Resin Bond to Indirect Composite and New Ceramic/Polymer Materials: A Review of the Literature

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ABSTRACT

Statement of the Problem: Resin bonding is essential for clinical longevity of indirect restorations. Especially in light of the increasing popularity of computer-aided design/computer-aided manufacturing-fabricated indirect restorations, there is a need to assess optimal bonding protocols for new ceramic/polymer materials and indirect composites.
Purpose of the Study: The aim of this article was to review and assess the current scientific evidence on the resin bond to indirect composite and new ceramic/polymer materials.
Materials and Methods: An electronic PubMed database search was conducted from 1966 to September 2013 for in vitro studies pertaining the resin bond to indirect composite and new ceramic/polymer materials.
Results: The search revealed 198 titles. Full-text screening was carried out for 43 studies, yielding 18 relevant articles that complied with inclusion criteria. No relevant studies could be identified regarding new ceramic/polymer materials. Most common surface treatments are aluminum-oxide air-abrasion, silane treatment, and hydrofluoric acid-etching for indirect composite restoration. Self-adhesive cements achieve lower bond strengths in comparison with etch-and-rinse systems. Thermocycling has a greater impact on bonding behavior than water storage.
Conclusions: Air-particle abrasion and additional silane treatment should be applied to enhance the resin bond to laboratory-processed composites. However, there is an urgent need for in vitro studies that evaluate the bond strength to new ceramic/polymer materials.

CLINICAL SIGNIFICANCE

This article reviews the available dental literature on resin bond of laboratory composites and gives scientifically based guidance for their successful placement. Furthermore, this review demonstrated that future research for new ceramic/polymer materials is required.

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INTRODUCTION

Resin bonding is a crucial step[1,2] in the process of placing indirect restorations that rely on adhesion, such as tooth-colored indirect inlays/onlays, and is indispensable for their longevity. Characteristics of a resilient and durable adhesive bond are prerequisites of high retention,[3] prevention of microleakage, and enhancement of marginal adaptation.[4] Furthermore, successful adhesive bonding can increase fracture resistance of the restored tooth and the indirect restoration.[2,5] It is still a challenge to bond indirect

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composite restorations to dental hard tissues, as different interfaces—the one between dentin/enamel and adhesive cement, and the interface between luting agent and indirect restoration—have to be considered.[6]

The final bond strength is defined by the weakest link in the chain. Therefore, the adhesive bond between the different material interfaces has to be constantly improved[7] and adapted to the requirements of new materials. Numerous studies have shown that surface treatment prior to the cementation process via different methods, such as air-particle abrasion systems, hydrofluoric acid (HF) etching, and/or silanization can enhance bond strengths of certain indirect restorations.[2,5,8,9] Adequate surface activation and increasing roughness of indirect, polymerized composite resins through various surface treatments provide a better mechanical interlocking and a stronger chemical bond to the cement.[5]

Modern adhesive cements can be classified in glass ionomer cements (resin-modified glass ionomer cement) and composite resin cements, which can be further divided according to their chemical curing reaction in light-activated, autopolymerizing, and dual-activated[5] materials. Another classification distinguishes between adhesives, which require enamel/dentin etching and application of a bonding agent (total-etch systems) and self-adhesive materials, which do not need any pretreatment steps. Each of them provides different application benefits.

In general, indirect composites represent a good alternative to ceramics as a material for indirect restorations. They can be divided in computer-aided design/computer-aided manufacturing (CAD/CAM) fabricated and hand-made laboratory-processed composite resins. Depending on the remaining tooth structure, intraoral conditions, and costs, indirect composite resins may[10] provide increasing reliability and durability, and are more favorable than their porcelain counterparts while presenting good esthetic results.[11] Compared with direct composites, laboratory-processed composites show reduced deficiencies, increased degree of conversion, and negate the negative effect of polymerization shrinkage in the oral cavity,[10,12] consequently improving mechanical and physical properties. Further advantages are better interproximal contacts, higher wear resistance, and simplified creation of natural and anatomical shapes in large defects.[12] Clinical long-term studies of indirect composite restorations show good clinical performance in both posterior[13–15] and anterior teeth.[16]

So-called "hybrid ceramics" have recently been introduced to the market. The currently available member of this new CAD/CAM material group is Vita Enamic (VITA Zahnfabrik, Bad Säckingen, Germany). The ceramic part consists of an aluminum oxide-enriched, fine-structure feldspar matrix (86 wt%) infused by a polymer material consisting of 14 wt% urethane dimethacrylate and triethylene glycol dimethacrylate.[17] So far, hybrid ceramic materials in dentistry are defined as: "a material consisting of a ceramic substructure infiltrated with a composite material."[18] Another innovative new CAD/CAM material is Lava Ultimate (3M ESPE, Bad Seefeld, Germany), a resin-based block nanocomposite.[19] The blocks consist of nanoceramic particles embedded in a highly cured resin matrix.[20] It is neither a composite nor a ceramic but rather a mixture of both.[21] The manufacturer characterizes Lava Ultimate as a "Resin Nano Ceramic" in their technical product profile.

Both materials can be taxonomically summarized as "new ceramic/polymer materials," which they are referred to in the following.

The new ceramic/polymer materials supposedly combine the positive aspects of both ceramics and composites with beneficial properties for patients. It is claimed that the dual network of a ceramic and polymer material provides less brittleness, excellent machinability, and edge stability.

Although resin-bonding protocols to silica-based[1,5,22] and high-strength ceramics[23–27] are well documented, there are only few reviews reporting on the bond to laboratory-fabricated composites.[2,8] Scientific evidence on bonding behavior and surface treatment of indirect composite[6,28] and new ceramic/polymer materials is more difficult to find.

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Therefore, the main objective of this review was to identify preferred bonding protocols and surface-treatment procedures for indirect composites and new ceramic/polymer materials by systematically searching the literature for respective in vitro studies and formulate clinical guidelines from the results, if possible.

MATERIAL AND METHODS

Search Strategy and Study Selection

A PubMed search for articles published in dental journals in English from 1966 to September 2013 was conducted. The following search terms were used: resin bond strength OR bond strength AND "indirect composite", surface treatment AND "indirect composite", resin bond strength OR bond strength AND "new ceramic/polymer materials", surface treatment AND "new ceramic/polymer materials", resin bond strength OR bond strength AND "hybrid ceramic" and surface treatment AND "hybrid ceramic", resin bond strength OR bond strength AND "resin nano ceramic" and surface treatment AND "resin nano ceramic". Furthermore, the bibliographies and related reviews of all chosen full-text articles were scanned for additional publications on the topic.

Inclusion Criteria

The inclusion criteria for study selection were:

- Only in vitro studies were considered
- Publications in the dental literature with language restriction to English
- Bonding of new ceramic/polymer materials or indirect composites to either human teeth or ceramic or composite
- Studies reporting on at least one common chemical (silane, silica coating) or mechanical (grinding, roughening with diamond burs, air-particle abrasion, acid etching, laser) surface treatment on tested specimens
- Studies describing at least one common method of artificial aging (water storage, artificial saliva storage, or thermocycling [TC])
- Studies applying a shear bond strength (SBS) test, tensile bond strength (TBS) test, micro-TBS (μTBS)/micro-SBS, or other bond strength test

Exclusion Criteria

- Studies about repair bond strength
- No detailed information on sample size
- Research question and purpose of the study focused on parameters other than solely bond strength (e.g. influence of specific parameters)

Selection of Studies

Figure 1 describes the process of identifying the selected studies. From an initial 198 studies, 33 studies were chosen for full-text analysis. After full-text analysis, 12 studies met the inclusion criteria. Moreover, a total of 10 studies were added through hand-search of the bibliographies of the 12 studies. Following detailed analysis, a final number of 18 studies were selected for review.[6,10–12,28–41]

Excluded Studies

Out of the 43 full-text articles, 25 were excluded from the final analysis.

Reason for exclusion:

- No surface treatment of indirect composite[42–51]
- No detailed information on number of specimens[52]
- Research question and purpose of the study focused above on other parameters[53–62] than bond strength
- Other bonding substrates than human teeth or ceramic or composite[63,64]
- No or uncommon artificial aging method[9,65]

Data Extraction

Out of the 18 studies included, information on the surface treatment, the cements, influence and method of artificial aging, and the influence of the different bond strength test used were evaluated.

Different mechanical and chemical surface treatment methods were examined, for instance silane treatment,

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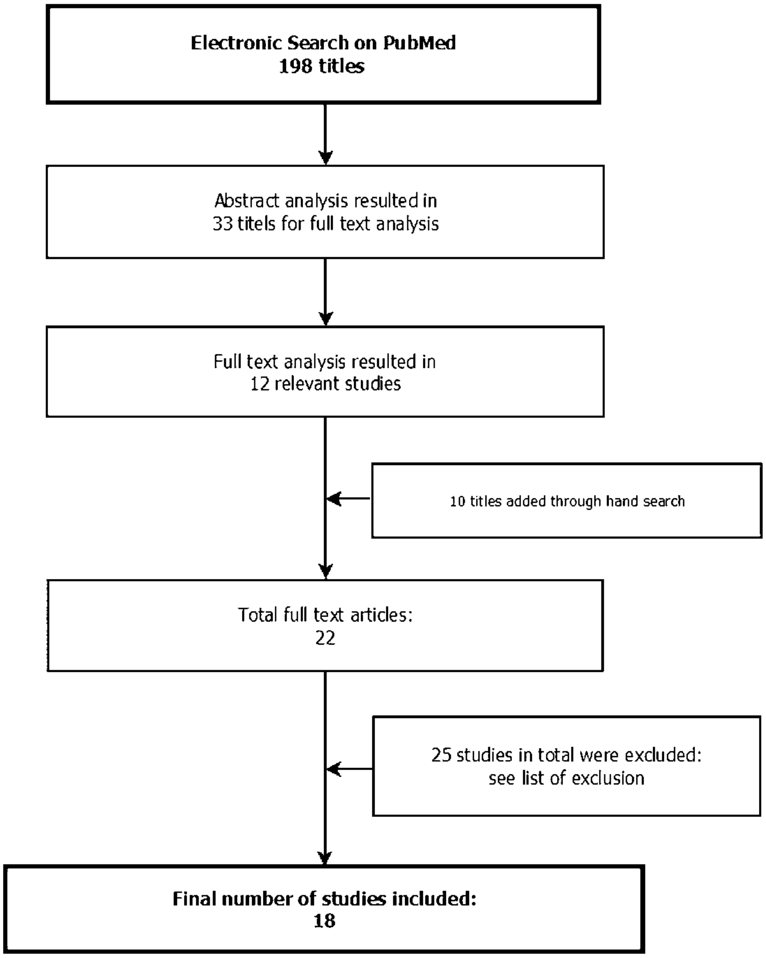

FIGURE 1. Search strategy.

air-particle abrasion with different particle sizes, HF etching with different concentrations and times, silica-coating and their combinations.

Investigation of common autopolymerizing (chemically activated), photo-activated or dual-activated resin cements, and their respective bonding agents was further performed. Moreover, water storage, artificial saliva, and TC as artificial aging methods and their effects on bonding behavior were tested.

RESULTS

Indirect Composites

A total of 18 studies[6,10–12,28–41] were included in the analysis of this review. The characteristics are shown in Table 1.

The oldest study was published in 1991 and the median year of publication was 2003. Eighteen different indirect composite materials were tested with 12 various surface treatment methods and 28 resin cements. Mostly human third molars were used as a bonding substrate for testing. The most common method for artificial aging was water storage at 37°C for 24 hours before testing. TC as an additional stress test was just used in six studies. Seven of the studies used the SBS test, six measured the μTBS, three the TBS, and two applied a different bond strength test.[33,39]

Surface Treatment

Twelve studies reported on several surface treatments of the prosthetic composites, and nearly all of them[10,28,33,36–40] found that air-abrasion with aluminum-oxide (Al_2O_3) particles with a particle size of 50 μm was the most effective method to roughen the

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TABLE 1. Study characteristics of the selected studies for indirect composite bonding

Study	Year of publication	Indirect composite	Manufacturing procedure surface treatment cement		No. of specimens per group	Bonding partner	Artificial aging method	Bond strength test
Fuentes et al.[6]	2013	Filtek Z250	Silane Silane + bonding agent	RelyX Unicem Maxem Elite G-Cem RelyX ARC	$N \geq 10$	Human molars	H_2O at 37°C for 24 hours	µTBS
Vaz et al.[29]	2012	Symphony	Air-particle abrasion + Silane	RelyX Arc C & B Cement RelyX Unicem	$N = 5$	Human molars	100 % rel. humidity at 37°C for 24 hours or 30 days	µTBS
Türkmen et al.[12]	2011	Estenia	Air-particle abrasion	Cement—It RelyX Unicem Maxcem Embrace Wet Bond	$N = 10$	Human molars	H_2O at 37°C for 24 hours	TBS
Honda et al.[11]	2008	Adoro Artglass	Air-particle abrasion Air-particle abrasion + Silane	Rely X ARC	$N = 30$	Human molars	Artificial saliva at 37°C for 6 days	µTBS
Hori et al.[30]	2008	Estenia	Air-particle abrasion HF etching Silane HF etching + Silane Air-particle abrasion + Silane	Panavia F	$N = 7$	Similar treated indirect composites (different size)	H_2O at 37°C for 24 hours + 0 TC or 50,000 TC	SBS
D' Arcangelo et al.[28]	2007	Enamel-Plus HFO UD3	Air-particle abrasion HF etching + Silane Air-particle abrasion + Silane	EnamelPlus UD2	$N = 22$	Human molars	Distilled H_2O at 37° C for 24h + 5000 TC	TBS
De Menezes et al.[31]	2006	Clearfil APX	Air-particle abrasion	Rely X Enforce Panavia F	$N = 24$	Human molars	H_2O at 37°C for 24 hours	µTBS
Soares et al.[10]	2004	Targis Solidex Filtek Z250	Air-particle abrasion HF etching Silane HF + Silane Air-particle abrasion + Silane	Rely X	$N = 12$	Similarly treated surfaces	100 % rel. humidity at 37°C for 24 hours	µTBS
Burnett et al.[32]	2004	BelleGlass Sculpture Targis	Silane HF etching Er:YAG laser Er:YAG laser + HF Air-particle abrasion Air-particle abrasion + HF	„Silane" + Single Bond	$n = 10$	Filtek Z250	Distilled H_2O at 37°C for 24 hours	TBS
Ellakwa et al.[33]	2003	Belleglass HP	Air-particle abrasion Air-particle abrasion + Silane Air-particle abrasion + Silane + dry storage Air-particle abrasion + Artglass liquid	Dual curing Luting Cement (Kerr)	$N = 5$	Similar indirect composites	H_2O at 37°C for 24 hours	Other bond strength test
Mak et al.[34]	2002	Light—activated hybrid resin composite (Bisco, Inc)	Air-particle abrasion + Silane	Choice RelyX ARC Super Bond C&B Panavia F	$N \geq 22$	Human molars	Distilled H_2O at 37°C for 24 hours	µTBS
Yoshida et al.[35]	2001	GN—I	Silane	Link Max Vita Cerec Duo Cement	$N = 5$	Similar indirect composites (different size)	Distilled H_2O at 37°C for 24 hours + 0 TC or 50,000 TC	SBS
Nilsson et al.[36]	2000	Z—100 Targis Artglass	Grinding Air-particle abrasion Air-particle abrasion + Silane	Scotchbond resin cement Variolink 2 bond 2	$N = 10$	Similar IC (?)	100 % rel. humidity at 37°C for 24 hours	SBS
Bouschlicher et al.[37]	1999	Artglass belleGlass HP Concept Targis	Air-particle abrasion CoJet-Sand	Dual	$N = 10$	Similar indirect composites (different size)	Double-deionized H_2O for 24 hours at 37°C + 300 TC	SBS

TABLE 1. Continued

Study	Year of publication	Indirect composite	Manufacturing procedure surface treatment cement		No. of specimens per group	Bonding partner	Artificial aging method	Bond strength test
Imamura et al.[38]	1996	Concept Herculite XRV	Air-particle abrasion Air-particle abrasion + Special Bond II Air-particle abrasion + Silane + All Bond 2 Air-particle abrasion + HF etch Silane + Rocatec System	Dual Cement Porcelite Dual Cure Cement	N = 10	Similar indirect composites	Distilled H_2O at 23°C for 7 days + 1,000 TC	SBS
Shortall et al.[39]	1996	Brilliant Dentin	Water rinsing + Air drying Air—particle abrasion Air—particle abrasion + fluoride gel	Duo Cure Cement Porcelite Dual Cure	N = 10	Similar indirect composites	Distilled H_2O at 37°C for 24 hours	Other bond strength test
		Herculite XRV Lab	Air—particle abrasion + HF Air—particle abrasion + Silane Air—particle abrasion + HF + Silane					
Swift et al.[40]	1992	Herculite XRV	HF etching Air-particle abrasion Air-particle abrasion + HF	Porcelite Dual Cure	N = 20	Human molars	Half: distilled H_2O RT for 7 days Half: distilled H_2O RT for 7 days + 500 TC	SBS
			Air-particle abrasion Air-particle abrasion + Silane Air-particle abrasion + HF		N = 10		Distilled H_2O for 48 hours + 500 TC	
Tam et al.[41]	1991	Isosit—N	HF etching Air-particle abrasion (different particle sizes) HF etching + Silane Special Bond	Heliolink G-Cera Prisma PVC Durafil Porcelite Chameleon	N ≥ 8	Ceramic blocks (Vita)	Distilled H_2O at 37°C for 24 hours	SBS

μTBS = microtensile bond strength; HF = hydrofluoric acid; RT = room temperature; SBS = shear bond strength; TBS = tensile bond strength; TC = thermocycling.

surface independently of the indirect composite used. According to Burnett and colleagues[32] Er:YAG laser abrasion can also be a favorable surface-conditioning method instead of air-particle abrasion. Furthermore, a study by Bouschlicher and coworkers[37] revealed that surface roughening with the silica coating Co-Jet system (3M ESPE) resulted in same bond-strength data as air-abrasion. The Rocatec System (3M ESPE) is the laboratory version of CoJet and has shown to be similarly effective.[38] Silane treatment yielded in further increased bond strength in most of the studies.[10,33,36] Yoshida and coworkers[35] even claimed that silane coupling is the essential factor. In contrast, D'Arcangelo and Vanini[28] stated that silane did not have a significant effect on resin bonds. Almost all of the studies agreed that HF etching in different concentrations showed lower bond strength data, except for the study by Hori and colleagues,[30] which resulted in highest bond strength value, when 1% HF etching for 5 minutes was applied.

Even combinations of HF etching and air-particle abrasion,[32,39,40] or silane treatment could not reach the bond strength values achieved by air-particle abrasion treatment. In general, increasing surface roughness through mechanical surface treatment had a greater impact on bond strength than chemical conditioning.

Resin Cements

Studies that compared different adhesive cements demonstrated that the chosen cements had a significant effect on bond strength and that there is no ideal universal luting agent. De Menezes and colleagues[31] pointed out that the type of bonding agent was important. Bonding agents with multiple steps yielded higher bond strength values than self-adhesive cements. Türkmen and colleagues,[12] and Vaz and colleagues[29] confirmed this statement, as did Fuentes and colleagues[6] in 2013; total-etch bonding agents still provided better values. In the same study, there were no

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significant differences in tested self-adhesive cements, except for Maxcem Elite (Kerr, Orange, CA, USA), which resulted in distinctly lower bond strengths.

TC as an additional artificial aging procedure seemed to have a greater impact than only short-term water storage.

New Ceramic/Polymer Materials

Despite this extensive literature search, no in vitro studies referring to the resin bond to new ceramic/polymer materials could be identified. Likewise, there was no information found regarding recommendations for surface treatment, resin cements, or artificial aging methods.

DISCUSSION

This review examined the effect of different bonding parameters, such as surface conditioning, resin cements, and artificial aging on the resin-bond behavior of indirect composites and new ceramic/polymer materials based on the current dental literature.

The search period was defined from 1966 to September 2013 based on the reviews by Blatz and colleagues,[5] and Soares and colleagues.[8] There were no studies that met the inclusion criteria published before 1991.

Surface Treatment and Resin Cements

Pretreatment steps of indirect restorations and supporting tooth structure plus luting with an adhesive cement is defined as resin bonding.[66] Therefore, the focus of this review was based on the different pretreatments steps and adhesive systems used in the studies. Air-particle abrasion increases surface energy of indirect restorations, such as high-strength ceramics[23,24,67] and indirect composites,[10,28,39,40] thus resulting in an increased surface roughness. Moreover, these irregularities provide better mechanical attachment of the luting agent to the finished composite.[10] Similarly, before silanization, the surface has to be preconditioned for the resin matrix to being partially destroyed and the filler particles being exposed.[38,40,41] This leads to better mechanical interlocking between the restoration and the substructure, which is a main reason for a durable bonding.[11] Silica-based ceramics also need adequate surface activation for a durable long-term bond.[5] Many laboratory studies[68–70] have investigated different methods for surface pretreatment. In contrast with high-strength ceramics, acid-etching with HF solutions between 2.5% and 10% applied for 1 to 3 minutes plus usage of a silane is reported as the best surface-conditioning protocol.[1,5,70] Hori and colleagues[30] detected that after TC, 1% HF etching for 5 minutes is also an adequate pretreatment method for prosthetic composites. However, according to them, neither etching time nor etchant concentration were significantly relevant to bond strength.

Silane is a bifunctional molecule that bonds through siloxane to the exposed fillers in the composite.[10] It also increases the bond strength[33] by improving the wettability of the treated surface. Soares and colleagues,[10] Ellakwa and colleagues,[33] Nilsson and colleagues,[36] and Swift and colleagues[40] reported on the positive effects of chemical treatment with silane in their studies, which is in conclusion with other studies[33,35] in the dental literature. Yoshida and colleagues[35] even preferred silane as a surface-roughening method because air-particle abrasion can induce material chipping and HF produces weaker bond strengths and additionally needs to be treated with special care and experience due to its toxic properties. However, studies by Tam and colleagues,[41] and Fuentes and colleagues[6] found conflicting results as they could not detect a significant increase in bond strength when silane was applied. Etching with HF resulted in dissolution of the embedded glass fillers in the laboratory composites, leaving no retention for silane molecules.[10] The silane had therefore no impact on bond strength.

Two other methods for pretreatment are the extraoral Rocatec System (3M ESPE) and Co-Jet (3M ESPE) for intraoral use. Both systems are mostly indicated to repair defective indirect restorations and treat material surfaces tribochemically through an air-particle

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abrasion step with silica-coated aluminum-oxide particles, which provides a silica coat, and silane coupling agent application.

In most of the included studies,[6,10,11,29–31,34] dual-curing resin cements were used. They have proven successful throughout the last decades and are characterized by good retention and esthetics.[12] However, clinicians prefer simplified applications, whereas composite resins require skillful handling, especially when removing excess cement, and are time-consuming.[12]

Self-adhesive cements were introduced to the dental market within the last decade.[71] Because of the fact that application of luting cements is technically demanding and technique-sensitive,[71] self-adhesive cements attempt to overcome these challenges without pretreatment of the supporting tooth structure. They combine ease of handling with good to dental hard tissues.[12] However, the few in vitro studies showed that these new adhesives are still inferior to multistep protocols that include total-etch and self-etch bonding systems, when bonding to indirect composites.

Fuentes and colleagues[6] found that choice of resin cement seemed to have a greater impact than surface treatment. They confirmed that total-etch bonding systems provide higher bond strength values than self-adhesive cements. The same findings were reported by Viotti and colleagues[72] in 2009, Türkmen and colleagues,[12] and Vaz and colleagues.[29]

Clinical long-term studies[13–16] of indirect composite inlays and veneers are in support as mostly dual-cure composite-resin cements were used.

Table 2 summarizes the outcome of the included studies and shows a bonding protocol recommendation based on them.

TABLE 2. Recommended bonding protocol for indirect composite

Indirect composite	**1. Cleaning of the indirect restoration** **2. Surface treatment: Air-particle abrasion with 50 µm aluminum oxide** **3. Application of a silane**
Supporting tooth structure:	Choosing of total-etch, self–etch, or self-adhesive cementing system. Steps according to manufacturer's recommendation.

Artificial Aging Methods

Indirect restorations are exposed to chemical, thermal, and mechanical stresses in the oral cavity.[5] Therefore, it is important to mimic these circumstances in in vitro studies with artificial aging methods to draw sound conclusions with respect to durability and long-term bonding behavior. The common artificial aging treatment methods to stress adhesive surfaces[5] were considered to simulate oral conditions, such as long-term water storage[73] and TC. Equally artificial saliva solutions can be used instead of water storage, as shown by Kitasako and colleagues.[74] No significant difference could be detected.

Test Methods and Conditions

In the dental literature, bond strength tests can be divided in mircotest and macrotest methods, depending on the bonding area.[75] Tensile, microtensile, and shear test are the most common bond strength tests described.[5] The advantages and disadvantages of each testing method are thoroughly discussed and described in an article by Van Meerbeek and colleagues[75] in 2010. The SBS test is considered the easiest and fastest method for reliable results. One of the advantages of the microtensile test is that all specimens from one tooth undergo the exact same sample preparation. It is, however, more technique sensitive.

Because of the fact that all tests are being carried out under different circumstances, comparisons between studies and measured bond strength are difficult.[76–78] Testing parameters like bonding area, etching time, air-particle abrasion distance, time and pressure, crosshead speed, and dwell time between different

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baths of TC differ in almost every study. To date, there is no consensus about a standardized TC method. The number of cycles varies from 100 up to 50,000, whereas 10,000 cycles is considered to simulate 1 year of clinical performance.[12]

In Vitro Tests

Although randomized, controlled, clinical trials present the highest level of evidence to identify the best dental materials, they require a complex performance and are usually associated with high costs.[77] Laboratory tests, on the other hand, provide information on bonding behavior under controlled conditions.[23,79] Variables can be controlled, and individual parameters can be evaluated separately. Furthermore, long-term bonding is difficult to measure clinically because of the fact that indirect restoration failure is often multicausal and simple debonding a rare occurrence.

However, results from in vitro studies have to be interpreted with care as they simulate clinical conditions with great limitations[66] and cannot imitate the complexity of the oral cavity. Nevertheless, laboratory tests under standardized testing conditions provide crucial information before clinical use and/or testing of new materials.[77]

New Ceramic/Polymer Materials

At the time of this review, no scientific evidence pertaining to the proper bonding protocols for new ceramic/polymer materials could be found in the literature. It seems, however, that these materials comprise a well-diverse material group. As per manufacturers' recommendation, hybrid ceramics (i.e., VITA Enamic) should be pretreated through HF etching and silane coupling agent application.[17] Resin nanoceramics (i.e., Lava Ultimate[21]), however, should be subject to air-particle abrasion and application of a universal bonding agent. Independent studies that investigate resin bond strength and preferred treatment protocols for this new and increasingly popular material group are needed.

CONCLUSIONS

Air-particle abrasion and additional silane treatment should be applied to enhance the resin bond to laboratory-processed composites. However, there is an urgent need for in vitro studies that evaluate the bond strength to new ceramic/polymer materials.

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