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REVIEW

The Classification and Selection of Adhesive Agents; an Overview for the General Dentist

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Abstract: Adhesive agents are essential to most restorative procedures used in everyday practice. Depending on the clinical situation, the dentist will choose among a rapidly evolving variety of adhesive agents (bonding agents). Due to the availability of many adhesive agents, appropriate selection can take time and effort. Typically, a practitioner relies more on marketing and experience than in-depth material knowledge. The classification of adhesive agents may need to be clarified and easier to remember due to its lack of relevance to clinical procedures. This paper reviews the published literature retrieved from PubMed, Google Scholar, and Scopus by using specific keywords "adhesive agents", "classification", "dentin", "enamel", "universal", "self-etch", "etch-and-rinse", and "bonding". The titles and abstracts were screened, and the relevant literature was retrieved. The list of references from each identified article was examined to find other potentially relevant articles. Adhesive agents can be classified as etch-and-rinse, self-etch, or "multi-mode" according to their approach to interacting with the smear layer, and each approach can be further classified according to the number of clinical steps required during application. This article reviews the classification of current adhesive agents and discusses the properties that make a specific adhesive agent the optimal choice for a particular clinical indication. The review will assist the general dentist in understanding the various types of available adhesive agents and how they function. Overall, the review will facilitate decision-making and allow the selection of appropriate materials.

Keywords: adhesive agents, bonding agents, classification, dentine, enamel, etch-and-rinse, self-etch, universal adhesives

Introduction

Restorative dentistry aims to treat carious or fractured teeth, restoring their structure, function, and aesthetics.[1,2] Advancements in dental materials and techniques have changed how dentists approach restorative dentistry.[3] Adhesive dentistry led to a paradigm shift in dental practice by allowing dentists to perform minimally invasive procedures, preserve tooth structure, and achieve superior aesthetic outcomes.[4,5] Selecting and applying the appropriate adhesive agent from the wide range of adhesives available is crucial to ensuring the success of direct and indirect restorative procedures.[2,6]

Adhesive agents are commonly categorized from the first to the eighth generation.[4,7] The concept of "generation" refers to "when" and in "what order" the manufacturer developed the adhesive.[7] Each new generation attempts to simplify the bonding procedure, provide faster application techniques, and offer enhanced chemistry to promote stable and durable bonding.[8] The generations overlap, and the classification becomes complex due to the perpetual development of adhesive agents, making generational classification problematic and unclear.[9] The other problem with referring to adhesive systems by generation is the misconception that the adhesive system will be better as we go higher in generations.[10]

A classification of adhesive systems reflecting their approach to interacting with the smear layer rather than "generation" has been proposed.[11] Etch-and-rinse (ER) and self-etch (SE) adhesives are the primary categories into which dental adhesives fall. According to the number of application steps during the application, ER adhesive systems are subdivided into "three-step (3-step ER)" and "two-step (2-step SE)" adhesives.[12] The SE adhesive systems, in contrast, are further classified into "two-step (2-step SE)" and "one-step (1-step SE)" adhesives.[13] The most recent generation of adhesives developed is the universal adhesives. These adhesives provide versatility and reduction in

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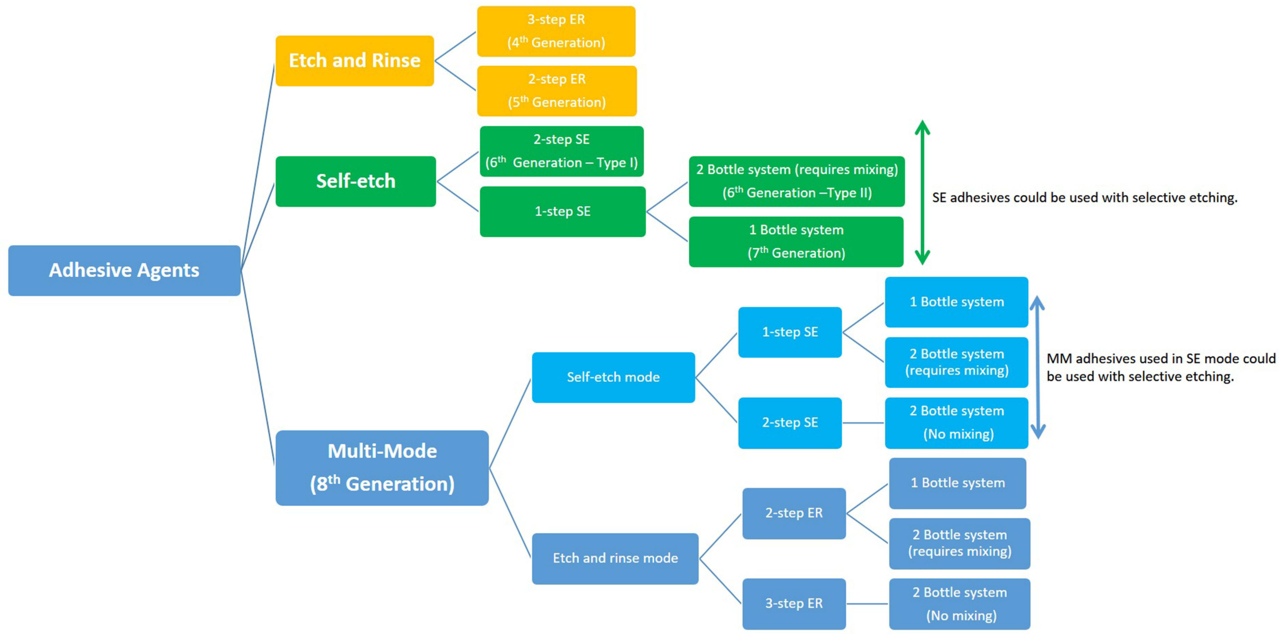

Figure 1 The classification of contemporary adhesive agent systems based on the approach to removing the smear layer and the number of application steps.
Note: The corresponding generations were included in brackets.

clinical steps. These adhesives are "universal" in two main ways: First, they can be applied to the tooth structures using any application approach (ER, SE, or selective etch) with claims by manufacturers that there is no compromise on bonding effectiveness when either bonding strategy is employed. Second, they can be used on a wide range of substrates; they can be used to bond to dentin and enamel, for the placement of both direct and indirect restorations.[14] Figure 1 shows the classification of adhesive agents.

When it comes to adhesive agents, the dental practitioner has various options, each with its clinical considerations. Choosing an adhesive agent is a critical decision that will affect the procedure's long-term success. Therefore, knowing the classification of the contemporary adhesive agents will assist the general dental practitioner make decisions. This paper reviews the classification of current adhesive agents and discusses the properties that make a specific adhesive agent the optimal choice for a particular clinical indication.

Materials and Method

A literature search was carried out in Google Scholar, PubMed and Scopus on the classification of adhesive agents. Search terms included the following MeSH terms in various combinations: "adhesive agents", "etch and rinse", "self-etch", "universal", "bonding", "enamel", "dentine". Related articles that appeared in various search engines were retrieved and evaluated. The reference lists from the identified articles were examined to find other potentially relevant articles. The cross-referencing process went on until no new articles were identified. No limits were imposed on the year of publication, but only full-text articles in English were considered.

Review

Enamel and dentin are two distinct components of a tooth's structure. Understanding these distinctions helps dental professionals tailor adhesive techniques to ensure reliable and durable bonds in both tooth components.[15] Enamel is a homogeneous substrate, by weight percentage, enamel is 96% inorganic matrix and 4% organic material, as well as water, which occupies the free spaces between hydroxyapatite crystals (HA).[16] The hydrophobic nature of enamel (due to the low water content) makes it an ideal and predictable substrate for micromechanical adhesion. On the other hand, the structure of the dentin poses some challenges during the adhesive procedure. On a weight basis, dentine is made up of 70% inorganic matrix, 20% organic matrix (mainly type 1 collagen), and 10% water.[16] The high protein and water content of dentin makes it a very heterogeneous and dynamic substrate, increasing the difficulty of the bonding procedure. To date, resin-dentin bonds created by infiltration of hydrophilic resin monomers into demineralized dentin are imperfect.[17,18] Incomplete permeation of monomer into the full depth of demineralized region may, however, leave, water-filled, exposed collagen fibrils that are unprotected from denaturation challenges[19] and cause nanoleakage of water into these regions through a 20–100 nm sized marginal gap, leading to subsequent hydrolytic degradation of these collagen fibrils and the hybrid layer.[20] The effect of hydrolytic (water-related) degradation seriously compromises the long-term integrity of the adhesive interface and the durability of the bond strength.[20]

The Etch-and-Rinse Adhesives

With ER adhesive systems, phosphoric acid is used to etch the enamel and dentin. Phosphoric acid etching raises the enamel's surface energy and demineralizes the inorganic hydroxyapatite. Etching creates microporosities within which the resin tag extensions of the adhesive agent interlock micromechanically.[21] On dentine, the acid removes the smear layer and open dentin tubules increasing dentin permeability and demineralizing the most superficial 1–5 μm of dentin, leaving behind a network of collagen fibers filled with water left from rinsing the acid.[22–24]

After etching and rinsing, excessive air drying of the dentin should be avoided. Overdrying the etched dentine causes the collapse of the demineralized collagen network and, consequently, the loss of the interfibrillar spaces.[8] The loss of interfibrillar spaces makes it hard for the adhesive monomers to diffuse into the etched dentine structure, resulting in poor hybridization and low bond strength.[12] The "wet bonding technique" was proposed[25] to solve the issues associated with bonding to over-dried dentine. The "wet bonding technique" implies that the etched dentin is kept slightly moist during adhesive procedures to keep the interfibrillar spaces. This helps the diffusion of primer and adhesive monomers into the demineralized dentine and favors the hybridization process.[25–27] Overall, determining "how wet dentine should be" makes the dentin bonding technique extremely sensitive. Moreover, achieving 'moist dentine' is not straightforward, as the enamel needs to be dried for bonding, and it is challenging to dry enamel alone without drying the dentine.

Solvents are essential components of dental adhesives and critical for optimal bonding to enamel and dentin.[28] Solvents dilute the viscous monomers, and are mainly responsible for water displacement from the demineralized dentin, and facilitate their infiltration into the collagen network.[25,29] Some adhesives contain acetone, whereas others contain water and/or ethanol.[29] Acetone is a water-chaser; acetone-based adhesive agents are highly sensitive to the moisture level of the acid-etched dentin surface. Using acetone-based adhesives on over-dried acid-etched dentin surfaces can lead to poor results as they cannot re-expand the collapsed collagen network.[30] Therefore, when an acetone-based ER adhesive is used for dentin bonding, it is necessary to keep the demineralized dentin moist and avoid over-drying the etched dentine (wet-bonding technique).[31,32] However, it is challenging to determine dentine's moisture content when such adhesives are used clinically. Ethanol is currently the solvent most commonly used in adhesive agents. It is used either alone or with water as a co-solvent. These systems are less sensitive to the moisture level, are good at re-expanding the collagen matrix, and yield higher bond strength in dry dentin.[30] Normally, applying one coat of the adhesive agent from this category is sufficient to cover the entire surface; additional coats may result in a thick layer of solvent between layers. Therefore, it should be noted that using the same bonding procedure for different adhesive systems with different solvents, volatilities, and water displacement capacities may have unfavorable results.[33]

Three-Step Etch-and-Rinse Adhesives

The 3-step ER system is applied using a separate etchant, primer, and bonding resin (adhesive resin). The most frequently used etching agent is phosphoric acid, used in gel form. The acid is used in a 30 to 40% concentration with a pH of 0.1 to 0.4. Most etching agents are colored gels (thickened with silica microparticles) to control application and ensure all the gel is rinsed off the tooth surface.[4] The primer incorporates one or more hydrophilic monomers with an organic solvent (acetone, ethanol, and/or water). The primer removes the water in the etched dentin and makes it easier for the adhesive resin monomers in the primer to penetrate the acid-etched collagen network.[8] Once placed on the tooth surface, primers should not be rinsed off or light-cured; they are only air-dried to evaporate the solvent and decrease the thickness of the adhesive layer before applying the bonding resin.[34,35] The bonding resin (adhesive resin) is a hydrophobic solvent-free unfilled resin applied over the primer and then light-cured.[36] The hydrophobic bonding resin copolymerizes with and covers the hydrophilic polymerized primer, making it less susceptible to water sorption.[8] The solvent-free adhesive resins must be gently air-blown before light curing. This is not for solvent evaporation but rather uniform and even distribution of the adhesive layer.

Two-Step Etch-and-Rinse Adhesives

The 2-step ER system (so-called one-bottle system) was introduced to reduce the number of clinical steps and simplify the procedure. In the 2-step ER adhesive systems, the hydrophilic primer and hydrophobic bonding resin are coupled with solvent(s) in the same bottle (self-priming adhesives).[8] This is achieved by incorporating higher concentrations of hydrophilic monomers, such as 2-hydroxyethyl methacrylate (HEMA), to stabilize the mix and facilitate the diffusion of the self-priming adhesive into the demineralized collagen network of the etched dentin. Due to the high concentration of HEMA, the literature reports that 2-step ER systems can be more susceptible to water degradation at the resin–dentin interface than three-step ER systems.[3,37]

The Self-Etch Adhesives

SE adhesives incorporate acidic functional monomers with a carboxyl or phosphate group that "etches" and "primes" the tooth substrate at the same time. These adhesives leave the smear layer in place. The acidic functional monomers in SE adhesives infiltrate and modify the smear layer and demineralize the underlying tooth substrate.[22,38] As a result, the dissolved smear layer and demineralization products are not rinsed away but incorporated in the hybrid layers.

Water, an inorganic and polar solvent, is a fundamental ingredient of SE adhesives. It provides the medium for ionizing the acidic monomers to demineralize dentin.[29] Therefore, water is always incorporated alone or with ethanol as a co-solvent in SE adhesives.[28] Consequently, SE adhesives are less affected by moisture on the dentinal surface than ER adhesives as ER adhesives are.[28] Hence, the technique sensitivity associated with the moisture level of the dentine is no longer a concern for the practitioner.

Although SE adhesives are user-friendly, their inability to etch enamel effectively and phosphoric acid is a crucial shortcoming, as they result in a shallow enamel-etching pattern that may result in marginal discoloration and debonding at the margins.[4] To address this issue, selective enamel etching, wherein phosphoric acid in a concentration between 30 and 50% for less than 15 sec is used to etch the enamel before the SE adhesive is applied, has been suggested.[39,40] It should be noted that applying the phosphoric acid etchant and the SE system differs from the conventional ER system. Therefore, the practitioner should avoid etching the dentine during the enamel bonding.

The bond strength to the tooth structure may differ depending on the pH level and etching aggressiveness. SE adhesives can be categorized into strong (pH $\leq$ 1), intermediately strong (pH 1–2), mild (pH ~2), and ultra-mild SE adhesives (pH > 2.5).[13] Mild SE adhesives provide excellent dentin bond strengths and poorer enamel bonds. In contrast, more aggressive SE systems provide the opposite—strong SE adhesives induce deep demineralizing effects on both enamel and dentine. For enamel, the acid-etch pattern created by strong SE adhesives resembles the pattern created by phosphoric acid etching. However, it differs from the phosphoric acid etching as the dissolved calcium phosphates are not rinsed away; these embedded calcium phosphates are very unstable and may compromise the integrity of the dentine-adhesive interface. The "ultra-mild" SE adhesives interact superficially with the tooth substrates. They can only expose dentin collagen superficially, producing "a nanohybrid layer" instead of a discrete hybrid layer.[41,42]

Two-Step Self-Etch Adhesives

In the 2-step SE adhesive systems, a self-etching primer that simultaneously "conditions" and "primes" the dental substrate is applied on enamel and dentin, air-dried, followed by applying and polymerizing a separate hydrophobic bonding resin. The advantage of the two-step SE adhesives is that their efficacy is less dependent on the dentin's moisture level than the ER adhesives. Generally, 2-step SE adhesives were reported to have better bonding ability than one-step SE adhesives.

One-Step Self-Etch Adhesives

The 1-step SE (all-in-one) adhesives incorporate all the fundamental steps for bonding in one bottle. These adhesives have been made more hydrophilic and acidic than their two-step counterparts to keep these complex chemical mixtures stable. The 1-step SE adhesives are categorized into one- and two-component systems: the first system incorporates all the fundamental bonding components into one bottle. Hence, the dental surfaces' etching, priming, and bonding are accomplished simultaneously in one step, while the other system is supplied in two bottles; the practitioner must mix the two components before application. Some manufacturers use this approach to keep water separated from the functional monomers until the time of application to avoid monomer degradation inside the bottle that might happen due to the hydrolysis of the ester groups of the resins,[43] which limits their shelf life. Examples of 1-step SE adhesive that requires mixing before application include One-up Bond F Plus (Tokuyama Dental Corporation, Tokyo, Japan), Xeno III (Dentsply Caulk, Milford, DE, USA) Adper Prompt L-Pop (3M ESPE, St Paul, MN, USA), All-Bond SE (Bisco Inc, Schaumburg, IL, USA), Brush&Bond (Parkell), Futurabond NR (VOCO, Cuxhaven, Germany).

The omission of the separate application of the hydrophobic bonding resin in the 1-step SE adhesives makes them more prone to hydrolytic degradation and poor clinical performance.[4,44–47] The 1-step SE adhesives have been reported to have low immediate and long-term dentin bond strengths,[48,49] poor bonding to intact enamel,[39] incompatibilities with self-curing resins,[50] reduced shelf-life,[51] poor clinical outcomes,[44,46] among other shortcomings.[4,48,52] Also, a meta-analysis of the literature showed that 1-step SE adhesives had weaker bonding ability than 2-step SE adhesives.[53]

The 1-step SE and 2-step ER adhesives are simplified variants of the 3-step ER and 2-step SE adhesives. Simplified adhesives are user-friendly and have become very popular as dentists tend to select materials that are easier to use.[54] Despite their user-friendliness and lower technique sensitivity, the simplification of the adhesive approach has resulted in a lower efficacy and reduced durability.[4,37,44] Due to their hydrophilicity and exclusion of hydrophobic bonding resin coating, cured adhesive layers may function as permeable membranes,[55] allowing water to pass through the adhesive layer. According to the literature, dental adhesives that include a hydrophobic bonding resin as the final step of the clinical procedure, that is, 3-step ER adhesives and 2-step SE adhesives, are more stable and produce more durable restorations than their simplified counterparts. Some manufacturers offer hydrophobic liners combined with the 1-step SE adhesive (All-Bond SE/All-Bond SE liner, Bisco).

HEMA is a water-soluble monomer frequently incorporated in simplified dental adhesives. It enhances adhesive systems' wetting properties and the adhesive's infiltration into the collagen network. Because of its solvent-like properties, it is also added to improve the miscibility and stability of hydrophobic and hydrophilic components. It keeps the ingredients in the solution and prevents phase separation.[29] Its high hydrophilicity over time increase water uptake and results in hydrolytic degradation of the adhesive interface.[56] Therefore, HEMA-free adhesives were introduced to avoid HEMA's adverse effects.[3] There is no consensus regarding the influence of HEMA the on the clinical performance of composite restorations. The clinical performance of HEMA-free and HEMA-containing adhesive systems has been proven to be comparable in some investigations. However, other studies showed that the adhesive systems (HEMA-free and HEMA-containing) had different clinical results.[56]

Moreover, the simplified adhesives are incompatible with dual or chemically activated composite resins. When chemical cure and dual-cure resin composites are used with simplified adhesives, residual uncured acidic monomers from the oxygen-inhibited layer of the cured adhesives (not covered with a hydrophobic bonding resin) remain in direct contact with the composite material.[50] The acid deactivates the aromatic tertiary amines from the dual or self-cure composite and inhibits their polymerization.[50,57–59] This may become more problematic when clinician use composites and adhesives from different manufacturers. Some simplified adhesives are specially formulated for use in combination with their proprietary dual or self-cure composites with separate light curing of the adhesive as a must (eg, Clearfil S^3 Bond Plus/ Clearfil DC Core Plus, Kuraray Dental). Other SE bonding systems claim incompatibility with self-cured or dual-cured composites is eliminated by mixing the adhesive with a dual-cure or self-cure activator (eg, AdheSE/ AdheSE DC, Ivoclar Vivadent). Table 1 presents the currently available ER and SE adhesives brands.

The Universal (Multi-Mode) Adhesives

Universal or multimode adhesives represent the latest generation of adhesive systems that were recently introduced following the increasing demand for simplified and user-friendly systems. The distinctive property of universal adhesives is that they can be applied with any adhesive strategy (ER, SE, and selective etching), so they have also been labeled

Table 1 The Currently Available Etch-and-Rinse and Self-Etch Adhesives Brands

Manufacturer	Etch-and-Rinse Adhesive Agents		Self-Etch Adhesive Agents			
	3-Step ER Adhesives' Commercial Names	**2-Step ER Adhesives' Commercial Names**	**2-Step SE Adhesives' Commercial Names**	**pH**	**1-Step SE Adhesives' Commercial Names**	**pH**
Bisco Inc, Schaumburg, IL, USA	All-Bond 3	One-Step	-	-	-	-
		One-Step Plus				
3M ESPE, St Paul, MN, USA	Adper Scotchbond Multi-Purpose	Adper Single Bond	-	-	Adper Prompt L-pop	1.0[60]
	-	Adper Single Bond Plus (has silica nanofillers)			Adper Easy One	2.5[61]
Kuraray Medical Inc, Tokyo, Japan	-	Clearfil New Bond	Clearfil SE	2.0[62]	Clearfil S^3 Bond (Clearfil Tri-S Bond)	2.7[60]
			Clearfil SE Protect	2.5[63]		
			Clearfil liner Bond F	2.0[64]		
Ivoclar Vivadent, Schaan, Liechtenstein	Syntac	Excite F	AdheSE	1.7[65]	AdheSE One F	1.5[66]
					Tetric-N Bond SE	1.5[67]
Heraeus Kulzer, Hanau, Germany	Gluma Solid Bond	iBOND Total Etch	-	-	iBOND	NA
		Gluma Comfort Bond				
GC, Tokyo, Japan	-	-	Unifil Bond	2.2[68]	G-Bond	1.5–2[60,69]
					G-ænial Bond	1.5[70]
Dentsply Caulk, Milford, DE, USA	ProBOND	Prime&Bond NT	-	-	Xeno IV	2.1[71]
		Prime&Bond XP			Xeno V	1.4[72]
Kerr, Orange, CA, USA	OptiBond FL	OptiBond Solo Plus	Optibond Solo Plus SE	1.5[68]	Optibond All-In-One	1.7–2.5[69,72]
Coltene- Whaledent, Altstatten, Switzerland	-	One Coat Bond	A.R.T Bond	NA	-	-
			One Coat SE Bond	NA		
Tokuyama Dental Corporation, Tokyo, Japan	-	-	-	-	Palfique Bond	2.8[a]
					Bond Force II	2.8[a]
DMG, Hamburg, Germany	LuxaBond Total-Etch	Solist	Contax	3.5[73]	-	-
Pentron	Bond-It	Bond-1	Nano-Bond	NA	Bond-1 SF	NA
SDI limited, Bayswater, Victoria, Australia	-	Stae	-	-	Go!	2.0[69]
VOCO, Cuxhaven, Germany	Solobond Plus	Solobond M	-	-	Futurabond M	2.0[60]
					Futurabond NR	1.4–2[66,74]

(*Continued*)

Table 1 (Continued).

Manufacturer	Etch-and-Rinse Adhesive Agents		Self-Etch Adhesive Agents			
	3-Step ER Adhesives' Commercial Names	2-Step ER Adhesives' Commercial Names	2-Step SE Adhesives' Commercial Names	pH	1-Step SE Adhesives' Commercial Names	pH
Shofu Inc., Kyoto, Japan	-	-	FL-Bond II	2.4[75]	BeautiBond	2.4[75]

Notes: Last access to the respective manufacturer' websites on 10th June 2023. Strong self-etching (pH ≤ 1), intermediately strong self-etching (pH 1–2), mild self-etching (pH ~2), and ultra-mild self-etching (pH > 2.5) adhesives. [a]Information obtained from the manufacturer (safety data sheet). -, no product was listed on the manufacturer's website.
Abbreviation: NA, not available.

"multi-mode". In addition, some of these universal adhesives have the potential to bond to various other substrates used in direct and indirect procedures, including ceramics, composites, and metal substrates. The pH of the universal adhesives ranges between 1.5–3.2; thus, most of them fall under the ultra-mild (pH >2.5), mild (pH ~ 2), and intermediately strong (pH between 1 and 2) categories.[14]

Universal adhesives should not be confused with 1-step SE single-bottle or "all-in-one" systems. These adhesives have unique chemical compositions, they contain carboxylate or phosphate monomers. The most common of these monomers is 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP). However, several other functional monomers can be found in universal adhesives (Table 2), such as glycerol phosphate dimethacrylate (GPDM), 4-methacryloxyethyl trimellitic acid (4-MET), 4-methacryloxyethyl trimellitate anhydride (4-META), and dipentaerythritol pentaacrylate phosphate (PENTA).

The acidic monomer 10-MDP had been used by one SE adhesive system (Clearfil SE, Kuraray) for years, was added to universal adhesives when the patent expired.[92] It has been shown that this 10-MDP monomer forms a stronger and more stable bond to tooth structure than acidic monomers previously used. These universal adhesives provide micro-mechanical retention and a chemical bond to the tooth tissues. 10-MDP has an affinity for hydroxyapatite and forms a chemical bond with apatite crystallites through ionic bonding.[93] The concentration of 10-MDP varies among universal adhesives. It has been shown that the higher the monomer concentration, the better the adhesive's bond strength.[94]

Universal adhesives are claimed to facilitate bonding to ceramic restorations. Universal adhesives containing 10-MDP promote bonding to zirconia,[95–98] and indirect resin-based composites.[99] In contrast, universal adhesives have not been able to replace silane-based primers for glass ceramics like lithium disilicate ceramics.[99–102] The manufacturer claims some universal adhesives are compatible with dual-cure and self-cure composite materials.[103] Not all universal adhesives are compatible with self-cured or dual-cured resin materials. Acidic universal adhesives can interfere with the polymerization of these materials.[103] Some manufacturers provide a dual-cure activator that should be mixed with the universal adhesive if it is to be used with an amine-containing cement or buildup material. Example of this, are Scotchbond Universal Dual Cure Activator (Scotchbond Universal), One Coat 7 Activator, (One Coat 7 Universal) and Clearfil DC Activator (Clearfil Universal Bond Quick). However, some universal adhesives are reported to have a high enough pH that the dual-cure activator is unnecessary (eg, All-Bond Universal).

Silane has been incorporated into universal adhesives to simplify the glass-ceramic bonding procedure (Table 2). Theoretically, clinicians would not need to apply a separate silane solution after the ceramic restoration intaglio has been etched with hydrofluoric acid (HF). However, silanes have been reported to be unstable in acidic conditions containing water, and their premature hydrolysis precludes chemical interaction with glass ceramics.[104–106] The literature has challenged the efficacy of using universal adhesives containing silanes with lithium disilicate restorations.[101,102,107,108] Therefore, for glass ceramics, a silane coupling agent should be applied separately before applying universal adhesives, even though some of them are silane-containing.[22,102,106,108] Some manufacturers provide a primer for bonding to silicate ceramics or metals. An example of this is the Gluma Ceramic Primer is used for adhesive bonding or repair of glass

Table 2 The Currently Available Universal Adhesives by Brand

Manufacturer	Brand	HEMA	Functional Monomer	Solvents	pH	Silane	Separate DC Activator
Bisco Inc, Schaumburg, IL, USA	All-Bond Universal	Yes	10-MDP	Ethanol	2.5–3.2[76,77]	No	Compatible and does not require the use of any DCA
Kuraray Medical Inc, Tokyo, Japan	Clearfil Universal Bond	Yes	10-MDP	Ethanol/Water	2.3[77,78]	Yes	Clearfil DC Activator Does not require separate activator if used with the same manufacturers' cement system
	Clearfil Tri-S Bond Universal Quick (Clearfil Tri-S Bond Universal Quick and Clearfil S^3 Bond Universal Quick are the same adhesive with different product names).	Yes	10-MDP AMIDE	Ethanol/Water	2.3[79,80]	Yes	
3M ESPE, St Paul, MN, USA	Scotchbond Universal (Scotchbond Universal and Single Bond Universal are the same adhesives with different product names that are sold in different regions of the world).	Yes	10-MDP, PAC	Ethanol/Water	2.7[77,79]	Yes	Scotchbond Universal DCA Dual Cure Activator Does not require separate activator if used with the same manufacturers' cement system (RelyX Ultimate)
Ivoclar Vivadent, Schaan, Liechtenstein	AdheSE Universal (AdheSE Universal and Tetric N-Bond Universal are the same adhesives with different product names that are sold in different regions of the world).	Yes	10-MDP, MCAP	Ethanol/Water	2.5–3[79,81]	No	No dual-cure activator is required with dual-cure resin cements as long as adhesive is light cured first, according to manufacturer. Adhese Universal DC is a dual-curing, single-component dental adhesive
GC, Tokyo, Japan	G2-Bond Universal (Two bottle system)	No	10-MDP, 4-MET, GDMA	Acetone	1.5*	No	G-Premio BOND DCA
	G-Premio Bond	No	10-MDP, 4-MET, MDTP, GDMA	Water/Acetone	1.5[79,81]	No	
DENTSPLY Caulk, Milford, DE, USA	Prime&Bond Universal	No	10-MDP	Isopropanol/ Water	2.5–2.7*[82]	No	Dentsply Self-Cure Activator
	Prime&Bond Active	No	10-MDP, PENTA	Isopropanol/ Water	2.5–2.7*[83]	No	
Kerr, Orange, CA, USA	OptiBond Universal	Yes	GPDM	NA	2.5–3.0[14]	Yes	No separate DC activator available. Use only with NX3/Maxcem Elite Cement
	OptiBond eXtra Universal (Two bottle system)	Yes	GPDM, GDMA	Primer: Acetone/ Ethanol Adhesive: Ethanol	1.6[84]	Yes	Compatible and does not require the use of any DCA

Coltene-Whaledent, Altstatten, Switzerland	One Coat 7 Universal	Yes	10-MDP	Ethanol/Water	2.0–2.8[76,77]	No	One Coat 7.0 Activator
Tokuyama Dental Corporation, Tokyo, Japan	Palfique Universal Bond (Two bottle system)	Yes	3D-SR, MTU-6,	Acetone	2.2[85]	Yes	This is a self-cure adhesive and does not require the use of any DCA
	Tokuyama Universal Bond (Two bottle system)	No	3D-SR, MTU-6,	Acetone	2.2*	Yes	
Heraeus Kulzer, Hanau, Germany	iBond Universal	No	10-MDP, 4-META	Water/Acetone, Isopropanol	1.6–1.8[86,87]	No	Compatible and does not require the use of any DCA
	Gluma Bond Universal	No	10-MDP, 4-META	Acetone	1.6–1.8[88,89]	Yes	Compatible and does not require the use of any DCA
VOCO, Cuxhaven, Germany	Futurabond M+	Yes	10-MDP	Ethanol/Water	2.3[81,87]	No	Futurabond M+ DCA
	Futurabond U (Two bottle system)	Yes	10-MDP, GPDMA. GDMA	Ethanol/Water	2.3[77]	No	This is a dual-cure adhesive and does not require the use of any DCA
Shofu Inc., Kyoto, Japan	BeautiBond Xtreme	No	No	Acetone	2.3[90]	Yes	Compatible and does not require the use of any DCA
Ultradent, South Jordan, UT, USA	Peak Universal Bond	Yes	No	Ethanol/Water	1.2–1.9*	No	Only compatible with light cure materials. No separate DC activator available
SDI	ZipBond Universal	No	No	Ethanol	3*	No	Compatible and does not require the use of any DCA
FGM, Joinville, SC, Brazil	Ambar universal	Yes	Yes	Ethanol/Water	2.6–3[91]	No	NA
DMG, Hamburg, Germany	LuxaBond Universal	Yes	No	Ethanol/Water	1.2	No	This is a dual-cure adhesive and does not require the use of any DCA

Notes: Last access to the respective manufacturer' websites on 10th June 2023. Strong self-etching (pH ≤ 1), intermediately strong self-etching (pH 1–2), mild self-etching (pH ~2), and ultra-mild self-etching (pH > 2.5) adhesives.
Abbreviations: 10-MDP, 10-methacryloyloxydecyl dihydrogen phosphate; MCAP, methacrylated carboxylic acid polymer; GPDM, glycero-phosphate dimethacrylate; PAC, Polyalkenoic acid copolymer; PENTA, dipentaerythritol penta acrylate monophosphate; 4-MET, 4-methacryloxyethyl trimellitic acid; 4-META, 4-methacryloyloxyethyl trimellitate anhydride; MTU-6, 6-methacryloyloxyhexyl 2-thiouracil- 5-carboxylate; 3D-SR, three-dimensional self-reinforcing monomer; DCA, dual cure activator; NA, Not Available.

ceramics with Gluma Bond Universal. Likewise, the BeautiBond Universal CR Enhancer which is used as a primer for silicate and lithium silicate glass ceramics with BeautiBond Universal.

Most universal adhesives are one-bottle systems. Nevertheless, there are two-bottle universal adhesive systems. For instance, the G2-Bond Universal is a two-bottle universal adhesive system where the primer and the bonding agent are in separate bottles and applied separately from traditional two-step self-etching adhesives. Likewise, Tokuyama Universal Bond and LuxaBond Universal are two-bottle systems, but their content is intended to be mixed before application. The separation of acidic monomer and ceramic primers can prevent the deterioration of silane coupling agents that could compromise their adhesive properties and shelf time.[109]

HEMA is the principal hydrophilic monomer in most universal adhesives (Table 2). HEMA can interfere with the interaction between 10-MDP and Ca, potentially impairing the formation of an adequate bond in 10-MDP–containing adhesives. The presence of HEMA[110] and both hydrophilic and hydrophobic ingredients in the same bottle may cause water sorption and hydrolysis of the adhesive layer, impairing universal adhesive stability.[81] Studies report that universal adhesives are material-dependent[4,14,111,112] and that long-term studies are still required to evaluate the stability of resin-dentin interfaces created by contemporary universal adhesives.[111,113,114]

The clinical performance of universal adhesives largely depends on the adhesive strategy, thus questioning their claimed versatility regarding the application mode in a clinical setting. Several systematic reviews investigated which universal adhesive application mode (SE vs ER) was best for dentin and enamel adhesion. Resin-dentin bonds were similar when using mild adhesives but statistically different (favoring the etch-and-rinse approach) when using ultra-mild adhesives.[81,115,116] Additionally, evidence suggests that selective enamel etching with phosphoric acid prior to the application of "universal" adhesives is an advisable strategy for optimizing bonding. Table 2 presents the universal adhesive brands currently available.

Application Protocols

Regardless of the adhesive used, following the manufacturer's instructions is essential. Each adhesive system will have slightly different protocols and recommended application times that are tailored to the specific composition of that adhesive. Nonetheless, a few key principles apply to all adhesives during the application process are presented in Table 3.

Table 3 Protocols of Current Adhesive Systems[a]

Etch and Rinse Adhesives (Requires a Separate Etch Step)		Self-Etch Adhesives (Does Not Require a Separate Etch Step)		Universal Adhesives
3-Steps ER	**2-Steps ER**	**2-Steps SE**	**1-Steps SE**	
Etch (30–40% phosphoric acid) enamel 15–30s, dentine 15s.[117]	Etch (30–40% phosphoric acid) enamel 15–30s, dentine 15s.[117]	Etch enamel margins for 15 sec using phosphoric acid (do not etch dentine)	Etch enamel margins for 15 sec using phosphoric acid (do not etch dentine)	Etch enamel margins for 15 sec using phosphoric acid (do not etch dentine)[81]
Rinse with water until the etchant has been completely removed (approximately 15 seconds).[118]	Rinse with water until the etchant has been completely removed (approximately 15 seconds).[118]	Rinse with water until the etchant has been completely removed (approximately 15 seconds).[118]	Rinse with water until the etchant has been completely removed (approximately 15 seconds).[118]	Rinse with water until the etchant has been completely removed (approximately 15 seconds).[118]
Gently air-dry for a few seconds (blot dry). Be careful not to desiccate dentin.	Gently air-dry for 10 seconds (blot dry).[119] Be careful not to desiccate dentin.	Gently air-dry for a few seconds.	Gently air-dry for 10 seconds.[119]	Gently air-dry for 10 seconds.[119]

(*Continued*)

Table 3 (Continued).

Etch and Rinse Adhesives (Requires a Separate Etch Step)		Self-Etch Adhesives (Does Not Require a Separate Etch Step)		Universal Adhesives
3-Steps ER	**2-Steps ER**	**2-Steps SE**	**1-Steps SE**	
Apply the primer to the prepared enamel or dentin surfaces with a light scrubbing motion with a microbrush for 15 seconds and then gently air dry for approximately 15–30 seconds.[120] The primed surface should appear glossy.	Self-priming adhesive (agitate onto preparation and then gently air dry to remove solvent (15–30 seconds)).[120] Surface should have a uniform glossy appearance. If not, repeat application and air- dry.	Active application (agitate) of the self-etching primer onto preparation[121] and then gently air thin the solvent with a mild air stream	Active application (agitate) of the self-etching primer for onto etched enamel and unetched dentine[121] and then gently air thin the solvent with a mild air stream. Application of a second layer of the adhesive[122,123] followed by a mild air stream for 10 sec	Place the solution that contains (etch/ prime/bond) and agitate then air thin the solvent. Apply another layer[122]
Apply the bonding resin to the prepared enamel or dentin surfaces with a light scrubbing motion for 15 seconds. Blow to distribute equally or to thin if necessary using a light application of air. At this point, the dentin or enamel surface should have a slightly shiny appearance.		Application of the bonding resin – air thin with a mild air stream for 10 sec		
Light cure according to manufacturer's recommendation.	Light cure according to manufacturer's recommendation.	Light cure according to manufacturer's recommendation.	Light cure according to manufacturer's recommendation.	Light cure according to manufacturer's recommendation.

Note: [a]Modifications might apply based on the product manufacturers' instructions.

Special Variations

Some manufacturers add filler particles to their adhesive agents to improve the mechanical properties of the adhesive layer (eg, Tetric N Bond Total Etch, Ivoclar Vivadent and Gluma 2Bond, Kulzer). Others add Chlorhexidine to their adhesive agents to achieve bond stability by decreasing adhesive bond degradation (eg, Peak Universal Bond, Ultradent and Futurabond U, VOCO). Glutaraldehyde is another ingredient manufacturers add to dental adhesives to prevent post-operative pain and stabilize the collagen fibers in the hybrid layer to improve durability (eg, iBond Total Etch, Heraeus, Kulzer). Manufacturers include antibacterial compounds in the adhesive's formulation to prevent recurrent caries beneath restorations. Methacryloyloxydodecylpyridinium bromide monomers (MDPB) is an example of an antimicrobial compound used in some adhesives (eg Clearfil Protect Bond, Kuraray). Another example is fluoride (eg, FL-Bond II, Shofu and Futurabond NR, Voco). Some manufacturers add dyes to their adhesives to facilitate the homogeneous mixing of two components and as a visual aid when performing the procedure. The bond becomes colorless after curing (Universal Bond, Tokuyama Dental). In general, the effect of these compounds on the performance of adhesive agents so far remains unclear and should be considered in future investigations.

Conclusion

Adhesive agents have moved towards technique simplification, and the current development of adhesive agents is driven by multitasking. The general dentist should be updated on the continually evolving adhesive agents to facilitate decision-making. The classification of adhesive dental agents typically includes three main categories: ER, SE, and universal adhesives. ER adhesives are available in 3-step and 2-step versions, while SE adhesives are available in 2-step and 1-step versions. The pH of SE adhesives has a significant impact on their bonding effectiveness. According to their pH, SE

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adhesives have been categorized as strong, moderately strong, mild, and ultra-mild. Universal adhesives offer versatility by enabling the dentist to select the application mode (ER, SE, or selective etch) based on the substrate and clinical situation. ER adhesives generally exhibit excellent bond efficacy. However, they require careful technique and may be sensitive to the level of dentine moisture. SE adhesives offer improved simplicity and reduced technique sensitivity, making them popular choices for clinicians. However, their bond strengths may be slightly lower compared to ER systems. Universal adhesives provide the flexibility of both techniques, combining the benefits of ER and SE adhesives. However, the performance of universal adhesives to dental hard tissues and indirect restorative materials is material-dependent because some adhesives are not indicated for bonding to all types of restorative materials. Understanding each category's properties and limitations is essential for successful bonding and dental restorations. Continued research and improvement in adhesives will advance the field of adhesive dentistry. Hence, the practitioner must be kept continuously updated.

Disclosure

The author reports no conflicts of interest in this work.

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