Adverse effects of salivary contamination for adhesives in restorative dentistry. A literature review

Pooja Nair, BDS, **Reinhard Hickel**, DDS, PhD & **Nicoleta Ilie**, Dipl-Eng, PhD

Abstract: Purpose: To review and critically analyze the literature concerning the influence of salivary contamination on the bond quality of adhesives used in restorative materials by comparing and contrasting the different adhesive materials. **Methods:** A detailed search on PUBMED, Cochrane Library, Google Scholar and Web of Science was carried out to identify publications on salivary contamination and dental adhesive materials, from 1990-2017 (March) which resulted in a total of 6,202 web-identified publications. After screening titles/abstracts and de-duplicating, 54 publications were selected that matched the requirements for this review. The condition for selection was English literature concerning the effect of salivary contamination on the adhesives used in restorative dentistry. The obtained articles were systematically evaluated. **Results:** Salivary contamination of adhesives during restorative procedures statistically (64.6%) showed an adverse effect on adhesives, occurring either at one or many stages of restoration. Methodological dissimilarities impeded the direct comparison of the selected studies. Nevertheless, the 2-step etch and rinse adhesives were relatively less vulnerable to salivary contamination than the others. 65% of the evaluated studies for decontamination achieved improved bonding when the contaminated surface was subjected to some kind of decontamination procedure. However, the duration and other specificities were not standard in all the evaluations and need further research to assess the course of action. It is necessary to do long term studies to evaluate the effectiveness of contaminated adhesive over time. (*Am J Dent* 2017;30:156-164).

Clinical significance: Salivary contamination is a potential cause for poor bond quality of adhesive systems during restorative procedures and to provide a successful treatment, proper care must be taken to ensure the operating area is free from contamination. Understanding the properties of the materials and its constituents as well as considering measures to manage the potential vulnerabilities due to salivary contamination in the area of bonding might help a clinician to produce better results.

✉: Pooja Nair, Department of Operative Dentistry and Periodontology, Ludwig Maximilians University Munich, Goethestraße 70, 80336 Munich, Germany. E-✉: poojanair8888@gmail.com

Introduction

Over the past decades, dental adhesives have progressed with changes in chemistry, application, and technique. The evolved adhesive materials have led to intense reconsiderations in the practice of restorative dentistry. The foremost objective of a dental adhesive in restorative dentistry is to offer retention to composite restorations. In addition to enduring mechanical forces and shrinkage stress from the overlaying composite material, an ideal adhesive ought to be able to prevent leakage along the restoration margins.[1]

The ability of modern formulations of adhesives is based on dual function. On one end, the adhesive attaches to the composite by co-polymerization of residual double bonds (-C = C-) in the oxygen inhibition layer and on the other, the adhesive adheres to enamel and dentin which is mainly based on micromechanical adhesion.[2] This is attained by an exchange process in which the inorganic tooth material is replaced by resin monomers that form tags and get interlocked in the retentions upon curing.[3]

The usual treatment procedures are often known to expose these materials to various factors in and around the oral cavity which may result in contamination and cause difficulty in their infiltration to provide the necessary mechanical bonding and eventually deteriorate quality.

Saliva is the most common component present in the oral cavity and has a high probability to influence an operative field. It is constituted of 99.4% water and 0.6% solids. The solids are aggregates of macromolecules such as proteins, glycoproteins, sugar, and amylase inorganic particles such as calcium, sodium and chloride and organic particles such as urea, amino acids, fatty acids, and free glucose.[4] An acid conditioned tooth surface readily absorbs salivary constituents and decreases the surface energy, leaving the surface unfavorable for bonding.[5] An essential requirement for strong adhesive bonds is that the restorative surface must be clean and should maintain a high energy state. Films of water, organic debris, and/or biofilms present in a clinical situation might interfere with wetting and spreading.[6,7]

This review provides a gist of the published articles, concerning the influence of salivary contamination on the quality of bonding of different generations of adhesives in restorative dentistry, and also critically analyzes the approaches and protocols used by the researchers.

Materials and Methods

For this literature review, 54 references[8-61] were selected. An extensive search on PUBMED, Cochrane Library, Google Scholar and Web of Science revealed a total of 6,202 published articles. The search terminologies used for searching on the online database were (saliva) AND (contamination) AND (adhesive) AND (dental). The search was restricted to the years 1990-2017 (March). The web search was also supplemented by a manual search of the reference lists from the identified papers. After screening titles and de-duplicating, 54 papers were shortlisted that matched the conditions entirely.

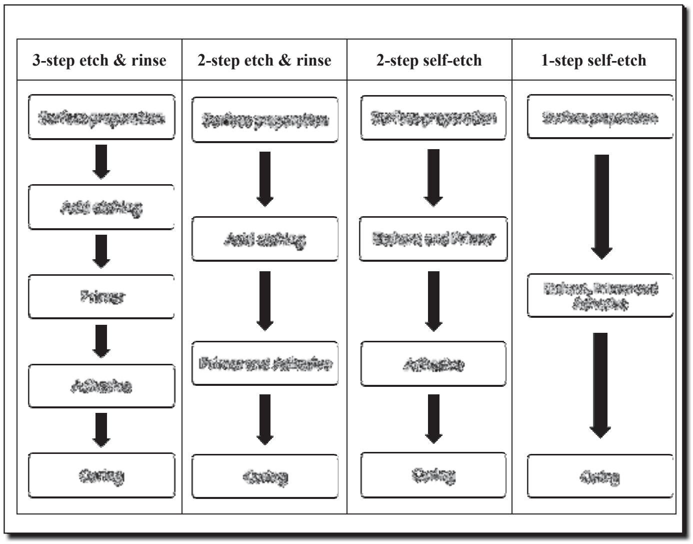

Fig. 1. Stages of possible salivary contamination on different classes of adhesives. (classified as per Van Meerbeek et al[3]).

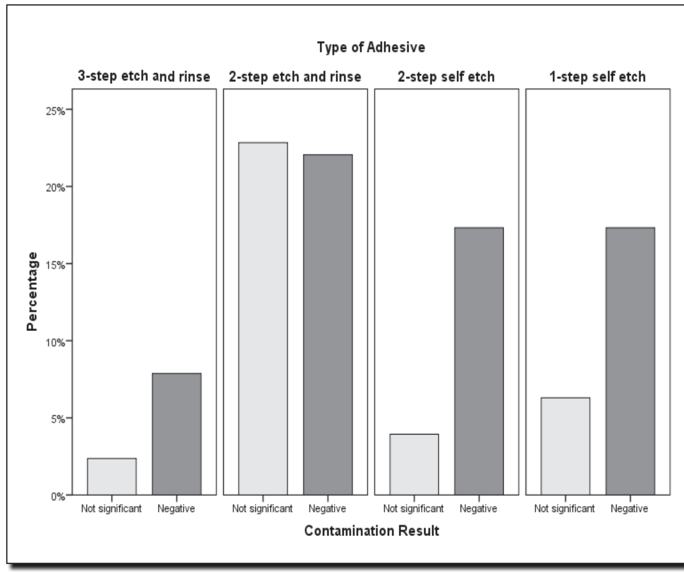

Fig. 2. Influence of contamination on different adhesives.

The criteria for selection of articles for this review were English literature pertaining to salivary contamination of adhesives in restorative dentistry. Studies were included if the investigators evaluated the influence of salivary contamination of enamel, dentin or both on the bond quality of adhesive systems in restorative dentistry.

The obtained papers were meticulously evaluated under various categories: year of publication, type of adhesive, type of contaminant, type of test, parameters of the test, results, surface preparation, method of contamination, quantity and details of contaminant, stages of contamination, decontamination procedure, time between contamination and testing, type of aging, size of bonding area, type of substrate and number of specimens.

Results

Dental adhesives

Dental professionals use various adhesive systems in their day to day clinical practice. Depending on the adhesive system used, bonding resin-based composite to tooth structure involves multiple steps, and the operating surface could be contaminated during any of these steps. Dental adhesives are broadly categorized into two groups, i.e. etch and rinse and self-etch adhesives (Fig. 1).[62] 64.6% of the evaluated adhesives were prone to have a deleterious impact due to salivary contamination.

Etch and rinse adhesives

Etching with phosphoric acid dissolves the apatite crystals in hydroxyapatite rich enamel surface to create microporosities, increasing surface area and also surface energy without any modifications of the chemical composition of the surface. In dentin, acid treatment removes the smear layer and demineralizes the intertubular dentin surface to expose the underlying collagen matrix.[63] Subsequently either a separate primer and adhesive resin is applied in a 3-step process, or a combined primer and adhesive resin is applied in a simplified 2-step process.[62] Both 3- and 2-step etch-and-rinse adhesives depend on a similar adhesion mechanism. The intention is to micro-mechanically interlock and polymerize the monomers into the enamel etch-pits and the opened dentin tubules with the exposed collagen network.

It is implicit that etch and rinse adhesive involve multiple steps in their application. Increased number of steps increases the vulnerability of the restorative surface for salivary contamination.

3-step-etch and rinse

The seven reviewed articles tested nine 3-step etch and rinse adhesives for consequences of salivary contamination (Table 1) and almost 77% of adhesives depicted a negative impact when there was salivary contamination (Fig. 2). It was observed that, it always had an adverse effect when enamel was contaminated and 62.5% showed a negative influence on dentin.

According to Xie et al,[57] the contamination after etching reduced the bond strength in enamel and dentin by 40% and rinsing the contaminated surface with water, air drying and re-etching followed by application of the adhesive, the proteins could be rinsed away improving the bond strength. Patil et al[39] reported that just rinsing the contaminated surface after curing the adhesive in the 3-step etch and rinse adhesive, could not reverse the harmful effect.

2-step-etch and rinse

A total of 30 articles investigated the influence of salivary contamination on 48 2-step etch and rinse and 46% had a deleterious outcome on the bond quality. The rest suggested that the effect of salivary contamination was non-significant. 80% of the contamination tested in enamel had an adverse impact and 47.2% suffered negatively in dentin.

el Kalla[17] believed that saliva contamination did not prevent hybrid layer formation in 2-step etch and rinse adhesives or the resin penetration into the dentin tubules, while Park & Lee[38] suggested that, following the salivary contamination of an etched surface, blotting and applying the primer could recover the bond strength.

Self-etch adhesives

Self-etch adhesives contain non-rinse acidic monomers that simultaneously condition and prime dentin. Self-etching only dissolves the smear layer, but does not remove the dissolved

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Table 1. Articles included in the review describing the influence of salivary contamination on various adhesives.

First Author	Year	Brand name	Type of adhesive	Substrate	Test	Contamination result
Abdalla[8]	1998	Scotchbond 1	2-step etch and rinse	Dentin	Shear bond strength	Not significant
		One Step	2-step etch and rinse	Dentin		Not significant
		Prime & Bond 2.1	2-step etch and rinse	Dentin		Not significant
		Syntac SC	2-step etch and rinse	Dentin		Negative
		Scotch Bond Multi Purpose Plus	3-step etch and rinse	Dentin		Not significant
Aboushelib[9]	2011	Clearfil SE Bond	2-step self-etch	Dentin	Micro-tensile bond strength	Negative
Ari[10]	2008	Clearfil SE Bond	2-step self-etch	Dentin	Micro-tensile bond strength	Negative
Benderli[11]	1999	Scotch Bond Multi Purpose	3-step etch and rinse	Enamel	Shear bond strength	Negative
Bhatia[12]	2015	Adper Easy One	1-step self etch	Dentin	Shear bond strength	Negative
		Xeno V	1-step self etch	Dentin		Negative
Cobanoglu[13]	2013	Clearfil SE Bond	2-step self etch	Dentin	Shear bond strength	Negative
		Optibond Solo Plus SE	2-step self etch	Dentin		Negative
Darabi[14]	2012	Single Bond	2-step etch and rinse	Dentin	Shear bond strength	Negative
				Enamel		Negative
Dietrich[15]	2000	Scotchbond 1	2-step etch and rinse	Dentin	Microleakage	Not significant
Duarte[16]	2005	Single Bond	2-step etch and rinse	Dentin	Microscopic analysis	Negative
		Single Bond	2-step etch and rinse	Enamel		Negative
el-Kalla[17]	1997	Prime & Bond 2.1	2-step etch and rinse	Dentin	Shear bond strength	Not significant
				Enamel		Not significant
		One Step	2-step etch and rinse	Dentin		Not significant
				Enamel		Not significant
		Tenure Quik	2-step etch and rinse	Dentin		Not significant
				Enamel		Not significant
		Syntac SC	2-step etch and rinse	Dentin		Not significant
				Enamel		Negative
el-Kalla[18]	1999	Prime & Bond 2.1	2-step etch and rinse	Dentin	Micromorphological assessment	Not significant
		One Step	2-step etch and rinse	Dentin		Not significant
		Tenure Quik	2-step etch and rinse	Dentin		Not significant
		Syntac SC	2-step etch and rinse	Dentin		Not significant
el-Kalla[19]	1999	Prime & Bond 2.1	2-step etch and rinse	Enamel	Micromorphological assessment	Not significant
		One Step	2-step etch and rinse	Enamel		Not significant
		Tenure Quik	2-step etch and rinse	Enamel		Not significant
		Syntac SC	2-step etch and rinse	Enamel		Negative
Elkassas[20]	2016	Single Bond	2-step etch and rinse	Dentin	Micro-shear bond strength	Negative
Fakhri[21]	2009	Clearfil SE Bond	2-step self etch	Both	Microleakage	Not significant
Farmer[22]	2014	Optibond Solo Plus	2-step etch and rinse	Both	Microleakage	Negative
Fritz[23]	1998	ARX (experimental adhesive)	2-step etch and rinse	Enamel	Shear bond strength	Negative
				Dentin		Negative
Guerriero[24]	2009	Single Bond 2	2-step etch and rinse	Dentin	Shear bond strength	Negative
Gupta[25]	2015	Single Bond	2-step etch and rinse	Dentin	Micro-tensile bond strength	Negative
		Adper SE Plus	2-step self etch	Dentin		Negative
		Single Bond Universal	1-step self etch	Dentin		Negative
Hegde[26]	2008	Xeno III	1-step self-etch	Dentin	Shear bond strength	Negative
		Clearfil SE Bond	2-step self-etch	Dentin		Negative
Hiraishi[27]	2003	Clearfil SE Bond	2-step self-etch	Dentin	Micro-shear bond strength	Negative
		Single Bond	2-step etch and rinse	Dentin		Negative
Hitmi[28]	1999	Syntac Sprint	2-step etch and rinse	Dentin	Shear bond strength	Negative
		One Step	2-step etch and rinse	Dentin		Negative
		Clearfil Liner Bond 2	2-step self-etch	Dentin		Negative
Jiang[29]	2010	Clearfil SE Bond	2-step self-etch	Enamel	Micro-tensile bond strength	Negative
		Xeno III	1-step self-etch	Enamel		Negative
		Frog	2-step self-etch	Enamel		Negative
		FL Bond H	2-step self-etch	Enamel		Negative
Johnson[30]	1994	All-Bond 2	3-step etch and rinse	Dentin	Shear bond strength	Not significant
		Scotch Bond Multi Purpose	3-step etch and rinse	Dentin		Not significant
Justin[31]	2012	Single Bond	2-step etch and rinse	Dentin	Shear bond strength	Negative
		UniFil bond	2-step self-etch	Dentin		Negative
Kermanshah[32]	2010	Scotch Bond Multi Purpose Plus	3-step etch and rinse	Dentin	Shear bond strength	Negative
		Single Bond	2-step etch and rinse	Dentin		Negative
		Adper Prompt L-Pop	1-step self-etch	Dentin		Not significant
Khoroushi[33]	2008	i-Bond	1-step self-etch	Enamel	Shear bond strength	Negative
Koppolu[34]	2012	Xeno III	1-step self-etch	Enamel	Shear bond strength	Negative
				Dentin		Negative
Kumar[35]	2012	Single Bond	2-step etch and rinse	Both	Microleakage	Not significant
		i-Bond	1-step self-etch	Both		Negative
Munaga[36]	2014	Filtek P90	2-step self-etch	Dentin	Shear bond strength	Negative
Neelagiri[37]	2010	AdheSE	2-step self-etch	Dentin	Shear bond strength	Negative
		Adper Prompt L-Pop	1-step self-etch	Dentin		Negative
Park[38]	2004	One Step	2-step etch and rinse	Dentin	Shear bond strength	Negative
		Clearfil SE Bond	2-step self-etch	Dentin		Negative
Patil[39]	2014	Scotch Bond Multi Purpose	3-step etch and rinse	Enamel	Shear bond strength	Negative
				Dentin		Negative
		Single Bond	2-step etch and rinse	Enamel		Negative

Table 1(continued). Articles included in the review describing the influence of salivary contamination on various adhesives.

First Author	Year	Brand name	Type of adhesive	Substrate	Test	Contamination result
Pinzon[40]	2010	Prime and Bond NT	2-step etch and rinse	Dentin	Micro-tensile bond strength	Not significant
		Single Bond Plus	2-step etch and rinse	Dentin		Negative
		Clearfil SE Bond	2-step self-etch	Dentin		Negative
		Clearfil S3 Bond	1-step self-etch	Dentin		Negative
Pinzon[41]	2011	One Up Bond F Plus	1-step self etch	Dentin	Shear bond strength	Not significant
		Adper Prompt L-Pop	1-step self etch	Dentin		Not significant
Powers[42]	1995	Gluma 2000	3-step etch and rinse	Enamel	Shear bond strength	Negative
				Dentin		Negative
Ramires-Romito[43]	2004	OptiBond Solo	2-step self etch	Enamel	Micro-tensile bond strength	Not significant
		Prime and Bond NT	2-step etch and rinse	Enamel		Not significant
Saayman[44]	2005	Prime and Bond NT	2-step etch and rinse	Dentin	Microleakage	Not significant
				Enamel		Negative
Santschi[45]	2015	Xeno V+	1-step self etch	Dentin	Shear bond strength	Negative
		Scotchbond Universal	1-step self etch	Dentin		Not significant
Sattabanasuk[46]	2006	One Up Bond F Plus	1-step self etch	Dentin	Micro-tensile bond strength	Negative
		Adper Prompt L-Pop	1-step self etch	Dentin		Negative
Sheikh[47]	2010	Adper Prompt L-Pop	1-step self etch	Dentin	Micro-tensile bond strength	Not significant
		Adper Easy Bond	1-step self etch	Dentin		Not significant
		Clearfil SE Bond	2-step self etch	Dentin		Not significant
Shimazu[48]	2014	Clearfil S3 Bond	1-step self etch	Enamel	Microleakage; shear bond strength	Negative
				Dentin		Negative
		OptiBond Solo Plus	2-step etch and rinse	Enamel		Not significant
				Dentin		Negative
Suresh[49]	2010	Single Bond	2-step etch and rinse	Dentin	Shear bond strength	Negative
Suryakumari[50]	2011	Single Bond	2-step etch and rinse	Dentin	Shear bond strength	Negative
Taskonak[51]	2002	Prime and Bond NT	2-step etch and rinse	Dentin	Shear bond strength	Not significant
		Gluma One Bond	2-step etch and rinse	Dentin		Not significant
		Syntac SC	2-step etch and rinse	Dentin		Not significant
Townsend[52]	2004	na	2-step self etch	Enamel	Shear bond strength	Negative
			2-step self etch	Dentin		Not significant
Tuncer[53]	2014	One Step Plus	2-step etch and rinse	Dentin	Shear bond strength, microleakage	Negative
		G- Bond	1-step self etch	Dentin		Negative
Ulusoy[54]	2012	Prime and Bond NT	2-step etch and rinse	Dentin	Micro-tensile bond strength	Negative
		Clearfil Protect Bond	2-step self etch	Dentin		Negative
		Prime and Bond NT	2-step etch and rinse	Dentin		Not significant
van Schalkwyk[55]	2003	Scotchbond 1	2-step etch and rinse	Dentin	Shear bond strength	Not significant
Vieira[56]	2010	Clearfil SE Bond	2-step self etch	Enamel	Micro-tensile bond strength	Negative
				Dentin		Negative
Xie[57]	1993	All-Bond 2	3-step etch and rinse	Enamel	Tensile bond strength	Negative
				Dentin		Negative
		Scotch Bond Multi Purpose	3-step etch and rinse	Enamel		Negative
				Dentin		Negative
Yalcin[58]	2013	Clearfil SE Bond	2-step self etch	Dentin	Micro-tensile bond strength	Not significant
		Clearfil S3 Bond	1-step self etch	Dentin		Not significant
Yazici[59]	2007	Single Bond	2-step etch and rinse	Both	Microleakage	Not significant
		Futura Bond NR	1-step self etch	Both		Not significant
Yoo[60]	2006	One Up Bond F Plus	1-step self etch	Dentin	Micro-shear bond strength	Negative
		Xeno III	1-step self etch	Dentin		Negative
		Adper Prompt L-Pop	1-step self etch	Dentin		Negative
Yu[61]	2014	Adper Easy One	1-step self etch	Dentin	Micro-tensile bond strength	Negative
		Clearfil S3 Bond	1-step self etch	Dentin		Negative

calcium phosphates, as it is not rinsed. This not only reduces the clinical application time, but also reduces technique-sensitivity.[3] Self-etch adhesives are available as ‘2-step’ and ‘one-step’ adhesives, depending on whether a self-etching primer and adhesive resin are individually offered or are combined into one single solution (Fig. 1).

The self-etch primers and self-etch adhesive systems are an aqueous mixture of acidic functional monomers, with a pH relatively higher than that of phosphoric acid etchants.[64]

Most self-etching adhesives contain specific functional monomers that, to a large extent, determine the adhesive performance. Functional monomers are used with the intent of etching tooth substrates, enhancing monomer penetration and also establishing a chemical interaction between the adhesive and the dental substrates.[65]

2-step self-etch adhesives

Around 20 articles investigated 24 different 2-step self-etch adhesives. 81.5% suggested that salivary contamination adversely influenced their bond quality (Fig. 2). It was also interesting to note that many of the articles suggested that the contamination occurring after the application of primer drastically affected the bond quality.[10,13,31,36,38,56] 84.2% of the investigations conducted on dentin and 85.7% on enamel reported an unfavorable impact.

Vieira et al[56] suggested that salivary contamination in the 2-step self-etching adhesive was deleterious in enamel as well as dentin at all the steps, and decontamination methods like rinsing with water, air drying or reapplication of primer could not restore the bond quality. Cobanoglu et al[13] reported that

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Table 2. Comparison of the test parameters to demonstrate variability among studies. (Number of articles).

		Type of test						
Parameters	Values	Shear	Tensile	Micro-shear	Micro-tensile	Microleakage	Others	Total
Surface preparation	600 grit SiC	9	1	3	7	0	1	21
	<600 grit SiC	1	0	0	0	0	0	1
	Serial grinding	13	0	0	2	0	0	15
	Cavity preparation	1	0	0	2	6	2	11
	Flattened with bur/disc	5	0	0	0	0	0	5
	Not available	0	0	0	1	0	0	1
Sample size/Group(n)	1-5	3	1	2	7	0	1	14
	6-10	18	0	0	4	4	1	27
	11-15	5	0	1	1	1	0	8
	16-20	3	0	0	0	1	1	5
Thermocycling	Yes	8	0	0	0	6	1	15
	No	21	1	3	12	0	2	39
Storage time	24 hours	19	1	2	10	3	1	36
	48 hours	6	0	0	0	0	1	7
	1 week	0	0	1	0	1	0	2
	3 weeks	1	0	0	0	1	0	2
	6 months	0	0	0	1	0	0	1
	3 years	0	0	0	1	0	0	1
	Not available	3	0	0	0	1	1	5
Duration of contamination	0-5 seconds	2	0	0	2	1	0	5
	6-10 seconds	2	0	0	2	1	1	6
	11-15 seconds	5	0	0	0	0	0	5
	16-20 seconds	4	0	1	0	0	0	5
	21-30 seconds	2	0	0	0	0	0	2
	1 minute	0	0	1	1	0	0	2
	Not available	14	1	1	7	4	2	29

when saliva contamination occurred after light polymerization of the bonding agent, repeating the bonding procedure recovered the bonding capacity. However, saliva contamination before or after application of primer negatively affected their bond strength. Townsend et al[52] observed that saliva contamination did not affect the dentin shear bond strength of the 2-step self-etching adhesive but had a detrimental effect on enamel bond strength.

One-step self-etch

1-step self-etch adhesive systems are considered all-in-one adhesives. They are a mixture of an etchant, primer and bonding agent, containing acidic functional monomers, hydrophilic and hydrophobic monomers, water and organic solvents in a single solution. These one-step self-etch adhesive systems called “Universal” or “Multi-Mode Adhesives”, can be applied to etched or un-etched enamel and dentin.[62]

A total of 20 papers investigated 30 one-step self-etch adhesives (Table 1). 73.3% of the adhesives were found to have a deleterious effect when contaminated with saliva (Fig. 2). The negative effect was more pronounced when the contamination occurred either after adhesive application or after polymerizing the adhesive. It was always negative when tested on enamel and 66.6% tested negative on dentin.

Bhatia et al[12] observed that the salivary contamination significantly affected the bond strength of both 1-step self-etching adhesives evaluated. However, the reapplication of the adhesive system after the salivary contamination improved the bond strength values.

Santschi et al[45] stated that saliva contamination reduced the bond strength of 1-step self-etching adhesive with the reduction being more pronounced when contamination occurred before light curing than after. In both situations, decontamination involving reapplication of the adhesive restored the bond strength.

Procedure

Contamination

The foremost objective of evaluating contamination-based studies is to simulate the possible oral condition and effectively create a situation that takes place in a clinical practice. Most of the authors have described the procedure by mentioning, “contaminating the specimen” or “applying saliva on the substrate”; only 18.5% specified the quantities of contaminants and 48.1% mentioned the duration of contamination. Saliva used for testing were mostly natural (85.2%). They were either freshly collected from one or many donors just prior to the experiment, or collected in advance, frozen at -80°C and thawed just before use.[45,46,56] Few investigators also used artificial saliva (14.8%) for their experiments.[10,11,27,41,42,48,50,57]

Decontamination

Seventy percent of the articles indicated that some form of decontamination procedure might restore the values to control levels and adopted a variety of approaches. While 33.3% of them tried to blow-dry the contaminant, 53.7% chose to rinse and dry, 20.4% re-etched the contaminated surface, 11.1% re-primed and 25.9% reapplied the adhesive in order to decontaminate.

Sheikh et al[47] proposed cleaning with agents like sodium hypochlorite, ethanol, acetone and chlorhexidine to improve the quality but found neither saliva nor the cleansing solutions adversely affected bond strengths of both one- and 2-step self-etch adhesive systems.

When the priming stage was contaminated in 2-step self-etching adhesives, re-priming improved the bond strengths considerably.[21,27,36-38]

Sixty-five percent claimed to have improved or restored the bond strength whereas 35% failed to restore the values or found no significant difference after decontamination.

Type of test

Generally, the quality of bonding via experiments on contamination is determined in vitro, except for one study done in vivo.[9] Intentionally contaminating a tooth for the purpose of experiment in an in vivo test may be considered unreasonable. Aboushelib et al[9] carried out the study on teeth intended to be extracted for orthodontic purposes and the teeth were extracted 3 years after restoration.

More than half (54.7%) of the reviewed articles used shear bond strength test to evaluate the bonding, followed by 22.6% that used micro-tensile bond strength test and 11.3% that used microleakage for assessment. The other testing procedures used were micro-shear bond strength (3.8%) tensile bond strength (1.9%) and microscopic analysis (5.7%). The tests were almost always accompanied by a microscopic evaluation of the specimens by a stereomicroscope or a scanning electron microscope. The irregularities of each testing method are shown in Table 2.

Surface preparation

Preparation of the surface varied in different test protocols and is often modified by individual researchers. The adaptation of different materials and substrates to different surface conditions could not be contrasted for an evaluation. The variability in the surface preparation procedure in different test procedures used is shown in Table 2. Grinding the surface with 600 grit silicon carbide (SiC) paper was the most widely used method of surface preparation (38.9%) for bond strength test, followed by serial grinding (27.8%) with two or more different grit sizes or roughness of SiC.

In bond strength testing, the most often overlooked guideline in the test protocol following the ISO/TS 11405 (2003) specification is that “a limitation of the bonding area is important”.[66] It is moreover essential to consider, that the precise bonding area is maintained from the stage of etching. This step however, is not very clear from all of the literature. In the methodologies explained, even most of the newer studies in bond strength have not specified whether the whole area or the defined area is subjected to the contamination, etching or bonding. This may lead to discrepancy in the data.

Substrate

Almost all (87%) of the investigations used human teeth as their substrates and 7.5% were conducted on extracted primary teeth. 5% were investigated on enamel, 61% were on dentin and 29% were conducted on both enamel and dentin. However, 5.6% of the studies used extracted bovine teeth.

Aging

The aging process can be simulated either by thermocycling or by storing for a stipulated amount of time in water or different solutions. 27.7% opted to perform thermocycling and it was done between 5 and 55°C and at various frequencies of 500, 1,000, 2,000, 2,500 and 5,000 cycles. Most studies (62.9%) stored the specimens for 24 hours at 37°C (Table 2) in either distilled water or dye. Few studies combined different durations of aging, in order to compare the variation. In vivo/clinical studies had an advantage of leaving the test specimens in the natural oral environment, which ensured an authentic condition for aging.[9] There was only one in vitro study[56] which examined the adhesive efficacy for a longer term, after a 6-month interval.

Discussion

Dental adhesives are complex blends of components. Insightful knowledge of these ingredients is vital to recognize the behavior of adhesives while using in clinical conditions. Better understanding of the components provides awareness in the correct clinical use of adhesives.[62]

The idea of the possible interactions of adhesives with saliva in adhesives is understood to be that when the surface gets contaminated with saliva after etching (in etch and rinse), or surface preparation, the presence of water and glycoproteins of saliva on the surface may hamper the proper infiltration of adhesives and subsequently hamper the micromechanical adhesion.

When the surfaces are contaminated with saliva after application of adhesive but before polymerizing, saliva may affect the degree of conversion because molecules with their hydrophilic nature may retain water within the adhesive layer and disperse in water, thus they become unable to participate in chain growth during polymerization and eventually alter the bond strength.

When surfaces are contaminated with saliva after polymerization, absorption of glycoproteins to the polymerized and air-inhibited adhesive surface may cause reduction of bond strength. These glycoproteins may prevent complete infiltration of the subsequent resin layer and prevent co-polymerization.[32]

To form an effective hybrid layer, hydrophilic monomers incorporated in water, ethanol, or acetone are used as primers. After primer/bonding agent is applied, carrier solvent is evaporated by slight air drying, allowing the resin material to remain within the collagen mesh. The bonding agent co-polymerizes with the primer, wetting the dentin surface and facilitating further penetration of the monomers.[67]

Ideally, all solvents and water should be completely eliminated from the adhesive before light-curing of the resin, as they may have an adverse effect on polymerization of the adhesive resin monomers. This is achieved by allowing an evaporation time between application and curing of the adhesive resin. Nevertheless, the monomer to water ratio increases as water evaporates from the adhesive and lowers the vapor pressure of water, reducing the ability of water and solvents to evaporate from the adhesive.[67] In case of contamination, it is likely that residual moisture from saliva and solvent will be trapped within the adhesive resin upon curing and this may compromise the overall bonding and the mechanical properties of the cured adhesive.

This review noticed that 2-step etch and rinse adhesive tolerated salivary contamination better. However, there were mixed results observed. This variation in behavior between the tested materials could be attributed to the difference in the chemical composition. Some of the materials tested included acetone as their solvent. Acetone is a “water chaser” and assists in replacing the water with primer on the dentin surface. When acetone-based primers come in contact with the moistened surface, the boiling point of acetone increases and that of water decreases. Acetone and water then evaporate leaving behind the resin.[8,68] However, when water-based solvents were used, the moisture in saliva tends to dilute the adhesive, reducing its efficacy. The favorable response to salivary contamination in dentin could be because saliva increased the hydration of the dentin surface producing a favorable performance with the acetone-based primers.[8]

In vivo clinical performance of any adhesive cannot be represented entirely based on the in vitro results.[69] This does not, however, suggest that proper technique and moisture control should not be followed while applying these adhesives.

Although there is a likelihood of salivary contamination during bonding procedures, one-step self-etch adhesive systems are simpler to use and faster than etch-and-rinse adhesives making them less technique sensitive. Simplification of the bonding procedure may have clinical advantages, but they are known to be very hydrophilic and absorb water from dentin tubules by osmosis. Unreacted monomers or oligomers can leach out from the polymer during water sorption with subsequent polymer expansion. Usually, increase in water sorption is associated with an increase in solubility, which leads to hydrolytic degradation of products, nanoleakage and a resultant decline in bond strength.[65,70]

Adhesive systems commonly also contain hydroxyethyl-methacrylate (HEMA) monomer. Bi- or multi-functional monomers are included to offer strength to the cross-linking formed from monomeric matrix. HEMA-containing adhesives are more vulnerable to moisture in saliva, as the HEMA in the uncured adhesive tends to absorb water and end up diluting the monomers to the extent that polymerization is inhibited.[62]

In good scientific research, specificities of contaminants like the quantity and duration, are crucial to compare the results and also to validate exactly how much contaminant is adversely affecting the material examined. The haphazardness of test protocols makes it difficult not only to compare the test specimens within the study but also from one study to another, thus making the findings non-reproducible.

Relatively few studies[10,11,27,41,42,48,50,57] used artificial saliva for experiments. Various types of artificial saliva have been formulated for studies. Although these formulations try to have a composition as similar as that of natural saliva, their use for contamination studies is questionable. Saliva is known to be very inconsistent[71] and it comprises of several hydrolytic enzymes competent of reacting with the tooth structure through different biochemical processes, which could modify the surface of the tooth structure and also compromise the material bond strength.[72] Therefore, the studies excluding these organic constituents might not entirely simulate the clinical contamination. One study incorporated mucin alone in the artificial saliva but could not elicit dramatic ill effects on bond strength.[41] Further investigations could be done to evaluate the effect of other salivary proteins at different protein concentrations as well as the influence of other salivary constituents in the adhesion to tooth structures in order to have a better understanding on the exact consequence.

There is still an apparent unpredictability in the decontamination procedures in all the investigations. The duration and other precise details of the decontamination process mentioned are not consistent, making it unsuitable for a comparative analysis. But then again, findings indicate that if contamination is discovered, the material strength could be salvaged if the remedial measures are taken.

Unavailability of extracted human teeth and the need of a large sample group have compelled researchers to find unconventional ways to conduct experiments. At present, bovine teeth are widely used in experiments. Nakimichi et al[73] found no statistical difference in bond strength in human teeth and bovine teeth when enamel and the superficial layer of dentin were used for experiments.

While early or 24-hour bond strength is mostly determined, there is a definite need to test bonding effectiveness of adhesives under more clinically relevant circumstances or upon aging of the specimens. Indeed, many currently available dental adhesives have presented a relatively high short-term bond strength, while not always equally favorable clinical results have been obtained. Therefore, more laboratory efforts should test durability of adhesion, rather than measuring the ‘immediate’ bond strength.

Water storage and thermocycling are the most popular artificial aging methods.[74]

The relationship between bond-strength tests and clinical outcomes was explored and concluded that aging the specimens will encourage the results to be more clinically relevant.[66] Also long-term durability of adhesive dentin bonds depends on the chemical bonding potential of the functional monomer.[75]

It is clear from the literature that, in most of the adhesives tested so far, saliva had the potential to impair the immediate bond quality. These altered circumstances need to be tested in a long term study to understand if it deteriorates with time.

It is not an unfamiliar idea in dentistry that contamination may harm the materials and it will never become an old subject for research. There is constant research in developing novel and improved adhesive materials. These newer materials ought to be verified under simulated oral cavity conditions. However, the test protocols need to be more standardized as well as the explanation of the test procedure needs to be more transparent in order for the tests to be reproducible and to obtain a fair comparison between the materials.

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Dr. Nair is a PhD student, Dr. Hickel is Professor and Chair, and Dr. Ilie is Professor, Department of Operative Dentistry and Periodontology, Ludwig-Maximilians University, Munich, Germany.

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