LITERATURE REVIEW

UNIVERSAL ADHESIVE SYSTEMS: A STATE-OF-THE-ART OVERVIEW

SISTEMAS ADESIVOS UNIVERSAIS: UM PANORAMA DO ESTADO DA ARTE

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ABSTRACT

Adhesive systems play a fundamental role in the adhesion of restorative materials to dental substrates. To make this adhesion more effective and long-lasting, these materials are in constant evolution, seeking to simplify the clinical steps and reduce the technique's sensitivity. The most recent generation of adhesives developed is the universal adhesives, which promise versatility and reduction of clinical steps. The aim of this study was to perform a literature review on universal adhesives and their characteristics. The literature review was performed by means of an electronic search in the Pubmed database. The literature shows that these adhesives chemically bond to tooth substrates and produce more stable and less hydrophilic dentin interfaces. However, some limitations exist when the use in self-etching mode is performed on enamel, and selective conditioning of this substrate is recommended. The use of these adhesives as a silane or primer in the cementation of glass-ceramics and metal alloys has also shown limitations. Nevertheless, in the cementation of zirconia-based ceramics and indirect composite resin-based restorations, the procedure can be simplified by the use of universal adhesives. Adhesive strength on dentin substrates under different conditioning modes varied between studies. As with any new material, long-term clinical evaluations are needed to demonstrate the efficacy of these universal adhesive agents, as reported in this literature review.

Keywords: Tensile Strength, Dentin Adhesives, Dental Materials.

RESUMO

Os sistemas adesivos têm papel fundamental na adesão de materiais restauradores aos substratos dentários. Para que esta adesão seja cada vez mais eficaz e duradoura, estes materiais encontram-se em constante evolução buscando a simplificação de passos clínicos e diminuição da sensibilidade da técnica. A mais recente geração de adesivos desenvolvida é a dos adesivos universais, os quais prometem versatilidade e redução de passos clínicos. O objetivo deste trabalho foi realizar uma revisão de literatura sobre os adesivos universais e suas características. O levantamento bibliográfico foi realizado por meio de uma busca eletrônica na base de dados Pubmed. A literatura mostra que estes adesivos ligam-se quimicamente aos substratos dentários e produzem interfaces dentinárias mais estáveis e menos hidrofílicas. No entanto, algumas limitações existem quando o uso no modo autocondicionante é realizado em esmalte, sendo recomendado o condicionamento seletivo deste substrato. O uso destes adesivos como silano ou *primer* na cimentação de cerâmicas vítreas e ligas metálicas também demonstrou limitações. No entanto, na cimentação de cerâmicas a base de zircônia e nas restaurações indiretas a base de resina composta, o procedimento pode ser simplificado pelo uso dos adesivos universais. A resistência adesiva em susbstrato dentinário sob diferentes modos de condicionamento variou entre os estudos. Como qualquer novo material, avaliações clínicas de longo prazo são necessárias para demonstrar a eficácia destes agentes adesivos universais, conforme relatado nesta revisão de literatura.

Palavras-chave: Resistência à Tração, Adesivos Dentinários, Materiais Dentários.

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INTRODUCTION

The adhesive procedures are in constant evolution since the introduction of the total acid etching technique by Buonocore in 1955 (1). Although a long-lasting and effective adhesion to enamel is already established, the demand for new techniques and materials still exists, since adhesion to dentin is still a complex and sensitive procedure, and there is also a demand for the reduction of clinical steps of acid etching, which tends to accelerate the appointment. In general, adhesives can be classified as total etching (conventional) or self-etching. This classification is made according to the form of demineralization of the tooth substrate and the treatment of the smear layer (2).

Conventional adhesives require acid etching of dental structures as a separate step, when there is a total removal of the smear layer (3), whereas the self-etching adhesives can modify the smear layer, simultaneously demineralizing and incorporating it to the dentin (4). In conventional systems, adhesion in enamel occurs by mechanical embrittlement, where the phosphoric acid increases the free surface area by creating microretentions, while in dentin there is a removal of the smear layer and exposure of collagen fibers due to demineralization (5). In this technique, the excessive drying of the conditioned dentin may cause the collapse of collagen fibers, leading to a deficient infiltration of the monomers present in the adhesive, which may reduce the bond strength (6).

In this sense, self-conditioning adhesives were introduced to eliminate the acid etching step, characterized by a highly sensitive step in the adhesive protocol. These adhesives condition and permeate the dentin simultaneously and are available in 1- or 2-bottle versions (3). In recent years, universal adhesive systems (UA) with a multimodal proposal have emerged. They are one step self-etching adhesives, which can be used with total acid etching, as self-etching or with enamel selective etching (7). Their differentials are the presence of functional monomers such as 2-methacryloyloxyethyl phenyl phosphate (Phenyl-P), 4-methacryloyloxyethyl anhydrotrimethyl (4-META) and 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) which chemically interact with the hydroxyapatite of the dental substrates forming calcium salts (8), and the presence of silane in some brands, which promises to simplify the protocol for adhesion to ceramics (9).

Thus, the objective of this study was to conduct a literature review on universal adhesives and their characteristics.

LITERATURE REVIEW AND DISCUSSION

A literature survey was carried out by means of an electronic search in the Pubmed database. The terms used were: “adhesive” or “adhesives” and “universal”. The search was restricted to English language articles published between the years 2010 and 2021, except for three articles with publication dates prior to this interval for historical reference contextualization purposes.

Emergence of the UA

The UA represent the manufacturers’ attempt to introduce versatility by adapting a single bottle self-conditioning adhesive to other application modes without compromising adhesive efficacy (5). When compared to previous generations, the main advantage of these adhesives is the indication for a wide variety of restorative procedures and adhesion strategies. Besides, they have functional monomers that confer the capacity of chemical bonding to dentin hydroxyapatite, promising a more stable and durable adhesive interface (10).

Kuraray was the pioneer brand in the use of these monomers in dental materials. When its patent on the 10-MDP functional monomer expired around 2003, its potential was explored by other manufacturers. In October 2009, Bisco, Inc. launched a zirconia primer, Z-Prime™, containing 10-MDP in its composition. 3M ESPE, 2 years later, launched Scotchbond™ Universal, also containing 10-MDP in its composition. In the same year, Bisco, Inc. launched its first UA, All-Bond Universal® containing 10-MDP. Thus, it is visible that the introduction of phosphate esters is apparently part of the history of UA (11).

Although Scotchbond™ Universal (3M ESPE) is the first adhesive marketed with the concept of universality, functional monomers such as Phenyl-P and 10-MDP have been part of Kuraray’s adhesives and cements since the 1980s (11). An example of a 10-MDP monomer formulation is Clearfil SE Bond (Kuraray), which due to its high shear bond strength and great stability over time has become the gold standard of self-etching adhesives, the generation before universal adhesives (2). Such monomers (Phenyl-P and 10-MDP) were created by Kuraray in 1976 and 1981, respectively, and are currently widely used and disseminated in the UA currently available in the market (12). Some examples of these adhesives are described in table 1, and the role of these monomers, as well as their mode of action on dental substrates, will be further discussed.

TABLE 1. CHARACTERISTICS OF SOME UNIVERSAL ADHESIVES.

Brand	Manufacturer	pH	Functional Monomer	Silane	Composition
Scotchbond™ Universal (3M ESPE)	3M ESPE (St. Louis) Paul, MN, USA).	2.7 Ultra Smooth	10-MDP	Yes	BisGMA, 10-MDP, Vitrebond copolymer, HEMA, ethanol, water, silane, initiators
Futurabond® U (Voco)	Voco (Cuxhaven, Germany	2.3 Soft	10-MDP	No	Liquid 1 - BISGMA, HDDMA, HEMA, adhesive of acidic monomer, UDMA, 10-MDP, silica Liquid 2-ethanol, initiators, catalyst
All-Bond Universal (Bisco Inc.)	Bisco (Inc, Schaumburg, Il, USA)	3.2 Ultra Mild	10-MDP	No	Resins from dimethacrylate, HEMA, BisGMA, 10-MDP, ethanol, water, initiators
Clearfil™ Universal (Kuraray)	Kuraray (Tokyo, Japan)	2.3 Soft	10-MDP	Yes	Dimethacrylate resins, 10-MDP, BisGMA, 2-HEMA, silane, silica, camphorquinone, ethanol, water, initiators
AdheSe® Universal (Ivoclar© Vivadent)	Ivoclar Vivadent (Schaan, Principality of Liechtenstein)	2.5 Ultra Mild	10-MDP	No	10-MDP, HEMA, BISGMA, D3MA, carboxylated methacrylic acid

HEMA - 2-hydroxyethyl methacrylate; BISGMA - Bisphenol glycidyl methacrylate; HDDMA - 1,6-hydroxyethyl methacrylate; HPMA - 2-hydroxypropyl methacrylate; UDMA - urethane; 10-MDP -Metacryloyloxyethyl dihydrogen phosphate, D3MA-hydrophobic dimethacrylate; Source: elaborated based on Burke et al., 2017 (3) and Cardoso et al., 2019 (13).

Versatility of UA

In general, UA can be defined as bonding agents which work in any conditioning mode that the clinician considers appropriate. Depending on the clinical situation, the conditioning of the substrates can be total, partial (when only the enamel is conditioned) or used in a self-conditioning mode (3). Some systems contain silane in their composition to simplify the protocol of adhesion to ceramic restorations. Thus, the clinician would not need to apply a separate solution of a silane agent after the ceramic is prepared or etched with hydrofluoric acid (HF) (10).

However, there are *in vitro* studies that challenge the efficacy of combining adhesive and silane in the same bottle. Kalavacharla et al. compared conditioning protocols with and without the use of a separate silane agent, using Scotchbond Universal adhesive (3M ESPE), which the manufacturer informs silane in the composition. Lithium disilicate ceramics were tested, and following the preparation protocol recommended by the manufacturer, the specimens were conditioned with 5% HF for 20 seconds. The results showed lower adhesive strength in the group treated with UA itself than in the groups in which silane was applied prior to bonding. Thus, the authors stated that since silane and 10-MDP were not effective in optimizing the bond between ceramic and resin, silane should always be applied prior to bonding on lithium disilicate ceramics (14).

A systematic review with meta-analysis conducted by Cuevas-Suárez and co-workers indicated a limited ability of UA to achieve adequate and durable adhesion to glass-ceramics and metal alloys, as the bond strength was shown to be greater with separate use of the silane or primer. On the other hand, the same study established that cementation of indirect zirconia and composite resin-based restorations can be simplified with the use of UA, and the bond strength is similar or even better when compared to the use of silane or primers applied separately (15).

Regarding the use of UA with the various strategies of conditioning of dental substrates, we must consider that self-conditioning adhesives such as UA contain acidic conditioning monomers and permeators of these substrates, dispensing the conditioning step with phosphoric acid (16). According to their acidity, these adhesives can be classified as strong, when the pH is less than 1; strong intermediate, with pH ranging between 1 and 2; mild, when the pH is approximately 2; and ultra-mild, with pH being greater than 2.5 (17). The pH of most UA lies between the mild and ultra-mild ranges.

These pH ranges effect adhesion on dentin but may not be as effective on enamel, especially on intact enamel (11).

Thus, similar to the reports of these adhesives, a reduction in the bonding effectiveness to enamel can be expected when UA are applied in a self-conditioning strategy (18). Cardenas *et al.* suggest that active application (friction) and for a longer time is a strategy that ensures a better micromechanical interaction between UA and enamel. Comparing the phosphoric acid etching to the self-conditioning mode, their results indicated a gain in the degree of conversion, better retention pattern of the enamel and higher bond strength when the UA was actively applied for 40 seconds (19).

However, using microtraction tests to evaluate the adhesive strength, one study stated that enamel etching with phosphoric acid may not be crucial for the adhesion of UA, and that the active application of these adhesives in the self-conditioning strategy may be a practical alternative to selective enamel etching, considering only the adhesion aspect. In self-conditioning mode, 5 out of the 7 tested adhesives showed statistically higher degree of conversion and adhesive strength when actively applied. Moreover, each adhesive actively applied in a self-conditioning mode resulted in an average adhesive strength statistically similar to that obtained by applying the same adhesive to enamel conditioned with phosphoric acid (20).

Conversely, a systematic review with meta-analysis, updated in 2019, by Cuevas-Suárez and colleagues, pointed out that the bond strength of UA to enamel increases with prior conditioning using phosphoric acid, besides selective enamel conditioning is still indicated to achieve long-lasting and effective adhesion to this substrate (21).

Regarding dentin, phosphoric acid conditioning removes calcium, leaving behind a 2 to 5 µm-thick area of exposed collagen fibers. For some authors, it is unclear at this point whether, and how, UA containing the functional monomer 10-MDP are able to bind ionically to calcium-deficient treated dentin (22).

Campos *et al.* evaluated *in vitro* the adhesive strength of dentin conditioned with phosphoric acid prior to the use of UA in cementation of indirect composite resin restorations. Three different adhesives and the amine-free RelyX Ultimate cement were used. The results showed that the groups in which the dentin was acid etched presented significantly lower bond strength values in the push-out test. Hence, acid etching of the dentin significantly reduced the bond strength between UA systems and dentin in indirect restorative procedures (23).

Cardoso *et al.* evaluated the immediate bond strength and after 6 months of 5 UA applied in conventional mode or in self-conditioning mode. As a control group, gold standard adhesives were used, namely Scotchbond Multipurpose Plus (3M ESPE) and Clearfil SE Bond (Kuraray). The authors concluded that the performance of the UA is material-dependent, and most of the agents tested had stable adhesion to dentin with results similar to gold standard adhesives, especially in the self-etch mode. Nevertheless, there were no significant differences in bond strength between the strategies used. The authors suggested, though, that the self-conditioning mode produces more stable bonds, due to the observation of a smaller decrease in bond strength after aging. Thus, the authors recommend that the application of UA to dentin should not be preceded by phosphoric acid etching (13).

Another even more recent study comparing the effect of phosphoric acid on dentin prior to the use of a 10-MDP-containing adhesive with a 10-MDP-free adhesive from the same manufacturer revealed higher bond strengths for the 10-MDP-containing adhesive even in the group that acid etching was applied, showing important questions about the interaction between adhesives containing 10-MDP and their application on phosphoric acid etched dentin (24).

Functional monomers and chemical adhesion

10-MDP is a functional monomer common to most UA that ensures not only a micromechanical bond, through the hybrid layer, but also binds ionically to calcium through a hydrophilic group (Figure 1) present in the molecule (3). This chemical bond was first demonstrated in 2004 by Yoshida et al (25).

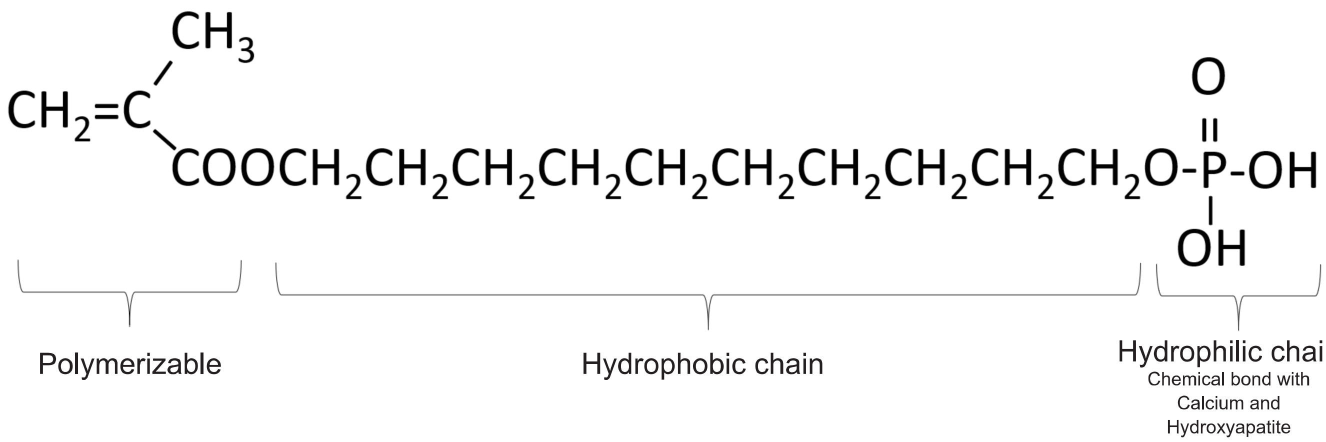

Figure 1. *Chemical structure of 10-MDP with its phosphate grouping (hydrophilic), its methacrylate grouping (polymerizable) and its long carbon chain (hydrophobic group).*
Source: adapted from Alex, 2015 (11).

When the adhesive containing MDP is rubbed onto dentin, the surface is partially demineralized to a depth of 0.5 to 1 µm. Calcium ions are released, due to a partial dissolution of the hydroxyapatite and diffuse into the hybrid layer and chemically bond to the MDP molecules forming nano-layers, as seen in Figure 2a. This process forms an MDP-Ca salt (26). These salts stay among the layers, and this is what holds them together (27). Theoretically the size of an MDP molecule is approximately 1.95 nm. Each of these nanolayers is made up of two MDP molecules, with their methacrylate groups directed towards each other and their phosphate functional groups directed away from each other. Thus, 3.90 nm is the approximate size of the nano-layer (Figure 2b) (28).

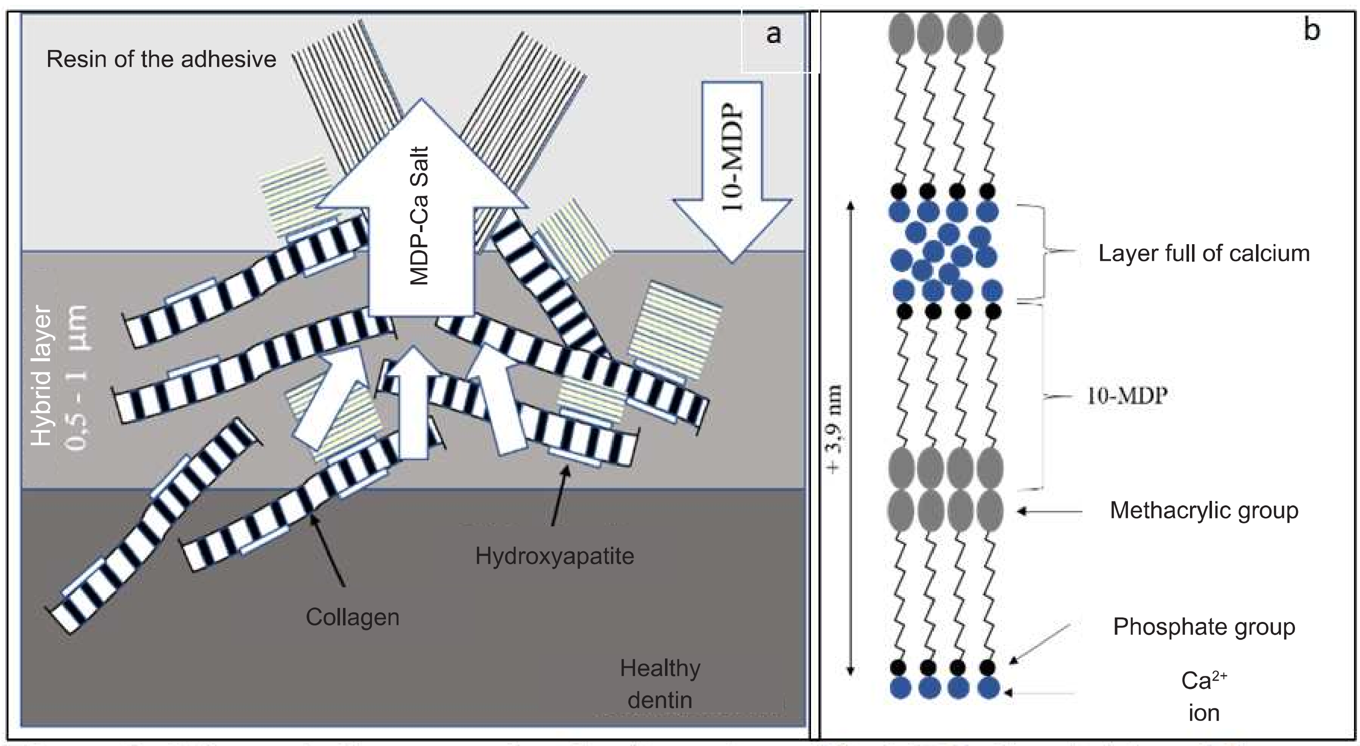

Figure 2. *Schematic demonstrating the formation of the MDP-Ca salt (a) and the nanolayers (b). Source: adapted from Yoshida et al. , 2012 (26).*

This nanolayer process is not identified with the functional monomers 4-META and Phenyl-P (27). Furthermore, data from previous studies comparing the adhesive efficacy of these three functional monomers revealed that the binding potential of 10-MDP to hydroxyapatite is significantly higher than that of 4-META, as an efficient chemical bond is achieved within 30 seconds. Only a strong binding potential is insufficient though. The ionic bonds must also be stable in an aqueous environment. In this sense, the chemical bond promoted by 10-MDP, besides being more effective, is more stable in water than that provided by 4-META and Phenyl-P, respectively. The dissolution rate of these calcium salts in the three monomers, as measured by atomic absorption spectroscopy, is inversely proportional to their chemical bonding potential. Thus, the more intense the binding power, the less soluble the resulting calcium salt will be (25).

Carrilho et al. stated in their systematic review that the selection of an UA system containing 10-MDP seems to be the safest choice due to its favorable molecular structure, hydrophobic behavior and adhesive interface characteristics that favor bond strength and durability. However, it recommends selective enamel conditioning to get the best out of these formulations and recalls the need for an active application on dentin. The clinician should allow time for the monomers to permeate, hybridize, and form the calcium salts that will protect the collagen fibers, improving adhesive stability (29).

Compatibility with chemical and dual-cure cements

Several reports have pointed out that simplified adhesives are incompatible with chemical and dual-cure resin cements, due to a reaction between the acidic monomers of these adhesives with the tertiary amines responsible for initiating the polymerization reaction of the cements. To circumvent this incompatibility, manufacturers of UA currently make polymerization activators separately. These activators are based on sulfinic acid salts and should be used with their adhesives whenever chemical or dual-cure cements are required. Some manufacturers also offer dual-cure cements free of tertiary amines, avoiding the use of separate activators, as is the case of RelyX Ultimate from 3M ESPE (3,30).

Most of the available literature on the incompatibility between simplified adhesives and dual-cure or chemical cements is based on the previous generation of self-etching adhesives. However, new adhesives with less hydrophilic and less water-permeable characteristics have been developed and are available on the market today. The addition of 10-MDP and its long carbon chain gives the UA interfaces with more hydrophobic characteristics than the previous generation (31).

Gutiérrez *et al.* after evaluating 3 UA used in the self-conditioning mode with dual-cure cements concluded that micro shear strength and nanoinfiltration were influenced by the different polymerization modes of the cements and the addition of polymerization activators, even though the authors stated that the influence was material-dependent (32).

In contrast, in 2020, Malaquias *et al.* evaluated, *in vitro,* 3 UA with polymerization activators added separately. The criteria tested were micro shear strength and nanoinfiltration when used in a total acid etching strategy and in association with dual-cure cements. The authors concluded that, in the total etching mode, the addition of polymerization activators to the UA and the different polymerization modes of the dual cements did not influence the micro shear bond strength. Regarding nanoinfiltration, some interactions were observed, which the authors also reported to be material-dependent (31). Based on this background, it is clear that further studies evaluating the incompatibility between dual-cure cements and UA are needed. The role of polymerization activators on the adhesive strength and the degree of conversion of dual-cure and chemically-cured resin cements is not yet well delineated in the literature.

CONCLUSION

This review pointed out that the UA are the adhesive class that seems to offer a more stable and durable dentin interface, due to the use of functional monomers. However, adhesive strength against different conditioning modes of this substrate was shown to be material-dependent in some studies while in others it showed no statistically significant difference. Thus, further studies are needed to elucidate the interaction of these adhesives with previously etched dentin. The literature has also shown that for adhesion to enamel, selective conditioning is still recommended to obtain maximum performance on this substrate. It was evident that the use of these adhesives in indirect procedures has limitations, and the separate use of a silane agent or primer is still recommended for glass-ceramics and metal alloys.

Incompatibility between UA systems and chemically or dual-cured cements appears to be resolved by the introduction of separate polymerization activators, but further studies are needed to evaluate the effects of these activators on adhesive strength to dental substrates and the degree of conversion of dual-cured cements.

The authors declare that they have no conflicts of interest.

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REFERENCES

1. Buonocore, MG. A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. J Dent Res. 1955;34(6):849-53.
2. Beltrami R, Chiesa M, Scribante A, Allegretti J, Poggio C. Comparison of shear bond strength of universal adhesives on etched and nonetched enamel. J Appl Biomater Funct Mater. 2016;14(1):e78-83.
3. Burke FJT, Lawson A, Green DJB, Mackenzie L. What's New in Dentine Bonding?: Universal Adhesives. Dent Update. 2017;44(4):328-40.
4. Tay FR, Pashley DH. Aggressiveness of contemporary self-etching systems. I: Depth of penetration beyond dentin smear layers. Dent Mater. 2001 Jul;17(4):296-308.
5. Chen C, Niu LN, Xie H, Zhang ZY, Zhou LQ, Jiao K, *et al.* Bonding of universal adhesives to dentine--Old wine in new bottles? J Dent. 2015;43(5):525-36.
6. Muñoz MA, Luque I, Hass V, Reis A, Loguercio AD, Bombarda NH. Immediate bonding properties of universal adhesives to dentine. J Dent. 2013;41(5):404-11.
7. Wagner A, Wendler M, Petschelt A, Belli R, Lohbauer U. Bonding performance of universal adhesives in different etching modes. J Dent. 2014;42(7):800-7.
8. Yoshihara K, Hayakawa S, Nagaoka N, Okihara T, Yoshida Y, Van Meerbeek B. Etching Efficacy of Self-Etching Functional Monomers. J Dent Res. 2018;97(9):1010-6.
9. Yoshihara K, Nagaoka N, Sonoda A, Maruo Y, Makita Y, Okihara T, *et al.* Effectiveness and stability of silane coupling agent incorporated in 'universal' adhesives. Dent Mater. 2016;32(10):1218-25.
10. Perdigão J, Swift EJ. Universal Adhesives. J Esthet Restor Dent. 2015;27(6):331-4.
11. Alex G. Universal adhesives: the next evolution in adhesive dentistry? Compend Contin Educ Dent. 2015;36(1):15-26.
12. Kuraray [Internet]. MDP Monomer. [accessed 2020 Nov 28]. Available from: https://kuraraydental.com/clearfil/key-technologies/mdp-monomer/
13. Cardoso GC, Nakanishi L, Isolan CP, Jardim PDS, Moraes RR. Bond Stability of Universal Adhesives Applied To Dentin Using Etch-And-Rinse or Self-Etch Strategies. Braz Dent J. 2019;30(5):467-75.
14. Kalavacharla VK, Lawson NC, Ramp LC, Burgess JO. Influence of Etching Protocol and Silane Treatment with a Universal Adhesive on Lithium Disilicate Bond Strength. Oper Dent. 2015;40(4):372-8.
15. Cuevas-Suárez CE, de Oliveira da Rosa WL, Vitti RP, da Silva AF, Piva E. Bonding Strength of Universal Adhesives to Indirect Substrates: A Meta-Analysis of in Vitro Studies. J Prosthodont. 2020;29(4):298-308.
16. Choi AN, Lee JH, Son SA, Jung KH, Kwon YH, Park JK. Effect of Dentin Wetness on the Bond Strength of Universal Adhesives. Materials (Basel). 2017;10(11):1224.
17. Van Meerbeek B, Peumans M, Poitevin A, Mine A, Van Ende A, Neves A, *et al.* Relationship between bond-strength tests and clinical outcomes. Dent Mater. 2010;26(2):e100-21.
18. Pashley DH, Tay FR. Aggressiveness of contemporary self-etching adhesives. Part II: etching effects on unground enamel. Dent Mater. 2001;17(5):430-44.
19. Cardenas AM, Siqueira F, Rocha J, Szesz AL, Anwar M, El-Askary F, *et al.* Influence of Conditioning Time of Universal Adhesives on Adhesive Properties and Enamel-Etching Pattern. Oper Dent. 2016;41(5):481-90.
20. Loguercio AD, Muñoz MA, Luque-Martinez I, Hass V, Reis A, Perdigão J. Does active application of universal adhesives to enamel in self-etch mode improve their performance? J Dent. 2015;43(9):1060-70.
21. Cuevas-Suárez CE, da Rosa WLO, Lund RG, da Silva AF, Piva E. Bonding Performance of Universal Adhesives: An Updated Systematic Review and Meta-Analysis. J Adhes Dent. 2019;21(1):7-26.
22. Perdigão J, Loguercio AD. Universal or Multi-mode Adhesives: Why and How? J Adhes Dent. 2014;16(2):193-4.
23. Campos MFTP, Moura DMD, Borges BCD, Assuncao IV, Caldas MRGR, Platt JA, et *al.* Influence of Acid Etching and Universal Adhesives on the Bond Strength to Dentin. Braz Dent J. 2020;31(3):272-80.
24. Hidari T, Takamizawa T, Imai A, Hirokane E, Ishii R, Tsujimoto A, *et al.* Role of the functional monomer 10-methacryloyloxydecyl dihydrogen phosphate in dentin bond durability of universal adhesives in etch-&-rinse mode. Dent Mater J. 2020;39(4):616-23.
25. Yoshida Y, Nagakane K, Fukuda R, Nakayama Y, Okazaki M, Shintani H, *et al.* Comparative study on adhesive performance of functional monomers. J Dent Res. 2004;83(6):454-8.
26. Yoshida Y, Yoshihara K, Nagaoka N, Hayakawa S, Torii Y, Ogawa T, *et al.* Self-assembled Nano-layering at the Adhesive interface. J Dent Res. 2012;91(4):376-81.
27. Yoshihara K, Yoshida Y, Nagaoka N, Fukegawa D, Hayakawa S, Mine A, *et al.* Nano-controlled molecular interaction at adhesive interfaces for hard tissue reconstruction. Acta Biomater. 2010;6(9):3573-82.
28. Yoshihara K, Yoshida Y, Hayakawa S, Nagaoka N, Irie M, Ogawa T, *et al.* Nanolayering of phosphoric acid ester monomer on enamel and dentin. Acta Biomater. 2011;7(8):3187-95.
29. Carrilho E, Cardoso M, Marques Ferreira M, Marto CM, Paula A, Coelho AS. 10-MDP Based Dental Adhesives: Adhesive Interface Characterization and Adhesive Stability-A Systematic Review. Materials (Basel). 2019;12(5):790.
30. Madrigal EL, A T, Hosaka K, Ikeda M, Nakajima M, Tagami J. The effect of curing mode of dual-cure resin cements on bonding performance of universal adhesives to enamel, dentin and various restorative materials. Dent Mater J. 2021 Mar 31;40(2):446-454.
31. Malaquias P, Gutiérrez MF, Sutil E, Matos TP, Hanzen TA, Reis A, *et al.* Universal adhesives and dual-cured core build-up composite material: adhesive properties. J Appl Oral Sci. 2020;28:e20200121.
32. Gutiérrez MF, Sutil E, Malaquias P, de Paris Matos T, de Souza LM, Reis A, *et al.* Effect of self-curing activators and curing protocols on adhesive properties of universal adhesives bonded to dual-cured composites. Dent Mater. 2017;33(7):775-87.