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## Laboratory Research

# Failure Strengths of Composite Additions and Repairs

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### Clinical Relevance

Repair of defective composite restorations is a common practice, but few studies have quantified the strength of various types of repair materials and techniques. This study provides evidence that may help clinicians choose the most promising techniques and materials.


### SUMMARY

**Purpose: When adding composite to a cured composite restoration, the intent is to achieve the same failure strength as the original restorative material. This study evaluated the failure strengths of added or repaired composite using various chemical and/or mechanical surface treatments.**

**Methods: Failure strengths were determined using a four-point bending test. Beam-shaped specimens were fabricated by adding new composite to cured composite (Filtek Supreme Ultra). The cured composites were either fresh or aged seven days (N=10-14). The composite surfaces were left unground or were ground before treatment with various combinations of roughening, acid etching, silane, and dental adhesives (conventional Adper SingleBond Plus or new multimode Scotchbond Universal) and/or tribochemistry (CoJet system). Monolithic composite specimens were the control. Failure strengths were statistically analyzed using one-way analysis of variance and the Fisher protected least significant difference ($\alpha$=0.05).**

**Results: Failure strengths (mean ± standard deviation) when composite was added to unground freshly cured composites (111±25 MPa) and aged composites using a new multimode adhesive with (102±22 MPa) or without (98±22 MPa) tribochemical treatment were not significantly lower than the monolithic specimens (122±23 MPa). Grinding the surfaces of freshly cured composite significantly reduced failure strength, either with (81±30 MPa) or without (86±31 MPa) use of conventional adhesive. Failure strengths of aged composites were also significantly lower (51±21 MPa with SingleBond Plus), even after tribochemical treatment (71±29 MPa with SingleBond Plus; 73±35 MPa with Silane-Visiobond).**

**Conclusions: Using a new multimode adhesive when adding composite to freshly cured or aged composite substrates recovered the fail-**



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**ure strength to that of the original monolithic composite.**

## INTRODUCTION

Composite repair for defective restorations is departing from the traditional approach of removing the whole existing restoration. Repair, rather than total replacement, is one of the main concepts of minimally invasive dentistry.[1] The main benefits of composite repair are that it preserves tooth substance, reduces the risk of pulpal complications, reduces costs for patients, and reduces treatment time.[2,3] Eighty-eight percent of dental schools in the United States and Canada and 95% of dental schools in Japan reported teaching repair of defective composite restorations.[2,3] Dental schools that did not include composite repair in their curriculum indicated poor experiences with restoration repairs and viewed the repair procedure as subjective and potentially increasing clinical risks.[2]

From a material point of view, adding fresh composite to a cured composite in a repair procedure raises questions about the adhesion and strength of the restoration.[4-7] To achieve chemical adhesion, unreacted double bonds in cured resin-based composites are essential when adding a new layer of material.[8] Freshly cured composites usually have a relatively high percentage of unreacted double bonds. Methacrylate groups in restorative composites remain 25%-55% unreacted after polymerization.[9] For aged composites, low bond strengths of added layers have been attributed to a reduced number of unreacted double bonds.[4]

Various surface treatment techniques have been used to improve repair bond strength by increasing surface roughness and/or chemically treating the substrate surfaces. Examples are bonding agent application, acid etching, surface abrasion, silica coating, and silanization.[10-14] As more than half of the components of composite restorative materials are ceramic-based filler particles, surface treatment and/or application of an adhesive that promotes affinity to both the methacrylate-based resin and the ceramic-based fillers should be advantageous. For instance, a tribochemical system (CoJet, 3M ESPE, St Paul, MN, USA) that combines sandblasting, a proprietary silica coated sand, silanization, and adhesive resin has been reported to increase repair bond strengths.[12,13] Moreover, a recently introduced multimode adhesive (Scotchbond Universal, 3M ESPE) combines methacryloxydecyl phosphate monomer and silane to enable bonding to various substrates, including metal, nonglass ceramic, and glass ceramic.[15] The indication for use of this new universal adhesive includes intraoral repair of existing composites.

The objectives of this study were to investigate failure strength of added or repaired composite using tribochemical pretreatment and/or the new multimode adhesive and to compare the results with traditional techniques of surface roughening, acid etching, and bonding agent. Two types of substrates were investigated: (1) freshly cured composite, representing a clinical situation where composite is added in the same visit as the restoration placement, and (2) aged composite, representing a clinical situation where composite is added (repaired) at a later visit. Monolithic composite served as the unrepaired control. The hypothesis was that with an appropriate surface treatment, the failure strength of added or repaired composite could be the same as the cohesive strength of monolithic composite.

## METHODS AND MATERIALS

Beam-shaped composite specimens were fabricated using Filtek Supreme Ultra (3M ESPE). The composition and application information for all materials used is summarized in Table 1.

### Monolithic Composite

Monolithic beam specimens ($2 \times 2.5 \times 25$ mm) were fabricated by filling a stainless steel mold with a restorative composite placed between two glass slides. The composite beams were light-cured from the top and the bottom (VIP junior light curing unit, BISCO Inc, Schaumburg, IL, USA) through the glass slides. The light tip was moved along the top ($4 \times 20$ seconds) and bottom ($4 \times 20$ seconds) to cover the entire length of the beams. The intensity of the light source was 600 mW/cm$^2$, as indicated by a radiometer (Model 100, Demetron Research Corp, Danbury, CT, USA). After curing, the beams were taken out of the mold, flash was removed, and the specimens were finished by wet grinding with 600-grit silicon carbide paper. The sample size of the monolithic group was 6.

### Adding to Freshly Cured Unground Composite

Half-length beam specimens ($2 \times 2.5 \times 12.5$ mm) were made by filling half the stainless steel mold (Figure 1A) with composite against a metal insert. The half-beams were light-cured following the same procedure as the full-length monolithic beams ($2 \times 20$ seconds from the top and $2 \times 20$ seconds from the

Table 1: *Materials Used in the Study*

| Material | Composition | Application |
|---|---|---|
| Filtek Supreme Ultra Restorative Composite[a] (A2 body shade), lot N323761 and N367652 | Silane treated ceramic 60%-80%; silane treated silica 1%-10%; UDMA 1%-10%; bisphenol A polyethylene glycol diether dimethacrylate 1%-10%; Bis-GMA 1%-10%; silane treated zirconia 1%-10%; polyethylene glycol dimethacrylate <5%; TEGDMA <5%; 2,6-di-tert-butyl-p-cresol <0.5% | Light-cure 20 s |
| Scotchbond Universal Etchant,[a] lot 476313 | Water 50%-65%; phosphoric acid 30%-40%; synthetic amorphous silica fumed, crystalline free 5%-10%; polyethylene glycol 1%-5%; aluminum oxide <2% | Etch 15 s, rinse with water 10 s, blot dry |
| Adper Single Bond Plus Adhesive,[a] lot 364852 | Ethyl alcohol 25%-35%; Bis-GMA 10%-20%; silane treated silica (nanofiller) 10%-20%; HEMA 5%-15%; copolymer of acrylic and itaconic acid 5%-10%; glycerol 1,3-dimethacrylate 5%-10%, water <5%, UDMA 1%-5%; diphenyliodonium hexafluorophosphate <0.5%; EDMAB <0.5% | Apply 15 s, air dry 5 s, light-cure 10 s |
| CoJet Sand Blast-Coating Agent 30 mm,[b] Lot 471342 | Aluminum oxide >97%; amorphous silica 3% | Sand blast 3 s |
| ESPE Sil Silane Coupling Agent,[b] lot 470876 | Ethyl alcohol >97%; 3-methacryloxypropyl trimethoxysilane <3%; methyl ethyl ketone <2% | Apply, allow to dry 30 s |
| Visio Bond Light-curing Bonding Agent,[b] lot 464854 | 2-propenoic acid, 2-methyl-, [(3-methoxypropyl)imino]di-2,1-ethanediyl ester 1%-5%; 2,2-dimethoxy-2-phenylacetophenone <0.3%; dicyclopentyldimethylene diacrylate >95%; 2-propenoic acid, 2-methyl-, 2-[(2-hydroxyethyl)(3-methoxyproply)amino]ethyl ester <0.8% | Apply 10 s, air thin 5 s, light-cure 20 s |
| Scotchbond Universal Adhesive,[a] lot 475230 | Bis-GMA 15%-25%; 2-hydroxyethyl methacrylate 15%-25%; decamethylene dimethacrylate 5%-15%; ethanol 10%-15%; water 10%-15%; silane treated silica 5%-15%; 2-propenoic acid, 2-methyl-, reaction products with 1,10-decanediol and phosphorous oxide 1%-10%; copolymer of acrylic and itaconic acid 1%-5%; dimethylaminobenzoat <2%; camphorquinone <2%; (dimethylamino)ethyl methacrylate <2%; methyl ethyl ketone <0.5% | Apply 20 s, air dry 5 s, light-cure 10 s |
| MicroEtcher II Intraoral Sandblaster,[c] Lot 23131-9 | Equipment | Sand blast 3 s |

*Abbreviations: Bis-GMA, bisphenol A diglycidyl ether dimethacrylate; EDMAB, ethyl 4-dimethyl aminobenzoate; HEMA, 2-hydroxyethyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate*
[a] *3M ESPE, St Paul, MN, USA.*
[b] *3M ESPE AG, Seefeld, Germany.*
[c] *Danville Materials, San Ramon, CA, USA*

bottom). After the half-beams were cured, the metal insert was removed and composite was inserted into the other half of the mold (Figure 1B), which was then light-cured ($2 \times 20$ seconds from top and $2 \times 20$ seconds from bottom). The final full-length beams were removed from the molds and finished using the same procedures as described for the monolithic beams. The sample size of the freshly cured composite group was 10.

### Fabrication of Half-Beams

Half-length beam specimens ($2 \times 2.5 \times 12.5$ mm) were made by filling half the stainless steel mold with composite against the metal insert and light-cured following the same procedure as described previously. After curing, the half-length beams were removed from the molds and flash was removed. All surfaces, including the surface where composite would be added, were finished by wet grinding with 600-grit silicon carbide paper. Composite was added to the half-beam specimens either immediately (freshly cured) or after being stored dry for 7 days at room temperature (aged).

### Adding to Freshly Cured Composite

The freshly cured half-beam specimens were (1) ground wet using 600-grit silicon carbide paper; or (2) ground wet using 600-grit silicon carbide paper etched with phosphoric acid gel (Scotchbond Universal Etchant, 3M ESPE) for 15 seconds, rinsed with water, and blotted dry. After adhesive was applied for 15 seconds (Adper SingleBond Plus, 3M ESPE),

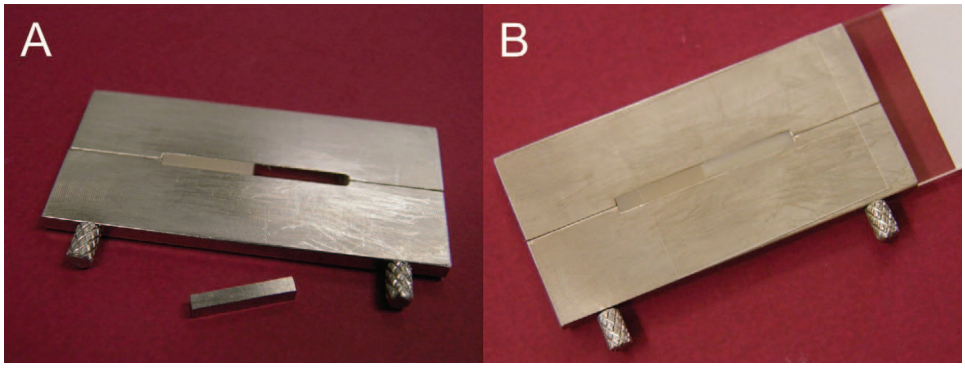


Figure 1. *Specimen fabrication. (A): Half-beam composite specimens (2 × 2.5 × 12.5 mm) were made in a stainless-steel mold. The metal insert was removed after curing. (B): Composite was added to repair the half-beam to full-length (2 × 2.5 × 25 mm).*

the specimens were air dried for 5 seconds and light-cured for 10 seconds. The surface-treated half-beam specimens were placed back into the mold, and the new composite was added to fabricate a full-length beam. The added composite was light-cured (2 × 20 seconds from top and bottom). The full-length beams were removed from the molds and finished using the same procedures as described for the monolithic beams. Sample size of the freshly cured composite groups was 10.

### Repair of Aged Composite

After wet grinding with 600-grit silicon carbide paper, the interfaces of the aged composite half-beam specimens were treated using one of the following protocols:

- Etch/SingleBond Plus: Etched with Scotchbond Universal Etchant for 15 seconds, rinsed with water, blotted dry, applied Adper SingleBond Plus adhesive for 15 seconds, air dried 5 seconds, and light-cured 20 seconds.
- Cojet/SingleBond Plus: Tribochemical treatment (CoJet sand-blast) for 3 seconds, applied Adper SingleBond Plus adhesive for 15 seconds, air dried 5 seconds, and light-cured 20 seconds.
- Cojet/Silane/Visiobond: Tribochemical treatment (CoJet sand-blast) for 3 seconds, applied ESPE Sil Silane Coupling Agent and allowed to dry 30 seconds, applied Visio Bond for 10 seconds, air-thinned 5 seconds, and light-cured 20 seconds.
- Etch/Universal: etched with Scotchbond Universal Etchant for 15 seconds, rinsed with water, blotted dry, applied Scotchbond Universal Adhesive for 20 seconds, air dried 5 seconds, and light-cured 20 seconds.
- Cojet/Universal: Tribochemical treatment (CoJet sand-blast) for 3 seconds, applied Scotchbond Universal Adhesive for 20 seconds, air dried 5 seconds, and light-cured 20 seconds.

The treated half-beam specimens were placed back into the mold, and new composite was inserted into the other half of the mold to fabricate a full-length beam. The added composite was light-cured (2 × 20 seconds from top and bottom). The repaired full-length composite beams were removed from the molds and finished using the same procedures as described for the monolithic beams. Sample sizes of the repaired aged composite groups were 10-14.

### Flexural Failure Strength Test

All specimens were stored dry at room temperature for 24 hours before testing. Before they were tested, the dimensions (length, height, and width) of each beam specimen were measured with a digital caliper. Width and height were determined as the average of three locations along each beam length. These dimensions were used in the failure strength calculations of each tested beam. Failure strengths were determined using a four-point bending test (Figure 2). Specimens were loaded until failure in a universal testing machine (Instron Electromechanical Testing System, Series 5567, Instron, Norwood, MA, USA) at a rate of 0.5 mm/min. Load at failure (N) was recorded. Failure strength (MPa) was calculated from the relationship: $3\,FL/(4BH^2)$, where F was the load at failure, L was the distance between the lower supports (20 mm), B was the beam width, and H was the beam height.[16] Failure strength comparisons between the tested groups were statistically analyzed with one-way analysis of variance followed by the Fisher protected least significant difference ($\alpha$=0.05).

## RESULTS

Failure strengths and sample sizes are shown in Table 2. It was observed that specimens with lower failure loads usually fractured along the interface of the repair, whereas specimens with higher failure

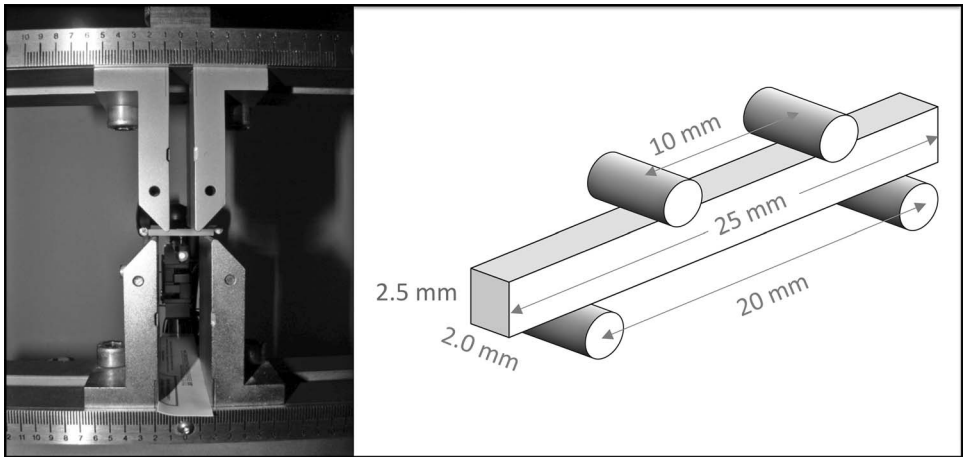


Figure 2. *Four-point bending test setup and diagram of the specimen dimensions and loading points.*

loads often failed cohesively. Monolithic beams, representing the strength of the original unrepaired composite, had the highest failure strength values of 122 ± 23 MPa (mean ± standard deviation). When new composite was added to unground freshly cured composite, the failure strength (111±25 MPa) was not significantly different from the values found for the monolithic specimens.

When the freshly cured composite surface had been ground and new composite material was added, the failure strength significantly decreased by about 25%, regardless of whether adhesive was used (86±31 MPa without adhesive; 81±30 MPa with Adper SingleBond Plus).

When new composite was added to aged specimens, failure strength decreased more than 50% when a conventional etch-and-bond technique had been used (51±21 MPa). CoJet sandblasting slightly increased the failure strength (71±29 MPa), but it was still about 35% lower than the original strength, even after application of silane coupling agent (73±35 MPa). Repairs using the universal adhesive, however, recovered about 80% of the original strength, yielding failure strengths that were not significantly different from those of the monolithic specimens regardless of whether CoJet sand-blast treatment was used (98±22 MPa without CoJet sand-blast; 102±22 MPa with CoJet sand-blast).

Table 2: *Sample Size and Failure Strengths (Mean ± Standard Deviation)*[a]

| Group | Sample size | Failure strength (MPa) |
|---|---|---|
| Aged: Grind, Etch/SingleBond Plus | 12 | 51 ± 21 a |
| Aged: Grind, CoJet/SingleBond Plus | 11 | 71 ± 29 a,b |
| Aged: Grind, CoJet/silane/Visiobond | 14 | 73 ± 35 b |
| Fresh: Grind, Etch/SingleBond Plus | 10 | 81 ± 30 b,c |
| Fresh: Grind | 10 | 86 ± 31 b,c |
| Aged: Grind, Etch/Universal | 11 | 98 ± 22 c,d |
| Aged: Grind, CoJet/Universal | 10 | 102 ± 22 c,d |
| Fresh: No grinding | 10 | 111 ± 25 d |
| Monolithic | 6 | 122 ± 23 d |

[a] *Same letters denote values not significantly different (one-way analysis of variance followed by the Fisher protected least significant different test, $\alpha$=0.05).*

## DISCUSSION

This study examined different techniques and adhesive materials for adding or repairing composite restorations. The effectiveness of the addition or repair techniques was evaluated 24 hours after a repair was made by measuring the maximum flexural strength in composite beams fabricated by adding new composite to a cured composite. Flexure was chosen to test the strength of the composite beams because bending involves both tensile and compressive stress conditions and thus can be argued to be more inclusive than a uniaxial tensile test.[12] Shear tests have also been used to evaluate repair strength,[13] but stress conditions in shear tests are not well defined.[17] Furthermore, the choice of a four-point instead of a three-point loading condition provided a wider failure area with the same stress conditions (because the longitudinal stress is constant between the two upper supports) and thus accommodated both cohesive and interfacial failures. The significance of this choice was evident during the testing, where specimens that failed at lower load values were more likely to fail along the interface, while specimens with relatively high failure loads tended to fail cohesively (ie, away from the repair interface).

The sample sizes among the groups varied between 6 and 14. The International Standard ISO 4049 for dental resin-based filling materials specifies at least five specimens for the flexural strength test.[18] The monolithic composite group had a sample size of six. Sample-size number was increased for specimens in groups with added or repaired composite because they had higher variation in failure strengths than the monolithic beams. Because a sample size of 9 has 95% confidence to detect a mean difference of 2/3 of the standard deviation between groups, sample size was increased to 10.[19] Some specimens in the aged composite groups had failure loads substantially lower than the group means. As these low values may represent actual repair complications, extra samples were added for each substantially lower value instead of excluding those samples. The final sample sizes are shown in Table 2.

Two clinical conditions were simulated in this *in vitro* study: (1) adding composite to a freshly cured composite to represent adding composite to a restoration within the same visit, and (2) adding composite to an aged composite to represent adding composite in a subsequent visit after the composite restoration reached its maximum possible conversion.

Freshly cured composite can be expected to have the highest number of unreacted double bonds for chemical adhesion of added composite. Failure strength did not decrease significantly compared with the monolithic specimens when composite was added directly to freshly cured composite. When the attachment surface was ground, which simulates finishing of a restoration within the same visit, the failure strength reduced significantly even when the surface was re-etched and a conventional bonding agent was applied. Other *in vitro* studies reported mixed results for bonding agent application on repair strength.[4,11,13] Under clinical conditions, re-etching and application of a bonding agent cleans the surface of contamination and provides better adaptation of the added composite. Nevertheless, clinicians should be aware that adding a new layer of composite within the same visit to correct inadequate contact, contour, surface voids, or shade mismatch may reduce the strength of a restoration.

When composite restorations chip, wear down, develop defective margins or have confined areas of recurrent decay, while large portions of the restorations remain intact and radiographically sound, adding new composite to the old (aged) restorations is highly desirable within the concepts of minimal intervention and preservation of tooth structure. Although partial removal of composite restoration is conservative and avoids potential pulp injuries, the bonding to tooth structure when the whole restoration is removed can be better ensured than bonding to old composite. Therefore, composite repair techniques are sometimes viewed as unreliable and potentially increasing clinical risks.[2] Indeed, the current study found that adding new composite to aged composite could result in a substantial (37% to 54%) reduction in failure strength compared with repair of fresh composite. This strength reduction may be attributed to the more complete polymerization of aged composites, which should have fewer remaining unreacted double bonds for chemical adhesion of the new layer.[4,8]

To improve bond strength of repairs made to aged composites, mechanical and/or chemical surface treatments are often recommended.[10-14] It has been shown that surface roughening by aluminum oxide sandblasting increased composite repair strength more than roughening with a diamond bur.[14] A tribochemical system, like the CoJet Sand Blast, is a step further than just sandblasting. The CoJet system blasts proprietary silica-coated sand with high energy to leave a ceramic coating (silicatized) on the surface to enhance chemical bonding by subsequent silanization.[20] Previous studies achieved good repair strengths with this tribochemical system.[12,13] The same tribochemical system was used in the present study and significantly increased the failure strengths of the repairs to aged composite by 40% compared with surface roughening with silicon carbide paper. Interestingly, no additional improvement in failure strength was found when a silane coupling agent was subsequently used to silanize the interface after Cojet Sand Blast.

Besides the conventional bonding agents, a new generation of multimode adhesive was tested for repairing aged composites, which combines methacryloxydecyl phosphate monomers for adhesion to nonglass ceramic substrates and silane for adhesion to glass-ceramic surfaces.[15] Surfaces that are ground in preparation of composite repair are likely to have a high fraction of exposed ceramic fillers. This may explain why the new multimode adhesive yielded the highest failure strengths for repair of the aged composites, regardless of tribochemical treatment. The failure strength values that were found with this new generation of adhesive were not significantly lower than the monolithic strength. This

confirmed the hypothesis that it is possible to repair composite without a significant reduction in failure strength, depending on the treatment of the attachment surface, in this case treatment with a multimode adhesive.

Ultimately, the durability of repaired composite restorations must be proven under clinical conditions. However, clinical studies cannot quantify the strength of repairs, which requires *in vitro* studies. Despite its limitations, an *in vitro* study can thus provide important insight about repair procedures and indicate the most promising techniques. The results of the current study indicate promising strength values with a new multimode adhesive. The multimode adhesive, which is already part of the enamel/dentin bonding procedure, is simple to use and does not require extra armamentarium, such as a tribochemical system. The ability to make additions or repairs to composite restorations without lowering the failure strength will contribute to the longevity of the dentition and thus oral health.

## CONCLUSION

- Adding new composite to aged or ground freshly cured composite significantly reduced composite failure strength when using a conventional bonding agent, regardless of surface treatment.
- Repair of aged composite using a new multimode adhesive, with or without tribochemical treatment, achieved failure strengths that were not significantly lower than those of additions to freshly cured unground composite or monolithic unrepaired composite.
- Tribochemical treatment alone increased repair strength but was not as effective as the multimode adhesive.

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### Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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## REFERENCES

1. Tyas MJ, Anusavice KJ, Frencken JE, & Mount GJ (2000) Minimal intervention dentistry—A review. FDI Commission Project 1-97 *International Dental Journal* **50(1)** 1-12.
2. Lynch CD, Blum IR, Frazier KB, Haisch LD, & Wilson NH (2012) Repair or replacement of defective direct resin-based composite restorations: Contemporary teaching in U.S. and Canadian dental schools *Journal of the American Dental Association* **143(2)** 157-163.
3. Lynch CD, Hayashi M, Seow LL, Blum IR, & Wilson NH (2013) The management of defective resin composite restorations: Current trends in dental school teaching in Japan. *Operative Dentistry* **38(5)** 497-504.
4. Boyer DB, Chan KC, & Reinhardt JW (1984) Build-up and repair of light-cured composites: Bond strength *Journal of Dental Research* **63(10)** 1241-1244.
5. Eliades GC, & Caputo AA (1989) The strength of layering technique in visible light-cured composites *Journal of Prosthetic Dentistry* **61(1)** 31-38.
6. Truffier-Boutry D, Place E, Devaux J, & Leloup G (2003) Interfacial layer characterization in dental composite *Journal of Oral Rehabilitation* **30(1)** 74-77.
7. Shawkat ES, Shortall AC, Addison O, & Palin WM (2009) Oxygen inhibition and incremental layer bond strengths of resin composites *Dental Materials* **25(11)** 1338-1346.
8. Vankerckhoven H, Lambrechts P, van Beylen M, Davidson CL, & Vanherle G (1982) Unreacted methacrylate groups on the surfaces of composite resins *Journal of Dental Research* **61(6)** 791-795.
9. Ferracane JL (1995) Current trends in dental composites *Critical Reviews in Oral Biology and Medicine* **6(4)** 302-318.
10. Puckett AD, Holder R, & O'Hara JW (1991) Strength of posterior composite repairs using different composite/bonding agent combinations *Operative Dentistry* **16(4)** 136-140.
11. Shahdad SA, & Kennedy JG (1998) Bond strength of repaired anterior composite resins: An in vitro study. *Journal of Dentistry* **26(8)** 685-694.
12. Özcan M, Barbosa SH, Melo RM, Galhano GAP, & Bottino MA (2007) Effect of surface conditioning methods on the microtensile bond strength of resin composite to composite after aging conditions *Dental Materials* **23(10)** 1276-1282.
13. Rinastiti M, Özcan M, Siswomihardjo W, & Busscher HJ (2010) Immediate repair bond strengths of microhybrid, nanohybrid and nanofilled composites after different surface treatments *Journal of Dentistry* **38(1)** 29-38.
14. Costa TRF, Ferreira SQ, Klein-Júnior CA, Loguercio AD, & Reis A (2010) Durability of surface treatments and intermediate agents used for repair of a polished composite *Operative Dentistry* **35(2)** 231-237.
15. 3M (2011) Scotchbond Universal Adhesive Technical Product Profile. Retrieved online July 15, 2014 from: http://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSuH8gc7nZxtUo8_Zo8_UevUqe17zHvTSevTSeSSSSSS--

16. Gere JM, & Timoshenko SP (1990) *Mechanics of Materials* PWS Publishing Company, Boston, MA.
17. Versluis A, Tantbirojn D, & Douglas WH (1997) Why do shear bond tests pull out dentin? *Journal of Dental Research* **76(6)** 1298-1307.
18. ISO-Standards (1992) *ISO 4049 Dentistry— Resin-based filling materials* International Organization for Standardization, Geneva, Switzerland.
19. Devore J, & Peck R (1993) *Statistics: The Exploration and Analysis of Data* 2nd ed Wadsworth, Belmont, CA.
20. 3M ESPE (2000) CoJet System Technical Product Profile. Retrieved online July 15, 2014 from: http://multimedia.3m.com/mws/mediawebserver?mwsId=66666UF6EVsSyXTtM8TalxftEVtQEVs6EVs6EVs6E666666--&fn=cojet_tp.pdf