Comparison of bond strength of universal adhesives using different etching modes: A systematic review and meta-analysis

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This review aims to evaluate whether the etch-and-rinse or self-etch mode is the better protocol for dentin adhesion by universal adhesives. A total of 15 articles were included in the meta-analysis. Two reviewers performed a literature search up to October 2020 in four databases: PubMed, Web of Science, Embase, and the Cochrane Library. Without considering the difference in aging mode, the analysis of the immediate and long-term bond strength of dentin showed that there was no statistical significance between the etch-and-rinse and self-etch mode of universal adhesive, and the long-term bond strength decreased relative to the immediate. In vitro studies suggest that prior acid etching did not improve bond performance. Whether from the perspective of long-term bonding performance or simplifying operating procedures, the self-etch mode is preferred.

Keywords: Universal adhesives, Dentin bonding, Meta-analysis, systematic review

INTRODUCTION

Recently, some new “universal” or “multimode” adhesives have appeared on the market, which does not require specific primers, and can act not only on the dental substrate, but also on the prosthetic materials, the former is what we are talking about in this review. The main advantages of these adhesives are that they can be used in self-etch mode (SE) or etch-and-rinse mode (ER), which not only reduce the application steps but also decrease the operation time and technical sensitivity and improve bond performance in routine clinical practice1,2. Universal adhesives, which are also called multi-mode adhesives, essentially belong to the one-step adhesive system, combining acidic primers and adhesives in a single solution. Additionally, universal adhesives restore enamel and dentin directly or indirectly in a “one-bottle” form, and self-etch, etch-and-rinse, or enamel selective etching can be used according to the dentist’s requirements3,4. Generally speaking, almost universal adhesives formulations contained acidic functional monomer (such as 10-methacryloyloxoydecyl dihydrogen phosphate (10-MDP), glycerol phosphate dimethacrylate (GPDM)) and hydrophilic (2-hydroxyethyl methacrylate (HEMA)) and hydrophobic monomer (bisphenol A-glycidyl methacrylate (Bis-GMA)), solvent (water, ethanol, acetone)5.

Etch-and-rinse mode is applied after the complete phosphoric acid etching of the dental substrate6. The dentin surface is etched with 30–40% phosphoric acid, which can remove the smear layer, and demineralize the 5–8 μm inter-tubular dentin under the smear layer, exposing the underlying collagen fibers and forming nanometer-sized porosities in the fiber matrix2,7. Meanwhile, the hydrophilic monomer penetrates the fiber network to form a thicker hybrid layer and entraps or wraps around the collagen fibers, obtaining the retention force generated by the micromechanical interlocking. Resin tags are wrapped in demineralized collagen fibers to obtain the interfacial bonding force8,9.

Omitting the etch step, the self-etch mode is combined with the dental substrates by acidic primer6. In other words, the acidic monomer can react with the smear layer on the dentin surface to partially dissolve it, resulting in different degrees of demineralization10-12. In addition, a smear plug is formed through the smear layer of the dentin tubules. At the same time, the adhesives penetrate the partially demineralized inter-tubular13, which reduces the possibility of nano-infiltration, thus improving the bonding efficiency and service life14. However, due to the weak acidity of the acidic monomer and limited permeability, the thickness of the hybrid layer formed in the self-etch mode is relatively thin, and the resin tag is also less and shorter15.

Most authors agree that measuring micro-tensile bond strength (μTBS) is of fundamental importance to evaluate the bond strength and consequently the possible longevity of the resin-dentin bond16. Despite immediate efficacy, irrespective of the etch-and-rinse or the self-etch mode, there are major concerns when dentin bond strength is tested after aging even for a short period, i.e. 6 months17-33. To obtain a long-term bond strength close to the oral environment in vitro, researchers have mainly adopted the following aging methods: water immersion aging, mechanical cycles or/and thermocycling aging. Water immersion aging is mainly caused by hydrolysis at the bonding interface; The main reason for thermo-cycling aging is that the
thermal stress caused by the temperature change leads
to the decrease of bond strength. For the mechanical
cycle process, a mimicked masticatory load is applied to
the dentin-resin adhesive interface over time.

Although universal adhesives have been widely
used in clinical practice, many dentists still struggle
with how to choose the etching mode to obtain the best
adhesive performance of dentin. As a consequence, this
study aimed to evaluate whether the long-term bonding
performance of universal adhesives would be improved
by prior acid etching through a systematic review and
meta-analysis. The hypothesis tested was that there
would be no difference in aged bond strength to dentin
when using universal adhesives by etch-and-rinse or
self-etch mode.

MATERIALS AND METHODS

The review report of this systematic review is based
on the PRISMA stated guidelines. The protocol was
registered in the PROSPERO international database for
systematic reviews (CRD42021230244). The key of this
study is as follows: does the use of the etch-and-rinse
mode for universal adhesives improve the long-term
bonding strength of dentin?

Systematic literature search

The literature search was systematically and
independently reviewed by two independent reviewers
until October 26, 2020. Different electronic data from
four databases were searched: MEDLINE (PubMed),
Web of Science, EMBASE, and the Cochrane Library.
The keywords related to the search strategy are listed
in Table 1. After identifying the articles in the database,
the articles were exported into Endnote X9 software
(Thompson Reuters, Philadelphia, PA, USA) to remove
duplicate articles.

Table 1  Search strategy used in PubMed (MEDLINE)

| Search terms                                                                 |
|------------------------------------------------------------------------------|
| No.1                                                                         |
| (Universal adhesive) OR (adhesive, universal) OR (universal adhesives) OR (adhesives, universal) OR (Multimode adhesive) OR (multi-mode adhesive) OR (multimode adhesives) OR (multi-mode adhesives) OR (G Bond Plus) OR (Adhese Universal) OR (All-Bond Universal) OR (One-step Universal Dental adhesive) OR (One-step plus universal) OR (Peak Universal Bond) OR (Clearfil Universal Bond) OR (gBond Self Etch) OR (FuturaBond U) OR (Optibond XTR) OR (Optibond Universal) OR (Prelude One) OR (Prime&Bond Elect) OR (One Coat 7 Universal) OR (Universal bond) OR (Universal bonding agent) OR (multi-mode bond) OR (multi-mode bonding agent) OR (multimode bond) OR (multi-mode bonding agent) | |
| No.2                                                                         |
| (Dental Bonding) OR (Bonding, Dental) OR (Dental Bonding, Chemically-Cured) OR (Chemically-Cured Dental Bonding) OR (Dental Bonding, Chemically Cured) OR (Dental Bonding, Self-Cured) OR (Dental Bonding, Self Cured) OR (Self-Cured Dental Bonding) OR (Chemical-Curing of Dental Adhesives) OR (Chemical Curing of Dental Adhesives) OR (Chemical Curing of Dental Adhesives) OR (Dental Bonding, Dual-Cure) OR (Dentin-Bonding Agents) OR (dental primer) OR (Dental Materials) OR (Materials, Dental) OR (Dental Material) OR (Material, Dental) OR (dental resin) OR (Dental Resins) OR (Resin, Dental) OR (Resins, Dental) OR (bonding interface) OR (adhesive) OR (Dentin-Bonding Agents) OR (Agents, Dentin-Bonding) OR (Bonding Agents, Dentin) OR (Agents, Dentin Bonding) OR (Dentin Bonding Agents) |
| No.3                                                                         |
| No.1 AND No.2                                                               |
| Study     | Country        | Number of teeth (per group) | Primary outcome | Secondary outcome                                                                 | Predominant failure mode | Universal adhesives used                                                                 | Composite                  | Type of composite |
|-----------|----------------|-----------------------------|-----------------|------------------------------------------------------------------------------------|----------------------------|------------------------------------------------------------------------------------------|----------------------------|------------------|
| Ahmed 2020 | Belgium        | 40 (10)                     | Dentin μTBS     | Failure mode and TEM characterization                                               | Adhesive                  | Scotchbond Universal (3M Oral Care)                                                        | Clearfil AP-X (Kuraray, Tokyo, Japan) | Microhybrid composite |
| Cardoso 2019 | Brazil | 120 (5)                     | Dentin μTBS     | SEM and degree of Conversion                                                          | Adhesive/Mixed            | Bond Universal (3M ESPE, St. Paul, MN, USA), Tetric N-Bond Universal (Ivoclar, Schaan, Liechtenstein), Ybond Universal (Yller, Pelotas, RS, Brazil) | Filtek Z350 (3M ESPE) | Nanocomposite |
| de Souza 2018 | Brazil | 80 (10)                     | Dentin μTBS     | Mechanical and thermal cycling, statistical analysis                               | Adhesive                  | Single Bond Universal (3M Oral Care)                                                       | Filtek Z350 XT (3M ESPE) | Nanocomposite |
| Farias 2016 | United States | 88 (11)                     | Dentin μTBS     | Failure pattern AND Field Emission Scanning Electron Microscopy (FE-SEM)             | Adhesive                  | Single Bond Universal Adhesive (3M Oral Care), All-Bond Universal (Bisco, Schaumburg, IL, USA) | TPH3 (Dentsply Caulk, Milford, DE, USA) | Hybrid |
| Gateva 2017 | Bulgaria      | 60 (20)                      | Dentin μTBS     | —                                                                                   | —                          | Single bond Universal (3M ESPE)                                                            | Filtek Ultimate (3M) | Nanocomposite |
| Giacomini 2020 | Brazil | 120 (40)                     | Dentin μTBS     | Failure mode                                                                       | Mixed                      | Single bond Universal (3M Oral Care)                                                       | Filtek Z250 Universal Restorative (3M Oral Care) | Microhybrid |
| Guan 2016 | Japan         | 45 (9)                       | Dentin μTBS     | SEM and TEM observation                                                             | Mixed                      | Single Bond Universal Adhesive (3M Oral Care), OptiBond XTR (Kerr, Orange, CA, USA).      | Clearfil AP-X (Kuraray) | Microhybrid |
| Manfroi 2016 | Brazil | 32 (8)                       | Dentin μTBS     | Failure mode and Adhesive interface analysis (SEM)                                   | Mixed                      | Scotchbond Universal (3M ESPE)                                                            | Filtek Z250 (3M) | Microhybrid |
| Pashaev 2017 | Turkey       | 216 (30)                     | Dentin μTBS     | SEM observation                                                                     | Adhesive                  | Single Bond Universal Adhesive (3M ESPE), All-Bond Universal (Bisco)                      | Filtek Ultimate Universal Restorative (3M ESPE) | Nanocomposite |
| Sezinando 2017 | USA  | 84 (12)                      | Dentin μTBS     | Failure mode and nanoleakage challenge                                              | Adhesive                  | Scotchbond Universal (3M)                                                                | Filtek Z250 (3M ESPE) | Microhybrid |
| Sismanoglu 2019 | Turkey | 50 (10)                      | Dentin μTBS     | Failure mode and SEM observations                                                   | Adhesive                  | Clearfil Universal Bond (Kuraray Noritake Dental, Tokyo, Japan) Prime&Bond Universal (Dentsply Sirona, York, PA, USA) Single Bond Universal (3M ESPE) | Filtek Ultimate Universal Restorative (3M ESPE) | Nanocomposite |
| Tekke 2016 | Turkey        | 50 (5)                       | Dentin μTBS     | Failure mode and SEM observations of the interface                                 | Adhesive/Mixed            | Single bond Universal (3M ESPE), All-Bond Universal (Bisco)                              | Filtek Ultimate Universal Restorative (3M ESPE) | Nanocomposite |
| Vermelho 2017 | Brazil      | 56 (8)                       | Dentin μTBS     | Ultramorphological dentin-resin interface TEM                                        | Adhesive                  | Scotchbond Universal (3M ESPE)                                                            | Filtek Z350 (3M ESPE) | Nanocomposite |
| Vivanco 2020 | Brazil        | 80 (10)                      | Dentin μTBS     | Fracture type and Hybrid layer evaluation                                          | Cohesive in resin         | Single bond Universal (3M ESPE, Sumare, SP, Brazil)                                      | Filtek Z350 (3M ESPE) | Nanocomposite |
| Zenobi 2018 | Brazil        | 24 (6)                       | Dentin μTBS     | Failure mode AND Nanoleakage analysis                                               | Adhesive/Mixed            | Single bond Universal (3M ESPE)                                                           | Spectrum TPH (Dentsply) | Microhybrid |

μTBS: micro-tensile bond strength
of the data and to construct the forest plots. First, a global analysis of dentin μTBS was performed using a random-effects model, and the analysis was performed independently for adhesives evaluated in at least two different studies. Descriptive statistics were used to analyze the influence of bonding modes between studies on bond strength of universal adhesives.

Comparing the standardized average differences between the bond strength (immediate and long-term) of universal adhesives using etch-and-rinse mode or self-etch mode, an estimated value of the combined effect was obtained. The immediate bond strength test was considered when the specimen was stored in distilled water at 37°C for 24 h, and the long-term bond strength was considered when the sample was stored in a standard mode, whose period is 6 or 12 months. During storage in the water, either a thermocycling process or a mechanical cycle was performed, and the long-term bond strength was tested. A $p$-value $\leq 0.05$ is considered statistically significant. The Cochran’s Q test and the inconsistency $I^2$ test were used to assess the statistical heterogeneity of treatment effects between studies, where a value greater than 50% is considered an indicator of large heterogeneity.$^{37}$

| Study        | Teeth randomization | Control group | Samples with similar dimensions | Evaluation of failure mode | Materials used according to manufacturers’ instructions | Description of coefficient of variation | Sample size calculation | Blinding of the examiner | Risk of bias |
|--------------|---------------------|---------------|---------------------------------|---------------------------|--------------------------------------------------------|----------------------------------------|------------------------|--------------------------|--------------|
| Ahmed 2020   | Yes                 | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | Yes                      | Low          |
| Cardoso 2019 | Yes                 | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | No                       | Medium       |
| de souza 2018| Yes                 | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | Yes                      | Low          |
| Farias 2016  | Yes                 | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | Yes                      | Low          |
| Gateva 2017  | Yes                 | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | No                       | Medium       |
| Giacomini 2020| Yes                | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | No                       | Medium       |
| Guan 2016    | Yes                 | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | Yes                      | Low          |
| Manfroi 2016 | Yes                 | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | No                       | Medium       |
| Pashaev 2017 | Yes                 | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | No                       | Medium       |
| Sezinando 2017| Yes              | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | Yes                      | Low          |
| Sismanoglu 2019| Yes            | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | No                       | Medium       |
| Tekce 2016   | Yes                 | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | No                       | Medium       |
| Vermelho 2017| Yes                 | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | Yes                      | Low          |
| Vivanco 2020 | Yes                 | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | No                       | Medium       |
| Zenobi 2019  | Yes                 | Yes           | Yes                             | Yes                       | Yes                                                    | No                                     | No                     | Yes                      | Low          |
RESULTS

Search strategy
A total of 4,102 references were searched from four databases. Figure 1 is a flow chart of the literature selection process based on the PRISMA statement. The initial literature review identified records of 2,880 duplicates. In addition to 1,177 studies reviewed in the title and abstract, 45 studies were left to be read in full, 31 of them were not included, among them, 13 articles evaluate dentin micro-shear bond strength which was different from dentin micro-tensile bonding strength. Fifteen only studied dentin’s immediate micro-tensile strength, and 2 did not obtain detailed dentin micro-tensile strength values. Finally, 15 in vitro studies were included and analyzed.

Descriptive analysis
Taking into account all included studies, eight different types of universal adhesives were evaluated (see Table 2). Among the 14 included works of literature, there is Scotch bond Universal (3M ESPE, St. Paul, MN, USA), which is

Table 4 Composition and classification of universal adhesives

| Universal adhesive | Manufacturer                        | Main components                                                                 | Classification according to pH |
|--------------------|-------------------------------------|---------------------------------------------------------------------------------|--------------------------------|
| All-Bond Universal (ABU) | Bisco, Schaumburg, IL, USA | MDP, bis-GMA, HEMA, ethanol, water, initiators | Ultra-mild (pH=3.2) |
| Ambar Universal (AU) | FGM, Joinville, SC, Brazil | UDMA, HEMA, methacrylate hydrophilic monomers, methacrylate acid monomers, ethanol, water, silanized silicon dioxide, camphorquinone, ethyl 4-dimethylamino-benzoate, surfactant, sodium fluoride | Mild (pH=2.47) |
| Clearfil Universal Bond (CUB) | Kuraray Noritake Dental, Tokyo, Japan | MDP, HEMA, Bis-GMA, hydrophilic aliphatic dimethacrylate, colloidal silica, CQ, silane coupling agent, ethanol, water, accelerators, initiators, hydrophilic amide monomer, Sodium fluoride | Mild (pH=2.3) |
| G-Bond Universal (GBU) | GC, Tokyo, Japan | Acetone, UDMA, dimethacrylate component, phosphoric acid ester monomer, photoinitiator | Intermediate stronge (pH=1.5) |
| Prime&Bond Universal (PBU) | Dentsply Caulk, Milford, DE, USA | Mono-, di- and trimethacrylate resins, PENTA, diketone, organic | Mild (pH=2.5) |
| Scotch bond Universal (SBU) | 3M ESPE, St. Paul, MN, USA | phosphine oxide, stabilizers, cetylamine hydrofluoride, acetone, water | Mild (pH=2.7) |
| Tetric-N-Bond Universal (TNBU) | Ivoclar, Schaan, Liechtenstein | Ethanol, phosphonic acid acrylate, Bis-GMA, HEMA, UDMA, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide | Ultra-mild (pH=3.52) |
| Y-Bond Universal (YBU) | Yller, Pelotas, RS, Brazil | Hydrophilic methacrylate monomers, hydrophobic methacrylate monomers, initiators, stabilizers, silane, ethanol, water, silanized nanoparticles | Intermediate strong (pH=1.4) |

Note: Scotch bond Universal (it is also called Single Bond Universal in some countries)
Fig. 2 (a) Results for the global analysis of the immediate and long-term μTBS of different universal adhesives to dentin. No statistically significant differences between the etch-and-rinse and self-etch modes for universal adhesives ($p > 0.05$).
(b) Results for the analysis of the μTBS to dentin. After aging, the long-term μTBS is significantly decrease ($p < 0.05$).
(c) Results for the analysis of the long-term μTBS to dentin using a random-effects model during water immersion aging. Etch-and-rinse mode was no significantly different than the self-etch mode ($p > 0.05$).
(d) Results for the analysis of the long-term μTBS to dentin using a random-effects model during mechanical cycles or/and thermocycling aging. Etch-and-rinse mode was no significantly different than the self-etch mode ($p > 0.05$).

also called Single Bond Universal in some countries$^{19-33}$. Four studies have evaluated the Bond strength of All-Bond (Bisco, Schaumburg, IL, USA)$^{23,28,30,31}$, Two studies assessed bond strength of Clearfil Universal Bond Quick (Kuraray Noritake Dental, Tokyo, Japan)$^{19,21}$ and other Universal adhesives evaluated include Ambar Universal (FGM, Joinville, SC, Brazil), Tetric–N-Bond Universal (Ivoclar Vivadent, Schaan, Liechtenstein), Y-Bond Universal (Yeller, Pelotas, RS, Brazil), Prime & Bond Universal (Dentsply Caulk, Milford, DE, USA)$^{19,22}$. Table 4 involves the manufacturers, abbreviation, pH values, and main components of these universal adhesives.
Furthermore, different types of composite resins were employed in each study, including micro-hybrid composite resins such as Filtek Z250 (3M ESPE, St. Paul, MN, USA), Clearfil AP-X (Kuraray), Spectrum TPH (Dentsply)\(^{15,21,26,27,33}\), among them, nanocomposite resins Filtek Z350 (3M ESPE) and the Filtek Ultimate Universal Restorative (3M ESPE) were used in 4 studies\(^{19,24,26,30}\). Additionally, the other restorative materials used was a micro-hybrid composite TPH3 (Dentsply Caulk)\(^3\).

Each study used its protocol for aging and storing the samples, and most studies stored the samples for 24 h in distilled water or artificial saliva at 37ºC. Thermocycling and/or mechanical cycles were also used by one in vitro study.

In this study, the bond strength results were similar before and after thermocycling/mechanical cycles. Long-term storage over 1 year in artificial saliva or distilled water separately was used by Velmelho\(^{30}\), Tekce\(^{29}\). The results for the dentin bond strength after 1 year were inferior to those after 24 h. From the overall analysis, regardless of which protocol is applied, the bond strength decreased significantly after aging.

**Meta-analysis**

A meta-analysis was performed with 52 data sets, although only 15 studies were included\(^{19-33}\). For the dentin immediate and long-term μTBS, all studies that included 52 data sets were included in the analysis. Nine studies evaluated the long-term bond strength with the storage in the distilled water or artificial saliva for 6 or 12 months. Additionally, 6 studies evaluated the dentin bond strength before and after thermo-cycling and/or mechanical cycles. For these studies, both results were included in the analysis to obtain the overall results (Figs. 2(a) and (b)).

From the overall analysis (regardless of the difference in aging methods), whether etch-and-rinse or self-etch mode, the immediate or long-term bond strength of dentin are no significant differences. In addition, no matter what bonding mode is adopted, the bond strength after aging decreased.

Given the different aging methods of each group of experiments, further classifications were made according to the aging methods. For water immersion aging, the statistical data of the long-term bond strength of the self-etch mode and the etch-and-rinse mode were similar (Fig. 2(c)). For mechanical cycles and/or thermocycling aging, the statistical data of the long-term self-etch mode and etch-and-rinse mode are no significant differences (Fig. 2(d)). Considerable heterogeneity is observed in the immediate and aging bond strength analysis of this global analysis (\(I^2\) was 85% and 88%, respectively). A large heterogeneity can be observed in the bond strength analysis during the water immersion aging (\(I^2=85\%\), on the other hand, it was 94% during mechanical cycles and/or thermo-cycling aging.

**Quality assessment**

Of the 15 studies included in the analysis, eight studies showed a medium risk of bias, while seven studies showed a low risk. According to the parameters considered in the analysis, the results are described in Table 3. These studies scored particularly poorly on the calculation of sample size, the description of the coefficient of variation, and the blindness of the examiner.

**DISCUSSION**

This review aims to compare the bond strength before and after aging to determine which bonding mode has the more stable long-term effect. According to the bonding mode of universal adhesives, the bond strength was systematically reviewed and meta-analyzed: the self-etch mode and the etch-and-rinse mode were evaluated in a meta-analysis published in 2015. In contrast, the review included 10 studies, but most of them only reported immediate bond strength\(^{67}\). Later, many new articles appeared to evaluate the performance of multipurpose adhesives, the updated review published in 2019 includes 59 studies involving adhesives with different pH values and bond strength evaluations after different aging modes, but most of them reported the bond strength of enamel or the micro-shear tensile strength of dentin\(^{68}\). Since the effect of prior etching on enamel has been sufficiently confirmed, this meta-analysis did not include experiments on the bond strength of enamel. Eventually, only 15 articles that were tested for both immediate and long-term micro-tensile strength were included.

It can be concluded that the performance of multimode adhesives evaluated in vitro studies does not depend on the adhesion mode. Although great heterogeneity was found in this meta-analysis, the literature for in vitro studies shows that the etch-and-rinse of a universal adhesive does not improve the bond strength to the dentin. However, since the 15 included studies all included Single Bond Universal, only 4 included All-Bond Universal, and the other adhesives only appeared once or twice, the results may be biased towards the bonding performance of Single Bond Universal.

Dentin differs from enamel in adhesive performance because of its more complex structure. Dentin is composed of a collagen matrix, which is filled with hydroxyapatite crystal. The tubules of dentin extend from the pulp to the enamel and are surrounded by peritubular dentin with a high degree of mineralization and less collagen. The inter-tubular dentin is composed of mineralized collagen fibrils\(^{69}\). The number and diameter of dentin tubules increased with depth, while the amount of dentin among tubules decreased toward the pulp cavity. Therefore, the surface dentin has a more inter-tubular matrix to form the hybrid layer\(^{69}\). During cavity preparation, the smear layer with dentin debris will be left on the surface of the tooth tissue, which is mainly composed of hydroxyapatite and denatured collagen. Later, these collagens block the entrance of dentin tubules and reduce their permeability\(^{54,70}\).

The three-step etch-and-rinse adhesive has been available since the early 1990s and is still considered the
“gold standard” for adhesive systems because it offers the highest immediate bonding strength. However, there is still a problem with the etch-and-rinse mode: the dentin that has been demineralized due to etching cannot be fully penetrated by the resin, and voids form inside or below the mixture layer, leaving some collagen fibers exposed. Thus, the bonding interface seems to be more susceptible to biodegradation the structure in this mode. As a result, the long-term bonding performance of the etch-and-rinse mode cannot be guaranteed and various hazards are likely to occur.

The self-etch mode will demineralize and penetrate the dentin surface to the same depth, theoretically preventing incomplete penetration of the adhesive into the exposed collagen network. Furthermore, these adhesives contain specific functional monomers, such as 10-MDP, 4-methacryloxyethyl trimellitic acid (4-MET) with carboxyl and phosphate groups. These functional groups can bond with calcium ions in hydroxyapatite to provide a satisfactory chemical bond to dentin, thus, the dentin-adhesive interface with a relatively stable bonding property is formed.

Many in vitro studies have indicated that universal adhesives have good immediate bonding performance. However, all adhesives will still suffer from a decline in bonding performance after artificial aging and accelerated aging. Even though adhesive systems have been significantly improved, the bonded interface remains the weakest area of resinous restorations. There are many reasons for the aging of the bonding interface, such as biodegradation, thermocycling, mechanical cycles, and so on.

Hydrolytic degradation is related to the absorption of water by the network structure of the adhesive. In this process, hydrophilic polar groups (such as hydroxyl groups, especially ester groups) in the adhesive may cause the polymer network structure to expand, soften, plasticize, and break chains, reducing the mechanical properties. Furthermore, in addition to hydrolysis, the mechanism leading to biodegradation of the bonding interface is enzymatic hydrolysis, which mainly includes degradation of external (derived from saliva and bacteria) and internal (derived from dentin) enzymes. Cholesterol esterase (CE) and Pseudocholinesterase (PCE) from saliva can decompose ester bonds, degrade monomers in adhesives, and affect their surface morphology. In addition, MMPs can degrade the bonding interface through extracellular matrix components, and cysteine cathepsin can cooperatively degrade the bonding interface with MMPs. More recently, it has been suggested that bacteria from dental plaque, such as Streptococcus mutans, have esterase activity similar to saliva and may also be involved in interfacial degradation.

During the thermo-cycling aging process, thermal stress and a certain degree of plasticization will occur at the dentin-adhesive interface of resin, which may lead to a change in its mechanical properties. Thermal stresses have two kinds of failure mechanisms. First, hot water may accelerate the hydrolysis of unprotected collagen and separate polymerized resin oligomers. Second, due to the high thermal shrinkage/expansion coefficient of the restorative material (compared to the tooth tissue) at the dental biomaterial interface, which may cause cracks to propagate along with the bonding interface, once a gap is formed, the change in the size of the gap will cause the pathogen fluid to flow in and out, a process known as “seepage”.

In the mechanical cycle aging process, the stress load acts on the bonding interface, causing the tooth structure to bend, leading to the formation of leakage around the margin of the prosthesis, thus affecting the bonding performance. The strain of the adhesive-dentin interface will cause Poisson’s effect, promote fluid absorption, and accelerate the interface’s degradation, resulting in a decrease in the strength of the adhesive.

In vitro studies indicated that universal adhesives did not improve the long-term bond strength of dentin in etch-and-rinse mode. The self-etch mode has less damage to the dentin, and reduces the risk of postoperative sensitivity or requires special etching steps for clinical operation, which increased technical sensitivity. Moreover, the etch-and-rinse mode damaged the dentin, and the collagen fibers were exposed to a large degree, which was easily hydrolyzed by enzymes, which affected the stability of the bonding interface. As a consequence, this meta-analysis agrees with the previous hypothesis that there is no significant difference in long-term bond strength between the self-etch mode and the etch-and-rinse mode.

CONCLUSION

Based on this meta-analysis, irrespective of the etch-and-rinse or the self-etch mode, the immediate or long-term bond strength is not significantly different, which indicates that the self-etch mode can achieve a perfect bond strength. Consequently, it is a reasonable choice to use universal adhesives with the self-etch mode to optimize long-term bonding performance.

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REFERENCES

1) Cho BH, Dickens SH. Effects of the acetone content of single solution dentin bonding agents on the adhesive layer thickness and the microtensile bond strength. Dent Mater 2004; 20: 107-115.
2) Van Meerbeek B, De Munck J, Yoshida Y, Inoue S, Vargas M, Vijay P, et al. Buonocore memorial lecture. Adhesion to enamel and dentin: current status and future challenges. Oper Dent 2003; 28: 215-235.
3) Hanabusa M, Mine A, Kuboki T, Momoi Y, Van Ende A, Van Meerbeek B, et al. Bonding effectiveness of a new multi-mode adhesive to enamel and dentine. J Dent 2012; 40: 475-484.
4) Perdigão J, Sezinando A, Monteiro PC. Laboratory bonding ability of a multi-purpose dentin adhesive. Am J Dent 2012;
Dent Mater J 2021; 33: 2356-2368.

43) Jacker-Guhr S, Sander J, Luehrs AK. How “Universal” is adhesion? Shear bond strength of multi-mode adhesives to enamel and dentin. J Adhes Dent 2019; 21: 87-95.

44) Kim HH, Choi Y, Park SJ. Shear bond strength of universal adhesives using different modes of application. Korean J Dent Mater 2017; 44: 299-309.

45) Pires CW, Lenzi TL, Soares FZM, Rocha RO. Bonding of universal adhesive system to enamel surrounding real-life carious cavities. Braz Oral Res 2019; 53: e038-e047.

46) Rechmann P, Bartolome N, Kinsel R, Vaderhobli R, Bmt R. Bond strength of etch-and-rinse and self-etch adhesive systems to enamel and dentin irradiated with a novel CO2 9.3 μm short-pulsed laser for dental restorative procedures. Lasers Med Sci 2017; 32: 1981-1993.

47) Schoenhals G, Berft CL, Naufel FS, Schmitt VL, Chaves LP. Bond strength assessment of a universal adhesive system in etch-and-rinse and self-etch modes. Rev Odontol Unesp 2019; 48: e20190083.

48) Takamizawa T, Barkmeier WW, Tsujimoto A, Berry TP, Watanebe H, Erickson RL, et al. Influence of different etching modes on bond strength and fatigue strength to dentin using universal adhesive systems. Dent Mater 2016; 32: E9-E21.

49) Thanaratikul B, Santiwong B, Harnirattisai C. Self-etch or etch-and-rinse mode did not affect the microshear bond strength of a universal adhesive to primary dentin. Dent Mater J 2016; 35: 174-179.

50) Yamauchi K, Tsujimoto A, Jurado CA, Shimatani Y, Nagura M. Does 2% chlorhexidine digluconate cavity disinfectant or copper chelate effectively and rapidly reduce bacterial contamination of universal adhesives? J Adhes Dent 2015; 37: 113-23.

51) Cengiz T, Unal M. Comparison of microtensile bond strength and resin-dentin interfaces of two self-adhesive flowable composite resins by using different universal adhesives: Scanning electron microscope study. Micron Res Tech 2019; 82: 1032-1040.

52) 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: 1224-1236.

53) Gré C, Andrade M, Júnior SM, Lise DP, Deucher C, Ruschel VC. Microtensile bond strength of universal adhesive system to deep dentin. Dent Mater 2014; 30: e144-e144.

54) Hass V, Cardenas A, Siqueira F, Pacheco RR, Zago P, Silva DO, et al. Micro-tensile bond strength of universal adhesives on etched dentin and surface dehydration of acid demineralized intertubular dentin: Effect of dentin depth and air-exposure time. Dent Mater 2010; 26: 35-43.

55) Bowen RL, Eick JD, Henderson DA, Anderson DW. Smear layer: Removal and bonding considerations. Oper Dent Suppl 1984; 3: 30-34.

56) Cardoso MV, de Almeida Neves A, Mine A, Coutinho E, Van Landuyt K, De Munck J, et al. Current aspects on bonding effectiveness and stability in adhesive dentistry. Aust Dent J 2011; 56 Suppl 1: 31-44.

57) Stape THS, Wik P, Mutluay MM, Al-Ani AAS, Tezvergil-Mutluay A. Selective dentin etching: A potential method to improve bonding effectiveness of universal adhesives. J Mech Behav Biomater 2018; 86: 14-22.

58) Rosa WL, Fiva E, Silva AF. Bond strength of universal adhesives: a systematic review and meta-analysis. J Dent 2015; 43: 765-776.

59) Cueva-Suarez CE, de Rosa WLO, Lund RG, da Silva AF, Fiva E. Bonding performance of universal adhesives: An updated systematic review and meta-analysis. J Adhes Dent 2019; 21: 7-26.

60) Fawzy AS. Variations in collagen fibrils network structure and surface dehydration of acid demineralized intertubular dentin: Effect of dentin depth and air-exposure time. Dent Mater J 2016; 26: 35-43.

61) Nicoloso GF, Antoniazzi BF, Lenzi TL, Soares FZM, Rocha RO. The bonding performance of a universal adhesive to artificially-created caries-affected dentin. J Adhes Dent 2017; 19: 317-321.

62) Ozan G, Owa R, Kivanc B, Kayhan U, Sancakli HS. Microtensile bond strength of different modes of universal adhesives to radiotherapy-affected dentin. J Adhes Sci Technol 2020; 35: 901-902.

63) Siao SH, Donmez N, Kahya DS, Uslu YS. The effect of calcium phosphate-containing desensitizing agent on the microtensile bond strength of multimode adhesive agent. Niger J Clin Pract 2017; 20: 964-970.

64) Sutil BGD, Susin AH. adhesive temperature as affecting factors on bond strength of a universal adhesive system. J Appl Oral Sci 2017; 25: 533-540.

65) Zhang ZY, Tian FC, Niu LN, Ochala K, Chen C, Fu BP, et al. Defying ageing: An expectation for dentine bonding with universal adhesives? J Dent 2016; 45: 43-52.

66) Bowen RL, Eick JD, Henderson DA, Anderson DW. Smear layer: Removal and bonding considerations. Oper Dent Suppl 1984; 3: 30-34.

67) Cardoso MV, de Almeida Neves A, Mine A, Coutinho E, Van Landuyt K, De Munck J, et al. Current aspects on bonding effectiveness and stability in adhesive dentistry. Aust Dent J 2011; 56 Suppl 1: 31-44.

68) De Munck J, Mine A, Poitevin A, Van Ende A, Cardoso MV, Van Landuyt KL, et al. Meta-analytical review of parameters involved in dentin bonding. J Dent Res 2012; 91: 351-357.

69) 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: 525-536.

70) Breschi L, Mazzoni A, Ruggeri A, Cadenaro M, Di Lenarda R, De Stefano Dorigo E. Dental adhesion review: Aging and stability of the bonded interface. Dent Mater 2008; 24: 90-101.

71) Liu Y, Tjaderhane L, Breschi L, Mazzoni A, Li N, Mao J, et al. Limitations in bonding to dentin and experimental strategies to prevent bond degradation. J Dent Res 2011; 90: 953-968.

72) Tersario IL, Geraldeli S, Mincioti CL, Nascimento FD, Paakkonen V, Martins MT, et al. Cysteine cathepsins in human dentin-pulp complex. J Endod 2010; 36: 475-481.

73) Nagase H, Visse R, Murphy G. Structure and function of matrix metalloproteinases and TIMPs. Cardiovasc Res 2006; 70: 562-573.

74) Bowen RL, Eick JD, Henderson DA, Anderson DW. Smear layer: Removal and bonding considerations. Oper Dent Suppl 1984; 3: 30-34.

75) Cardoso MV, de Almeida Neves A, Mine A, Coutinho E, Van Landuyt K, De Munck J, et al. Current aspects on bonding effectiveness and stability in adhesive dentistry. Aust Dent J 2011; 56 Suppl 1: 31-44.

76) De Munck J, Mine A, Poitevin A, Van Ende A, Cardoso MV, Van Landuyt KL, et al. Meta-analytical review of parameters involved in dentin bonding. J Dent Res 2012; 91: 351-357.

77) 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: 525-536.

78) Breschi L, Mazzoni A, Ruggeri A, Cadenaro M, Di Lenarda R, De Stefano Dorigo E. Dental adhesion review: Aging and stability of the bonded interface. Dent Mater 2008; 24: 90-101.

79) Liu Y, Tjaderhane L, Breschi L, Mazzoni A, Li N, Mao J, et al. Limitations in bonding to dentin and experimental strategies to prevent bond degradation. J Dent Res 2011; 90: 953-968.