Journal of Dentistry and Oral Biology

Research Article
Published: 20 Sep, 2018

Bonding of Composite and Glass-Ionomer to Amalgam

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Abstract

Aim: This *in vitro* study was to investigate bond strength between dental amalgam and a) composite or b) Glass-Ionomers (GI) to mimic restoration repair.

Materials and Methods: Cylindrical substrates of amalgam were made and ground (sanding paper #500). Repair materials were fixed to amalgam in groups of 20 specimens. Composite and three different bonding agents were tested in 3 modes; 1) short term (48 hr water storage), 2) water storage for 60 days, 3) thermo-cycling (TC) 5000/5-55°C. For the two Self-etch bonding-agents, the amalgam surface was not etched with acid. Three glass-ionomer products were tested in the same modes, two of them with and without dentine conditioner (optional from manufacturer). Altogether 24 groups were tested for sheer bond strength according to ISO/TS 11405.

Results: None of the GIs adhered to the amalgam surface, resulting in bond strength value of 0 MPa. Composite testing: Mode 1) 6.5-8.3 MPa, Mode 2) 6.4-7.7 MPa, Mode 3) 0.6-2.2 Mpa. There was no significant difference between mode 1 and 2. Mode 3 differed significantly from mode 1 and 2.

Conclusion: GIs did not bond to amalgam. Composite-amalgam repair bond strength is low compared to previous results on bonding composite to composite. TC seems to be detrimental to composite-amalgam repair-interface.

Introduction

All dental restorations have a limited lifespan and will eventually be replaced or repaired. According to modern dental philosophy, repair of defective restorations should always be considered when evaluating treatment options [1-3]. Repair has become increasingly more popular over the last two decades as the concept of "Minimal Intervention Dentistry" (MID) has been rooted in clinical practice [4-6].

The use of amalgam as a dental restorative material is banned or strongly restricted for environmental reasons in Scandinavia [7]. Other countries are evaluating the use of mercury containing materials, and we shall probably, in line with the Minimata Convention, which entered into force on Aug 16th 2017- (UNEP. Minimata Convention on Mercury 2017. Available online: http://www.mercuryconvention.org) -see more restrictions on the use of dental amalgam in years to come [8]. Nevertheless this debated material has been in use for more than a century and will be present in our patients for decades. Dental surgeons will often be in a situation where the question is repair or replacement of an amalgam restoration. In a questionnaire from 2015, Norwegian dentists were asked about their view on what to do with defective amalgam restorations. In many cases repair with composite was the preferred option [9]. The Norwegian dentist's positive attitude towards repair was also confirmed in another questionnaire from 2016 concerning defective composite restorations [10]. Treatment goals are long-lasting restorations of good quality, and repair of resin-based composites is reported to have a favourable outcome for the longevity and quality of the restoration without compromising the sound tooth tissue more than necessary [11-14].

According to many authors; repair, refurbishment and monitoring restoration defects increase the survival time of restorations significantly [2,15-17]. Schwendicke et al. [18] have in a publication on "Consensus Recommendations on Carious Tissue Removal" recommended that "Retreatment of restorations should aim to repair by resealing, refurbishing, or re-polishing where possible, and replacement should be last resort (strong recommendation)".

The advantages of not replacing the entire restoration due to minor flaws are several. Tooth structure and strength are preserved [1]. There might be reduced risk of accidental pulp damage and iatrogenic damage to neighbour teeth, not to forget the "cycle of re-restoration" that points

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Received Date: *14 Jun 2018*
Accepted Date: *15 Sep 2018*
Published Date: *20 Sep 2018*

Citation:
Staxrud F, Mulic A. Bonding of Composite and Glass-Ionomer to Amalgam. J Dent Oral Biol. 2018; 3(6): 1145.

ISSN: 2475-5680

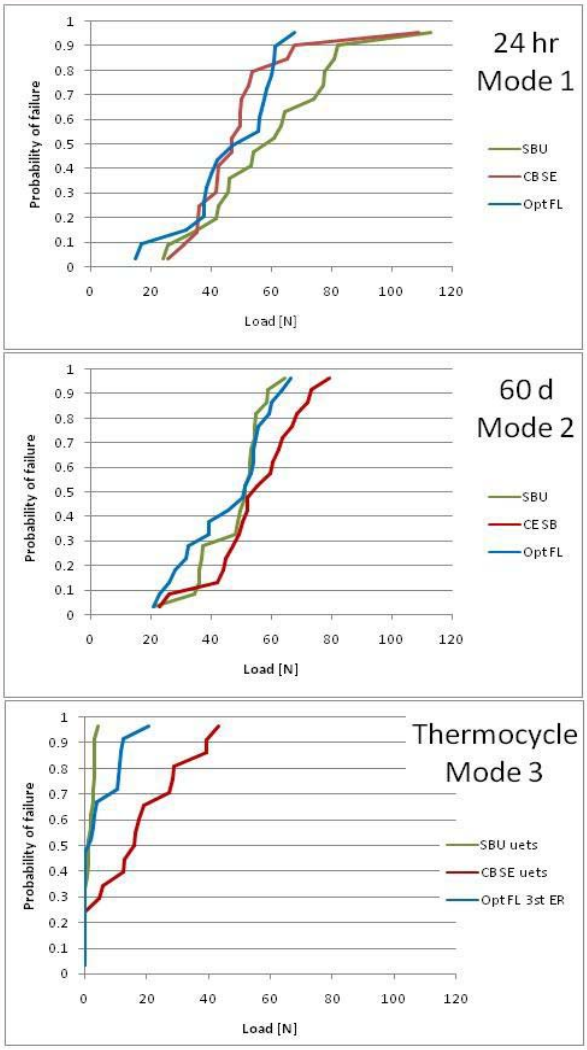

Figure 1: Distribution plot of the results of the SBS tests of composite in a vertical set up for ease of comparison between the modes.

to the repeated treatment of teeth as a journey to destruction of the tooth [19,20]. There is also a financial issue concerning the patients, repair can be performed quicker, at a lower cost and the need for local anaesthetics is reduced [1-3].

Ray et al. found that repair of amalgam with amalgam gave adequate bond strength, but that repair of amalgam with composite demanded extra retention [21]. Today, in line with the concept of MID, resin-based composite (RC) will often be the first restorative material of choice for both new restoration and as repair material [16,22,23]. Özcan et al. [24,25] found that when repairing amalgam with adhesive approaches and composite, the bonding strength was significantly improved when using metal primers (containing sulphur compounds), silica coating air abrasion, silanising agents and glass fibre mesh at the interface before applying bonding agents. The procedures seem safe and reliable and a repair protocol has been launched [26]. The problem is that most dentists in a clinical situation do not take time to go through a comprehensive and complicated procedure for minor restoration repair. Many are relying on bonding procedures, with the intention to obtain adequate and reliable strength at the repair interface with simple use of bonding agents.

The aim of this *in vitro* study was to investigate the bond strength at the repair interface between amalgam restorations and; 1) composite as repair material with 3 different bonding agents, or 2) 3 different GIs (with and without dentin conditioner).

The following null hypotheses were therefore proposed:

a) There is no bond strength between amalgam and RC at repair interface when using only bonding agent as adhesive medium.

b) There is no bond strength between amalgam and GI at repair interface.

Material and Methods

Test substrates were made by condensing amalgam (Dispersalloy) into copper bands, Θ 8 mm height 10 mm, and ground flat with sanding paper P #500 FEPA (Struer, Denmark) (Particle size 30.2 µm, corresponding to extra fine diamond burs). In the present study, three commonly used bonding systems were chosen; one 3 steps etch and rinse (ER) type; Opti bond FL (OFL), one 2 steps "self-etch" (SE) bonding agent; Clearfield SE Bond (CSEB) and one 1 step SE, also called "Universal", bonding agent; Scotch bond Universal (SBU).

Three different glass-ionomers (GIs) were chosen as they might be a good alternative in not stress bearing areas. The chosen GI materials were; GC Fuji II LC (with and without conditioner), GC Fuji IX (with and without conditioner) and Ketac Universal Applicap (no conditioner according to manufacturer's recommendation). Materials used are listed in Table 1.

Repair material of composite (Filtek Supreme XTE, shade A3) was mounted as cylindrical buttons on the ground amalgam surface, Θ 3 mm, h: 2 mm with the chosen bonding systems, bonded area equals 7.07 mm^2. Glass-Ionomer buttons were mounted both with and without conditioner as described above.

Handling of the bonding materials, composite and glass-ionomers was performed according to manufacturer's instructions. They were light cured with Kerr Demi Ultra, pulse, irradiation 900-1000 mW/cm^2. The specimens were made according to ISO/TR 11405 [27] for shear bond strength (SBS) testing, which was performed in an Instron universal testing machine (Lloyds, England). For this test the specimens were fixed in a specially designed jig and the force applied directly at the bonding interface parallel to this at cross-head speed of 1 mm/min. Maximum load at breakage is registered by the instruments. Three different test modes were used:

Mode 1

Short term test; the substrates had new buttons of RC/GI fixed and the specimens were SBS tested after 48 hr in water storage (no TC was performed).

Mode 2

Water storage 60 days; the test specimens were SBS tested after 2 months at 37°C in water (no TC was performed).

Mode 3

Thermo-cycling (5000 x 5/55°C) (TC); after mounting the repair materials (RC/GI) the specimens were stored in water (14 days) before TC and SBS testing.

The amalgam-composite-repair-specimens (test specimen) were tested in 9 different groups (3 series x 3 modes) of 20 specimens each, see Table 2. The amalgam-GI-repair specimens were tested in 15 groups (5 series x 3 modes).

Table 1: Materials used.

Material	Manufacturer	Bonding type	Lot
Amalgam			
Dispersalloy	Dentsply Caulk, DE, USA		160309
Composite			
Filtek Supreme XTE,	3M ESPE, MN, USA		N491979
Bonding agent			
Clearfil SE Bond (CSEB)	KurarayNoritake, Japan	2 step SE	200
Scotchbond Universal (SBU)	3M ESPE, Germany	1 step SE «Universal»	633337
Optibond FL (OFL)	Kerr Italia, Italy	3 step ER	5962575
Glass ionomer (GI)			
GC Fuji II LC	GC Corporation, Japan		160416A
GC Fuji IX	GC Corporation, Japan		160224A
Ketac Universal Aplicap	3M ESPE, Germany		614726
Conditioner			
GC Dentin conditioner	GC Corporation, Japan		1602041

"The Norwegian Environment Authorities" granted import of mercury containing dental amalgam to Norway for use in this project (ref. 2016/97).

Statistics

The statistical analyses for calculating mean and variance were performed using the Statistical Package for the Social Sciences (SPSS, Inc. Chicago, IL, USA version 24). The probability of failure in the test specimens was assessed by means of a distribution plot, and the significance of the differences was evaluated by the Kolmogorov-Smirnov test [28].

The level of significance was set at 5%.

Results

The SBS results for the bonding of RC to amalgam are given in Table 2 and Figure 1. The composite repair gave rather weak results, however the GI substrates could not be SBS-tested as they did not adhere to the amalgam surface at all. Therefore they are regarded as pre-test failures with the value = 0.

All the specimens were analyzed for fracture mode after breaking off the repair material by means of a light microscope (Wild Photomakroskop M400, Wild Heerbrugg AG, Switzerland). One hundred percent were of adhesive type. A few specimens exposed remnants of repair material in small pits and grooves (Figure 2).

Discussion

The results of this study show rather low values for adhesion between composite and amalgam. When repairing composite to composite in laboratory studies the reported test values are found to be much higher. Earlier tests in the same laboratory, with the same equipment and personnel [29] showed values 3 to 4 times higher for short term tests of composite to composite than for amalgam to composite repair. When TC is performed the results for composite to composite are about ten times higher. A likely explanation for the higher values for composite repair is the possible re-silanating of filler particles in old composite and that there might be some functional monomers in the new composite to bond with resin in the old restoration after application of primer/adhesive. Laboratory tests are not *in vivo* experiments, but they can give an indication on how the materials will perform clinically [30,31]. The present results are initially rather low and will certainly attenuate by time.

Fracture mode was examined in stereo light microscope for all specimens and they were all of adhesive type. On a few occasions some of the repair material got into grooves and porosities at the amalgam surface giving small spots of cohesive fractures (Figure 2). This may explain some of the variance in the results and emphasise the importance of micro/macro-mechanical retention.

The Short Term mode (Mode 1) did not show any statistical significant difference between the bonding agents. Storage in water for 60 days before testing (Mode 2) gave similar results. After thermo-cycling (Mode 3) we could see a substantial drop in SBS values. An interesting finding in the present study is that the 3 step etch and rinse (3-step ER) (OFL), did not perform better than the other two when TC was performed. Rather, it looks like 2-step Self-Etch was the better alternative. One difference between the two self-etch bonding types and OFL is that the latter is bonded after etching the surface to be repaired as this is the manufacturer's advised procedure for "etch and rinse" bonding type. This may affect the results to some degree as it is well known that phosphoric ions in the acid may bind to cations at the surface blocking them for phosphoric compounds in the bonding agent thus preventing adhesion. However, as the number of specimens that disintegrated before testing is high for all groups in Mode 3 (Figure 1), the results must be considered uncertain. As TC was omitted in Mode 1 and 2 the results were quite within the same range for 3 steps ER and 2 steps SE. This brings up the discussion around TC as aging method in studies like this where the materials are very different. The idea of ageing the bonding interface with TC might be more suitable for materials with similar thermal expansion coefficient than for two very different materials like resin composite and amalgam alloy. As amalgam tends to increase less by volume with increasing temperature than composite (this may vary considerably) [32], there will be a movement between the materials at the interface. These movements might physically tear off any newly formed bond/interlocking between adhesive and metal. Thermal expansion coefficients for amalgam and resin may differ as much as 3 times [32]. Thermal variation in the mouth does not fluctuate as much as the TC conditions although this phenomenon might be considered to a certain degree as hot and cold food and drinks pass the teeth. Hot

Table 2: SBS test results.

Material fixed to amalgam	Bonding agent	SBS(SD)
Composite repair:		
Mode 1; Short term		**MPa**
Filtek Supreme XTE	Clearfil SE Bond	**6.9 (±2.6)**
	Scotchond Universal	**8.3 (±3.2)**
	Optibond FL	**6.5 (±2.2)**
Mode 2; 60 days in water		
Filtek Supreme XTE	Clearfil SE Bond	**7.7 (±2.0)**
	Scotchond Universal	**6.8 (±1.5)**
	Optibond FL	**6.4 (±2.0)**
Mode 3; TC 5000,5/55°C:		
Filtek Supreme XTE	Clearfil SE Bond	**2.2 (±2.1)**
	Scotchond Universal	**1.6 (±1.5)**
	Optibond FL	**0.6 (±0.9)**
Glass-ionomer (GC) repair:		
All three ageing modes		
GC Fuji IX	Conditioner	**0**
	No conditioner	**0**
GC Fuji II LC	Conditioner	**0**
	No conditioner	**0**
Ketac universal	No conditioner	**0**

N=20 for all groups. Ketac Universal does not need conditioner according to manufacturer. Glass Ionomers would not adhere to amalgam in any of the modes. Thermo-cycling seems to be devastating to the interface bond strength when combining two materials with very different thermal expansion coefficient. There is no statistical significant difference between the results in Mode 1 and Mode 2, $p>0.05$. Mode 3 (TC) gave statistically significant different results (lower) than Mode 1 and 2, $p<0.5$. Within Mode 3 Optibond FL and Scotchbond Universal gave statistically significant lower results compared with the other bonding agent, $p<0.5$. CSEB: Clearfil SE Bond; SBU: Scotchbond Universal; OFL: Optibond FL

drinks may have a temperature of 55°C, but it is unlikely that the tooth substance or restoration materials reach this temperature in 20 sec. The movement of food and drinks in the mouth along with the temperature controlling effects of saliva, tongue and mucosa, plays an important moderating role.

The idea of ageing amalgam was omitted, as amalgam does not take up water and the surface to be repaired is ground and rinsed for slurry, revealing a fresh surface of both new and old substrates.

The GI substrates disintegrated, or would not adhere at all, at the interface with amalgam. They de-bonded before any possibility of testing SBS, and should be regarded as pre-test failures with the value 0. A conclusion to be drawn is that GIs do not adhere to amalgam with any relevant force unless there is additional macro mechanical retention.

Aboush et al. found in 1989 and 1991 that Resin Modified Glass-Ionomers (RMGI) made relatively strong and reliable connections with amalgam [33,34]. It was claimed that bond strength between amalgam and RMGI was comparable with strength to enamel and significantly higher than to dentine. They used micro tensile bond strength (μTBS) test method. Their figures in 1991 were from ca. 4 MPa to ca. 9 MPa. In our study we could not find any reliable figures for the bonding strength between GIs and amalgam. This does not necessarily mean that the interface between amalgam and GIs is not tight. It is well known that the interface between amalgam and dental

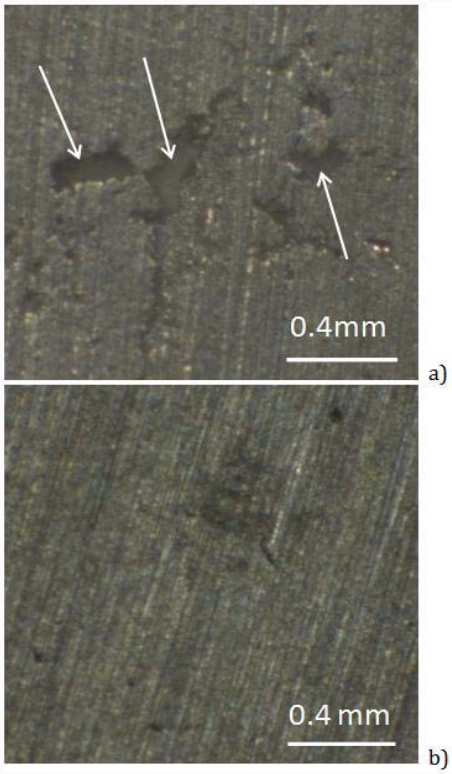

Figure 2: a) Remnants of composite in defects, pits and grooves teared off cohesively (arrows), but no composite on the ground surface as in b) where the composite has been detached adhesively from the amalgam.

hard tissue normally is tight due to corrosion products from amalgam filling up the gap, although there is no adhesion between dental hard tissue and amalgam. One might deduct from this knowledge that this corrosion phenomenon is at work between amalgam and GIs as well, and there is probably limited leakage between amalgams and GIs. Oxides present at the amalgam surface might form some bonds to GIs, but as it is recommended to prepare and roughen the surface for reasons of retention and clean surface, any possible oxides would most certainly be removed. The adhesion of GIs to teeth is mainly relying on chemical bonding to dentin and enamel and on possible undercuts the operator may prepare. According to these results null hypothesis a) have to be rejected, however null hypothesis b) Cannot be rejected from current evidence.

As repair of minor to moderate defects of dental restorations or fractured parts of teeth is up-to-date dentistry and in accordance with the minimal-invasive philosophy [1-3], there is a need for knowing how to use the suitable materials. It seems to be very low bond strength between composites/GIs and amalgam compared to composite to composite bond strength when using simple, ordinary bonding procedures. The bonding is simply not reliable alone and should be regarded as inadequate. Fortunately the cavities or defects have other elements to which the bonding agents can bond e.g. enamel and dentine. Depending on the size and shape of the cavity/damage it should be recommended to create additional macro mechanical retention like dove tails and undercuts in the old restorations. Other procedures have been tested by other researchers like air abrasion and alloy primer, silica coating (providing oxides) and silane surface treatment, grooves and use of coarse burs would absolutely be favorable, and give bond strength improvements [35]. More complex bonding procedures with glass fiber reinforcement and metal primers

could also be beneficial [26].

The main reasons for restoration failure are still caries and fractures [16,36-40]. Cusp fractures restored with composite adjacent to old amalgam restorations seem to be good practice, likewise treatment of secondary caries at the margins of crowns or amalgam restorations with composite or GI. When taking into account the advantages and limitations of the bonding agents, the repaired restorations are long lasting and may prolong the longevity of the existing restoration considerably [16,23].

Conclusion

Amalgam restorations of adequate standard and condition can very well be repaired with composite, but there should be provided for extra retention into the amalgam filling as the bond strength alone is not adequate. Glass-Ionomer may also be used for repair at amalgam restoration margins in not stress bearing areas, but as they do not adhere to amalgam, they need enamel and dentine for retention and possible undercuts towards amalgam interface.

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