Shear bond strength of different dentin substitute restorative materials to dentin of primary teeth

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This in vitro investigation compared the shear bond strength (SBS) of four dentin substitute/replacement materials to caries-affected dentin of primary teeth. Dentin surfaces were randomly divided into four groups of 12 each according to the material used as follows: SDR/Smart Dentin Replacement, Biodentine, MultiCore Flow, and Fuji II LC. The SBS was measured and failure modes were determined. There was a statistically significant difference in the mean values of SBS among the four materials (F=741.523, p<0.0001). The mean values of SBS of SDR were statistically significantly higher followed by MultiCore Flow compared to the other groups. The mean values of the four materials were significantly different from each other in all combinations of pairs of four materials. The SBS between the four dentin substitute/replacement materials to dentin of primary teeth was significantly different. The highest SBS was for SDR followed by MultiCore Flow then Fuji II LC and the lowest was for Biodentine.

Keywords: Bonding, Primary tooth dentin, Caries-affected dentin, Bulk-fill resin composite

INTRODUCTION

One of the major challenges in dentistry has been to find an ideal restorative material that has physical properties similar to those of tooth structure, maintain adhesion to dentin and enamel and resist degradation in the oral cavity1. In attempt to reach these characteristics and with the increase in the demands made by patients for esthetic restorations, improvements in technology have led to the current development of resin-modified glass ionomer cement (RMGIC) and resin-based composite resins (RBC)2. A bulk-fill resin-based composites were introduced to reduce the time for placement of the restoration by allowing up to 4 mm thick increments to be cured in a single phase, thus allow timesaving of the layering process3. Flowable bulk-fill resin-based composites have easy-handling properties, low-viscosity, the capability to yield layers with reduced air trap and the excessive flexibility to be used as cavity liners3-4. Tricalcium silicate based restorative materials such as Biodentine™ (Septodont) was developed as dentin replacement material5-6. Biodentine has been shown to be biocompatible7. RMGIC have improved handling characteristics of conventional glass ionomer and enhanced physical properties of GIC and the photopolymerizable resin component which diminishes initial hardening time considerably2. The use of cavity liners before restoring deep carious lesions has been widely practiced over many years8. Cavity liners have been described as materials that are used as a layer to seal the dentin floor from the invasion of bacteria and irritants as well as for thermal insulation9-11. These materials aim to encourage the formation of tertiary dentin and remineralization as well as improve the marginal integrity of composite restorations8,12. Glass-ionomer cements (GICs), RMGICs, flowable resin composite, calcium hydroxide (Ca(OH)2), adhesive systems and bioactive Biodentine have been utilized as cavity liners13-15 to provide the stress buffering capacity for reducing the contraction stress and gap formation at the dentin/resin adhesive interface16. Dentin substitute/replacement materials included in this study are: SDR which is intended to be used as a liner under direct class I and II restorations and class II box, Biodentine which is indicated in deep or large carious lesions, deep cervical lesions and pulp capping, MultiCore which is indicated for core build-up of vital and non-vital teeth and Fuji II LC which is indicated as a liner and restoration of class III, V and limited class I cavities and primary teeth.

During the restoration of carious teeth, clinicians usually deal with sclerotic, caries-infected dentin or/and caries-affected dentin (CAD)16. However, CAD is commonly seen after excavation of caries where the restorative material is bonded17. The bond between adhesive material and sound dentin is stronger than with CAD17. CAD is more porous and softer than sound dentin due to partial demineralization, with narrow and obliterated dentinal tubules due to deposition of intratubular dentin and with a hybrid layer thinner than that of sound dentin18. The interfaces of bonded CAD are more vulnerable to hydrolytic degradation than sound dentin bonds CAD17. Furthermore, there are significant dissimilarities in the bond interface, adhesive infiltration and depth of demineralization of CAD as compared to sound dentin CAD17. Longevity of a restoration is predicted to some extent by its adhesive ability, and this in turn can be measured by bond strength testing19. Bond strength can predict the longevity of a restoration.
to some extent. Although the correlation of bond strength assessments to foresee clinical performance of different restorations is questionable, existing evidence indicate that clinical performance can be predicted by appropriate types of laboratory studies.

Clinical practice of dentistry is being challenged to find a better replacement of lost dentin during cavity preparation so numerous materials have been introduced to find an answer to this critical issue. Currently, there is limited research on the SBS of dentin substitute/replacement materials to dentin of primary teeth and in addition, information is inadequate on the properties and structure of the interface between dentin replacement materials and dentin of primary teeth. Therefore, the purpose of this in vitro study was to assess and compare the SBS of four dentin substitute/replacement materials (Multicore Flow, Fuji II LC, Biodentine and SDR, Smart Dentin Replacement) to CAD of primary teeth. The null hypothesis was there is no difference in SBS of different dentin replacement materials and dentin of primary teeth.

MATERIALS AND METHODS

Specimen preparation
This investigation protocol was approved by the Research and Ethical Committee of Human Studies at King Saud University, College of Dentistry Research Center. Forty-eight recently extracted human carious primary molars were collected and stored in 0.1% thymol solution for no longer than 2 weeks after extraction and used in this study. Teeth included having caries extending into the middle one-third of the dentin thickness but not into the deep dentin, as verified and assessed during caries removal. Roots were removed using low-speed carborundum discs (3M ESPE Dental Products, St. Paul, MN, USA) under water spray. Specimens were mounted inside a cylindrical-shaped Teflon mold, 2.5 cm in diameter and with a height of 2.5 cm using autopolymerizing acrylic resin (Ortho-Jet, Lang Dental MFG, IL, USA).

After caries was removed with round carbide burs (sizes 3 and 5) in a slow-speed handpiece, the occlusal surfaces were slightly polished with 320- and 600-grit silicon carbide abrasive papers (Buehler, Lake Bluff, IL, USA) under water lubrication to create a flat surface and a standard smear layer. Carious dentin was evaluated by means of the combined criteria of visual examination and degree of hardness to a sharp explorer without pressure by two investigators to verify that only affected dentin is present.

Specimens were then randomly allocated into 4 groups of 12 each according to the material used as follows: SDR/Smart Dentin Replacement (Dentsply Caulk, Milford, DE, USA), Biodentine (Septodont, Lancaster, PA, USA), Multicore Flow (Ivoclar Vivadent, Schaan, Liechtenstein) and Fuji II LC (GC, Tokyo, Japan).

All specimens were stored in distilled water at room temperature (25°C) for 72 h before bonding procedures. The dentin surface was bonded to assigned material according to the instructions of the manufacturers using a standard PVC tube with internal diameter of 2 mm and a height of 2 mm which was placed perpendicularly on the dentin surface. For SDR, dentin surface was washed thoroughly with water spray and lightly air-dried (not desiccated), 34% phosphoric acid gel was applied for 15 s and rinsed for 15 s and then dried with an air syringe. Then Prime & Bond Eject universal dental adhesive was applied and agitated for 20 s, gently dried with clean air for at least 5 s and then light-cured for 20 s. SDR was dispensed into the PVC tube and then light-cured for 20 s. For Biodentine, dentin surface was washed thoroughly with water spray and air dried before Biodentine was inserted into the PVC tube followed by a 15-min wait. For MultiCore, 37% phosphoric acid gel was applied to clean dentin surface for 10 s and rinsed for 10 s and dried with an air syringe. AdheSE Primer was applied to dentin and agitated for 30 s and then dispersed into a thin layer with a stream of air and AdheSE Bond was then applied and light-cured for 10 s. MultiCore was applied into the PVC tube and then light-cured for 20 s. For Fuji II LC, GC cavity conditioner was applied to clean dentin surface for 10 s and rinsed thoroughly with water and dried (not desiccated). GC Fuji II LC was applied to the PVC tube and light-cured for 20 s. Where applicable, all specimens were polymerized using a curing light (Bluephase, Ivoclar Vivadent) with a light intensity of 1,200 mW/cm² placed as closely as possible to the surface of each material.

Surface was washed thoroughly with water spray and air dried before Biodentine was inserted into the PVC tube followed by a 15-min wait. For MultiCore, 37% phosphoric acid gel was applied to the surface of each material. All specimens were then stored in distilled water at 25°C for 24 h after which they were thermocycled for 1,000 cycles between 5 and 55°C with a swelling time of 20 s and transferring time of 10 s based on the standards of the International Organization for Standardization.

Bond strength testing
The SBS was measured for each specimen in a universal testing machine (model no. 8500, Instron, Canton, MA, USA) at 0.5 mm/min crosshead speed. Bond strength was expressed in MPa.

Failure mode evaluation
Failure mode evaluation and fractured surfaces were examined by two investigators using a stereomicroscope at ×25 magnification and representative digital images were obtained. Failures were classified as: adhesive interface failure (100% of the bonded interface failed between dentin and bonding resin); cohesive failure (100% of failure in resin composite and/or dentin); or mixed failure (partial cohesive failure and partial adhesive failure).

Statistical analysis
Data were analyzed using SPSS statistical software version 21. Descriptive statistics (Mean, standard deviation, minimum and maximum) were used to describe the quantitative outcome variable (SBS). A one-way analysis of variance (ANOVA) was used to compare the mean values of these outcome variables,
followed by Tukey’s test post hoc for multiple comparisons of mean values. A p-value of <0.05 was considered as statistically significant. Kappa statistics was calculated to quantify an agreement between the two examiners in assessing the type of dentin as well as the three types of failures (adhesive, cohesive and mixed) in each of the treatment groups.

RESULTS

When all 48 samples of the 4 materials were assessed together for inter-examiner agreement between the two examiners in assessing the affected dentin, the data shows highly statistical significant agreement between the two examiners (p<0.0001). There was a moderate statistical significant agreement between the two examiners in assessing the failure modes (kappa=0.553; p<0.0001). Descriptive statistics of SBS of the four materials is presented in Table 1. There was highly statistically significant difference in the mean values of SBS among the four materials (F=741.523, p<0.0001). The post hoc test for multiple comparisons of mean values indicated that the mean values of SBS of SDR were statistically significantly higher (p<0.0001) than other groups followed by Multicore Flow (p<0.0001). Whereas the mean values of SBS of Biodentine was statistically significantly lower (p<0.0001) than other groups followed by Fuji II LC (p<0.0001). Furthermore the mean values of the four materials were significantly different from each other in all combinations of pairs of the four materials (p<0.0001).

Comparison of categories of failure mode among the four study groups showed a statistically significant difference in the distribution of failure mode among the four materials. A higher proportion (58.3 and 75%) of the adhesive failures was occurred in the SDR and Multicore Flow groups when compared with Fuji II LC and Biodentine groups (33.3 and 8.3%). Higher proportion of mixed failures (41.7, 58.3, and 58.3%) occurred in the SDR, Fuji II LC and Biodentine groups when compared with the occurrence in Multicore Flow group (16.7%). Table 2 shows a comparison of categories of failure mode among the four study groups.

Table 1 Descriptive statistics of the SBS in MPa for the four materials

| Material         | Mean (SD)   | Minimum | Maximum | p**  |
|------------------|-------------|---------|---------|------|
| Multicore Flow   | 10.733 (1.050) | 7.859  | 11.643  | 0.0001 a |
| Fuji LC          | 4.391 (0.550)  | 3.576  | 5.450   | 0.0001 b |
| Biodentine       | 1.861 (0.421)  | 1.299  | 2.720   | 0.0001 c |
| SDR              | 14.044 (0.676) | 12.873 | 14.850  | 0.0001 d |

* n=12
** Materials with different letters are statistically significant at the 0.05 level

Table 2 Comparison of categories of failure modes among the four study groups

| Materials  | Adhesive | Cohesive | Mixed | Total |
|------------|----------|----------|-------|-------|
| Multicore Flow | 9    | 1 | 2 | 12 |
| Fuji LC    | 4 | 1 | 7 | 12 |
| Biodentine | 1 | 4 | 7 | 12 |
| SDR        | 7 | 0 | 5 | 12 |

*χ²=16.19; p=0.013
DISCUSSION

The remarkable improvement in dentin substitute/replacement materials and the abundance of varieties makes it difficult to choose which material is the best. The null hypothesis of this investigation was rejected as there was difference in SBS of dentin replacement materials to dentin of primary teeth. It should be noted that each one of the tested materials has a different method of bonding to the dentin surface as their composition is unlike from each other.

Caries dentin is comprised of two layers, the affected dentin which constitutes the inner less infected, demineralized, with apatite crystals bound to sound collagen fibers with the potential of repairing layer and the infected dentin which constitutes the external highly infected, necrotic layer and containing degenerated collagen fibers which cannot be calcified. In the present study tested materials were bonded to CAD. There are differences in modulus of elasticity and hardness between bonded CAD and bonded sound dentin in primary teeth. The physical and chemical properties of sound dentin are unlike from those of CAD. The latter is more porous and softer than sound dentin due to partial demineralization, with narrow and obliterated dentinal tubules due to deposition of intratubular dentin and with a hybrid layer thicker than that of sound dentin. Numerous studies have shown that bond strengths of resin to CAD and sound dentin rely on the type of dentin and the adhesive systems used. Bonding to sound dentin with different adhesive systems showed significantly higher bond strengths than to CAD. In an attempt to improve bond strength to CAD, a study assessed the influence of the bond strength of extended and additional etching time to CAD and reported improvement of bond strength to CAD but bond strength was significantly lower to CAD than to sound dentin. On the other hand, a study reported that bond strength was significantly higher to CAD than to sound dentin of primary teeth when the conventional adhesive was used, but with the self-etch adhesive, no significant difference in bond strength was reported.

Macro and micro bond strength methods that depend on the size of the bonded area have been used to quantify adhesive performance to enamel and dentin. A finite element stress analysis evaluated shear versus micro-shear bond strength test reported a pronounced stress concentration at the interfacial edges due to the geometric change and for the micro-shear test, the relatively thicker adhesive layer and use of low modulus composites may lead to relevant stress intensification. Nevertheless, micro-shear tests remain an extremely useful test for those substrates with properties such as glass ionomers or enamel that make them particularly susceptible to the specimen preparation effects and testing conditions of micro-shear bond testing. So, micro-bond tests are more reliable than macro-bond tests but no standard format exists for reporting the bond strength tests which could lead to misinterpretation of the data and bonding abilities of adhesives. In the present study, macro-shear bond was used as some tools and facilities were not available in our laboratory.

In the present study, there was highly a statistically significant difference in the mean values of SBS among the four materials and the mean values of SBS of SDR were statistically significantly higher followed by Multicore Flow. The high SBS may be due to compositions of each material. SDR had been developed specially for dentin replacement and cured increments up to 4 mm depth. The polymerization stress had been reduced by 50% or more compared to conventional resin composites. It was based on the chemistry of universal composite with the main difference in the monomer that incorporated in the Urethane-based dimethacrylates. In this study, the SDR exhibited the highest mean SBS (14.044 MPa). Another study reported SBS of 18.56 MPa. The manufacturer explained that SDR has a constituent called as a “polymerization modulator” which is included chemically in the polymerizable resin. The “polymerization modulator” synergistically interacts with the camphorquinone photoinitiator. Multicore Flow is resin-based composite which is dual-curing, radiopaque, containing fluoride fillers. Multicore Flow demonstrates exceptional mechanical properties for core build-ups and it cures chemically without the use of light which is optional. In the present study, the mean values of SBS of Biocement were statistically significant followed by Fuji II LC. Biocement powder is composed of tricalcium silicate, zirconium oxide, and calcium carbonate and the liquid is mostly composed of water with the addition of calcium chloride. The benefits of using calcium silicate-based-a hydrophilic polymer materials as a dentin replacement is the leaching of calcium hydroxide from the set material. In the present study, Biocement showed the lowest SBS out of the four materials which was 1.861 MPa. A similar result (2.485 MPa) was reported by another study. In the present study, the mean SBS of Fuji LC was 4.391 MPa which is less than another study which reported the mean SBS of 16.75 MPa.

Bond strength was tested in the present study, and the highest SBS was for SDR followed by MultiCore Flow. The higher bond strength of SDR and MultiCore Flow is more likely dependent on the adhesive system. For SDR, the phosphoric acid gel and Prime & Bond Elect universal dental adhesive were applied before placement of SDR. Similarly, for MultiCore, the phosphoric acid gel, primer and bonding agent were applied before placement of MultiCore. The application procedures and the high bond strength of SDR and MultiCore Flow are reflected on the high adhesive failure modes of SDR (40%) and MultiCore Flow (75%). In contrast, Fuji II LC and Biocement showed lower bond strength which may be due to the different physical and mechanical properties of resin composites (SDR and MultiCore Flow). For Fuji II LC, GC cavity conditioner was applied before placement of Fuji II LC. While for Biocement, dentin surface was washed
thoroughly with water spray and air dried before application of Biodentine. The application procedures and the lower bond strength of Fuji II LC and Biodentine are reflected on the low adhesive failure modes of Fuji LC (33.3%) and Biodentine (8.3%). It is important that practitioners be familiar with the physical and mechanical properties of the cavity liners and decide which material to use depending on cavity preparation/size and the need of cariostatic properties as well as all their advantages and disadvantages.8,10,12,44

After tooth preparation, most dentin surfaces show a smear layer 3- to 10-μm thick —an amorphous layer of inorganic and organic debris that firmly adheres to the surface and prevents resin adhesion to dentin18. In the present study, the occlusal surfaces of carious teeth were slightly polished with 320- and 600-grit silicon carbide abrasive papers with water lubrication to create a flat surface and a standard smear layer. To obtain adequate bonding, the smear layer must be treated or removed prior to resin placement by brief etching of the dentin surface21. In the present study, the manufacturer’s instructions were followed for placement of each material.

One of the limitations of this study was the use of only four dentin substitute/replacement materials to bond to CAD of primary teeth and 12 specimens each. It would be beneficial if more specimens and dentin substitute/replacement are tested. In addition, the evaluation of the aged bond strengths in primary teeth was not tested in this study. Furthermore, comparison of SBS of CAD and sound dentin was not performed.

CONCLUSIONS

Under the experimental conditions and within the limitations of this in vitro study, the following conclusions can be drawn:

1. The bond strength values of the four dentin substitute/replacement materials to caries-affected dentin of primary teeth after thermocycling was significantly different.
2. SDR shows the highest bond strength while Biodentine shows the lowest one.
3. The failure mode among the four tested materials showed a statistically significant difference with a higher proportion of the adhesive failures in the SDR and Multicore Flow compared with Fuji II LC and Biodentine.

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REFERENCES

1) Van Meerbeek B, Peumans M, Poitevin A, Mine A, Van Ende A, Neves A, De Munck J. Relationship between bond-strength tests and clinical outcomes. Dent Mater 2010; 26: e100-121.
2) Tyas MJ, Burrow MF. Adhesive restorative materials: a review. Aust Dent J 2004; 49: 112-121.
3) Kim EH, Jung KH, Son SA, Hur B, Park JK. Effect of resin thickness on the microhardness and optical properties of bulk-fill resin composites. Restor Dent Endod 2015; 40: 128-135.
4) Lassila LV, Nagas E, Vallittu PK, Garoushi S. Translucency of flowable bulk-filling composites of various thickness. Chin J Dent Res 2012; 15: 31-35.
5) Biodentine™ Scientific file. Active Biosilicate Technology™, Septodont, Saint-Maur-des-Fosses Cedex, France, R & D Department; 2010.
6) Camilleri J, Sorrentino F, Damidot D. Investigation of the hydration and bioactivity of radiopacified tricalcium silicate cement, Biodentine and MTA Angelus. Dent Mater 2013; 29: 580-593.
7) Laurent P, Camps J, De Meo M, Dejou J, About I. Induction of specific cell responses to a Ca(O3SiO)6-based posterior restorative material. Dent Mater 2008; 24: 1486-1494.
8) Weiner R. Liners and bases in general dentistry. Aust Dent J 2011; 56: 11-22.
9) Gopikrishna V, Ashok P, Kumar AP, Narayanan LL. Influence of temperature and concentration on the dynamic viscosity of sodium hypochlorite in comparison with 17% EDTA and 2% chlorhexidine gluconate: An in vitro study. J Conserv Dent 2014; 17: 57-60.
10) Karatas O, Turel V, Bayindir YZ. Temperature rise during polymerization of different cavity liners and composite resins. J Conserv Dent 2015; 18: 431-435.
11) Schwendicke F, Tu YK, Hsu LY, Gösthemeyer G. Antibacterial effects of cavity lining: a systematic review and network meta-analysis. J Dent 2015; 43: 1298-1307.
12) Aggarwal V, Singla M, Yadav S, Yadav H. Effect of flowable composite liner and glass ionomer liner on class II gingival marginal adaptation of direct composite restorations with different bonding strategies. J Dent 2014; 42: 619-625.
13) Costa CA, Ribeiro AP, Giro EM, Randall RC, Hebling J. Pulp response after application of two resin modified glass ionomer cements (RMGIcs) in deep cavities of prepared human teeth. Dent Mater 2011; 27: e158-170.
14) Cannon M, Gerodias N, Viera A, Percinoto C, Jurado R. Primate pulpal healing after exposure and TheraCal application. J Clin Pediatr Dent 2014; 38: 333-337.
15) Sampaio PC, Almeida Junior AA, Francisconi LF, Casas-Apayco LC, Pereira JC, Wang L, Atta MT. Effect of conventional and resin modified glass-ionomer liner on dentin adhesive interface of Class I cavity walls after thermocycling. Oper Dent 2011; 36: 403-413.
16) Harnriatissai C, Inokoshi S, Shimada Y, Hosoda H. Interfacial morphology of an adhesive composite resin and etched caries-affected dentin. Oper Dent 1992; 17: 222-228.
17) Erhardt MC, Tolefano M, Osorio R, Pimenta LA. Histomorphologic characterization and bond strength evaluation of caries-affected dentin/resin interfaces: effects of long-term water exposure. Dent Mater 2008; 24: 786-798.
18) Pashley DH, Carvalho RM. Dentine permeability and dentine adhesion. J Dent 1997; 25: 355-372.
19) Sirisha K, Rambabu T, Shankar YR, Ravikumar P. Validity of bond strength tests: A critical review: Part I. J Conserv Dent 2014; 17: 305-311.
20) Suddsangiam S, van Noort R. Do dentin bond strength tests serve a useful purpose? J Adhes Dent 1999; 1: 57-67.
21) Peumans M, Kanumilli P, De Munck J, Van Landuyt K, Lambrechts P, Van Meerbeek B. Clinical effectiveness of contemporary adhesives: A systematic review of current clinical trials. Dent Mater 2005; 21: 864-881.
22) Ricci HA, Scheffel DL, de Souza Costa CA, dos Santos FJ, Jafelicci M Jr, Hebling J. Wettability of chlorhexidine treated
non-carious and caries-affected dentine. Aust Dent J 2014; 59: 37-42.

23) Ricci HA, Scheffel DL, Mariusso MR, Spolidorio DM, de Souza Costa CA, Hebling J. Exposed collagen in resin bonds to caries-affected dentin after dentin treatment with aqueous and alcoholic chlorhexidine solutions. J Adhes Dent 2014; 16: 21-28.

24) International Organization for Standardization. ISO TR 11405. Dental material guidance on testing of adhesion to tooth structure. 1994.

25) Nikaido T, Kunzelmann KH, Chen H, Ogata M, Harada N, Yamaguchi S, Cox CF, Hickel R, Tagami J. Evaluation of thermal cycling and mechanical loading on bond strength of a self-etching primer system to dentin. Dent Mater 2002; 18: 269-275.

26) Fusayama T. Two layers of carious dentin: diagnosis and treatment. Oper Dent 1979; 4: 63-70.

27) Hosoya Y, Tay FR, Miyakoshi S, Pashley DH. Hardness and elasticity of caries-affected and sound primary tooth dentin bonded with 4-META one-step self-etch adhesives. Am J Dent 2008; 21: 223-228.

28) Nakajima M, Kitasako Y, Okuda M, Foxton RM, Tagami J. Elemental distributions and microtensile bond strength of the adhesive interface to normal and caries affected dentin. J Biomed Mater Res 2005; 72: 268-275.

29) Yoshiyama M, Tay FR, Doi J, Nishitani Y, Yamada T, Ito K, Carvalho RM, Nakajima M, Pashley DH. Bonding of self-etch and total-etch adhesives to carious dentin. J Biomed Mater Res 2002; 81: 556-560.

30) Arrais CA, Giannini M, Nakajima M, Tagami J. Effects of additional and extended acid etching on bonding to caries-affected dentine. Eur J Oral Sci 2004; 112: 458-464.

31) Nakornchai S, Harnirattisai C, Surarit R, Thiradilok S. Microtensile bond strength of a total-etching versus self-etching adhesive to caries-affected and intact dentin in primary teeth. J Am Dent Assoc 2005; 136: 477-483.

32) Burke FJT, Hussain A, Nolan L, Fleming GJP. Methods used in dentine bonding tests: An analysis of 102 investigations on bond strength. Eur J Prosthodont Rest Dent 2008; 16: 158-165.

33) Placido E, Meira JB, Lima RG, Muench A, de Souza RM, Ballester RY. Shear versus micro-shear bond strength test: A finite element stress analysis. Dent Mater 2007; 23: 1086-1092.

34) Armstrong S, Geraldeli S, Maia R, Raposo LH, Soares CJ, Yamagawa J. Adhesion to tooth structure: A critical review of “micro” bond strength test methods. Dent Mater 2010; 26: e50-62.

35) Sirisha K, Rambabu T, Ravishankar Y, Ravikumar P. Validity of bond strength tests: A critical review-Part II. J Conserv Dent 2014; 17: 420-426.

36) Rullmann I, Schattenberg A, Marx M, Willershausen B, Ernst CP. Photoelastic determination of polymerisation shrinkage stress in low-shrinkage resin composites. Schweiz Monatsschr Zahnmed 2012; 122: 294-299.

37) Duarte SJR, Botta AC, Park JH, Sadan A. A selected mechanical and physical properties and clinical application of a new low-shrinkage composite restoration. Quintessence Int 2009; 40: 631-638.

38) Nicoleta I, Christian S, kathrina B, Renhard H. Assessment of the shear bond strength of bulk-fill resin composites to permanent and deciduous teeth. J Dent 2014; 7: 850-855.

39) Ilie N, Hickel R. Investigations on a methacrylate-based flowable composite based on the SDRTM technology. Dent Mater 2011; 27: 348-355.

40) Multicore Flow—Instructions for Use. Accessed on December 20, 2015 at http://www.ivoclarvivadent.us/en-us/products/core-build-up-endodontics/core-build-up-composites/multicore.

41) Camilleri J. Characterization and hydration kinetics of tricalcium silicate cement for use as a dental biomaterial. Dent Mater 2011; 27: 836-844.

42) Vignesh R, Venumbaka NR, Mungara J, Vijayakumar P, Rajendran S, Elangovan A. Comparative evaluation of shear bond strength and microleakage of tricalcium silicate-based restorative material and radiopaque posterior glass ionomer restorative cement in primary and permanent teeth. J Indian Soc Pedod Prev Dent 2014; 32: 304-310.

43) Prabhakar AR, Raj Sb, Raju OS. Comparison of shear bond strength of composite, compomer and resin modified glass ionomer in primary and permanent teeth. J Indian Soc Pedod Prev Dent 2003; 21: 86-94.

44) Jain P, Raj J. Dentin substitutes: A review. Int J Pharm Bio Sci 2015; 6: 383-391.