the bonding effect: A narrative review. Biomedicines. 2022;10(9):2313. doi:10.3390/biomedicines10092313. DOI
32. Sabatini S, Aguilar R, Zhang Z et al. Mechanical characterization and adhesive properties of a dental adhesive modified with a polymer antibiotic conjugate. J Mech Behav Biomed Mater. 2022;129:105153. doi:10.1016/j.jmbbm.2022.105153. DOI
33. Lopes SR, Matuda AGN, Campos RP et al. Development of an antibacterial dentin adhesive. Polymers. 2022;14(12):2502. doi:10.3390/polym14122502. DOI
34. Frankenberger R, Tay FR. Self-etch, bonding: Self-etch, total-etch, and selective enamel etch adhesives in clinical dentistry. Oper Dent. 2021;46:E330–E345.
35. Malaquias P, da Silva LP, Lemos BF et al. Universal adhesives and dual-cured core buildup composite material: Adhesive properties. J Appl Oral Sci. 2020;28:e20200121. doi: 10.1590/1678-7757-2020-0121. DOI
36. Vichi A, Zhao Z, Paolone G et al. Factory crystallized silicates for monolithic metal-free restorations: A flexural strength and translucency comparison test. Materials. 2022;15(21):7834. doi: 10.3390/ma15217834. DOI

**CONFLICT OF INTEREST**
The Authors declare no conflict of interest

**CORRESPONDING AUTHOR**
**Anatoliy Potapchuk**
Uzhhorod National University
16a University St, 88000 Uzhhorod, Ukraine
e-mail: anatoliy.potapchuk@uzhnu.edu.ua

**ORCID AND CONTRIBUTIONSHIP**
Anatoliy Potapchuk: 0000-0001-9857-1407 A B E F
Vasyl Almashi: 0000-0002-2943-4844 A B E
Viktoria Demidowa: 0009-0005-3035-6651 E F
Nazar Basarab: 0009-0000-8280-8510 E F

A – Work concept and design, B – Data collection and analysis, C – Responsibility for statistical analysis, D – Writing the article, E – Critical review, F – Final approval of the article

**RECEIVED:** 19.10.2024
**ACCEPTED:** 28.03.2025