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EFFECT OF THERMAL CYCLING ON MARGINAL SEAL OF DIFFERENT DENTIN SUBSTITUTES

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ABSTRACT

Objectives: To investigate the marginal seal of new dentin substitutes using environmental SEM and evaluate the longevity of the seal after being subjected to thermal stresses.

Methods: Four different dentin substitute materials (SDR, DENTSPLY; Sonic Fill, Kerr; Filtek Bulk Fill, 3M ESPE; and Fuji II LC, GC Corporation) were tested in this study. MOD cavities (4mm depth and half of the intercuspal distance width) were prepared on eighty human sound extracted premolars. Teeth were divided randomly into four groups according to the tested material. Each group was further divided into two subgroups (n=10): subgroup A; No thermal cycling was applied, and subgroup B; was subjected to thermal cycling (5±2 ºC - 55±2 ºC for 1000 cycles). The teeth were sectioned vertically through the resin composite parallel to their long axis in mesiodistal direction. Specimens were then tested for gap formations along pulpal dentin interface using Environmental SEM. Data were tabulated and statistically analyzed.

Results: Regardless of thermal cycling; Fuji II showed the statistically significantly highest mean gap distance (26.6 ± 12.6). Sonic Fill showed statistically significantly lower mean value (23.4 ± 4.3). There was no statistically significant difference between Bulk Fill (17.5 ± 1.7) and SDR (16.3 ± 1.5); both showed the statistically significantly lowest mean gap distance. Without thermal cycling, Sonic Fill showed the statistically significantly highest mean gap distance (19.4 ± 1.2). No statistically significant difference was found between Filtek Bulk Fill (16.1 ± 1.0), SDR (15.3 ± 0.9) and Fuji II (14.6 ± 0.7); all showed the statistically significantly lowest mean gap distances. While with thermal cycling, Fuji II (38.5 ± 0.9) showed the statistically significantly highest mean gap distance. Sonic Fill showed statistically significantly lower mean value (27.3 ± 0.9). There was no statistically significant difference between Filtek Bulk Fill (18.9 ± 0.7) and SDR (17.4 ± 1.2); both showed the statistically significantly lowest mean gap distance.

Conclusions: Under the test conditions, Bulk Fill and SDR provided an adequate marginal seal, regarding gap distance, when compared to Sonic Fill and Fuji II. Meanwhile, thermal cycling significantly increases gap distance in all tested dentin substitutes, thus affecting longevity.

Keywords: Dentin substitutes, gap distance, sealing, thermal cycling, longevity, Bulk Fill.

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INTRODUCTION

The successful compound or complex restoration is dependent not only on the skill with which the clinician executes the procedure but also on the type of dental material used for restoration.[1] Recently, direct resin-based composite (RBC) restoratives have been favored as restorations for considerably large cavities in the posterior area.[2,3] One of the major factors affecting longevity of the restorations intra-orally is the marginal and internal adaptation of the restorative material to cavity margins and internal cavity surfaces, respectively.[4,5]

Also, RBC has only lately been accepted as a good core 'build-up' material, which contributes considerably to the structural durability and retentiveness of the crown preparation, regarding the fact of being as strong as amalgam.[6,7] However microleakage is still a considerable concern in the absence of good bonding and sealing with the underlying tooth tissue.[8,9]

Since the first successful RBC material was introduced, 1963,[10,11] attempts for physical and mechanical properties improvements by the manufacturers have been made.[12,13] Post-gel contraction resulting from the free radical polymerization of methacrylate RBC materials,[14] is responsible for the shrinkage stresses created at the tooth/RBC interface.[15]

For a long time, incremental layering has been considered as a standard technique for composite resin placement in cavities.[16] It consists of placing subsequent 2 mm, or less, increments of composite resin followed by blue light exposure from an occlusal direction until the cavity is filled.[17] Limiting increment thickness to 2 mm or less assures its adequate polymerization, resulting in enhanced physical properties and improved marginal adaptation.[18,19] Another rationale for the use of this technique is decreasing the amount of polymerization shrinkage.[20]

However, the incremental technique has many shortcomings, such as the probability of voids or contamination inclusion between layers, bond failures between subsequent increments, problem in placement in conservative cavities because of limited access, and the extensive chair time consumed for the placement and polymerization of each layer.[21]

Recently, in order to overcome these disadvantages[22] and to further simplify the restorative procedure thus saving valued chair time, flowable "bulk fill" (RBC) restoratives have been developed to be placed in bulk up to 4 mm thickness,[23-26] without adversely affecting the degree of conversion (DC), polymerization shrinkage as well as cavity adaptation.[27] Furthermore, manufacturers claimed that, when compared to contemporary flowable and conventional RBCs, the polymerization shrinkage of those materials is even inferior.[28] Accordingly, drawbacks associated with polymerization shrinkage,[25] like gap formation, causing secondary caries,[14,30] pulp irritation, post-operative sensitivity upon chewing,[31] or cusp deflection with cavities where the "C" factor is high,[32,33] could be decreased.

Among the currently used flowable bulk fill RBCs, the SDR (Smart Dentin Replacement) (Dentsply, Konstanz, Germany) which was introduced to the market claiming that it incorporates a new stress decreasing resin technology.[1] However, it was recommended to cure a conventional posterior composite on top of the 4-mm thick flowable base.[34]

Another novel RBC system is the Sonic Fill System (Kerr/Kavo), in which the bulk placement is facilitated by a particular hand-piece, which transmits sonic energy at different intensities leading to drop of the viscosity (up to 87%) during the composite insertion, by the aid of the incorporated modifier. Upon stoppage of the sonic energy, the composite returns to a more viscous state which is more convenient for shaping.[35]

Filtek™ Bulk Fill Flowable Restorative (3M ESPE) uses the nanofiller technology and comprises two methacrylate-based monomers that, together, act to lower polymerization stress, without wear deterioration. The manufacturer claimed that the intelligent monomer and filler selection resulted in the creation of a restorative with 4 mm cure-depth, decreased shrinkage and little polymerization stress, thus enabling its placement as bulk not only as direct restorations but also as an excellent core build-up material under extra-coronal restorations. Furthermore, it assumed that its flow allows for easy adaptation in deep posterior restorations with little or no instrumentation.[36]

Glass-ionomer restorative materials are well known as adhesive restorations for non-retentive cervical cavities,[37] but because of their inconvenient setting characteristics, they have been poorly accepted initially. This restraint was primarily faced by resin modification of glass-ionomer cement in which curing is accelerated by the existence of light-cured resins.[38] Fuji II LC (GC Corporation) restorative as one of the most commonly used resin-modified glass ionomer, demonstrates the advantages of a conventional glass ionomer, in addition to dual curing, non-delayed finishing, and excellent aesthetics.[39,40]

One of the detrimental effects of polymerization shrinkage stress is interfacial gap formation with subsequent microleakage.[1,41] The resulting marginal discoloration is usually misinterpreted as marginal recurrent caries entailing unnecessary restoration replacement and further tooth tissue loss.[42,43] Furthermore, dental restorations placed intra-orally are constantly subjected to thermal variations during food and fluids intake at various temperatures.[44-46] Therefore, thermal cycling seems to be an important process for testing the sealing ability of any restorative material.[47,48] For this it was found of value to investigate the marginal seal of different dentin substitutes using environmental SEM and evaluate the longevity of the seal after being subjected to thermal stresses.

MATERIALS AND METHODS

I. Preparation of the cavities:

80 sound human upper premolars of almost same size were selected, cleaned of debris with curettes and pumice paste at low speed. MOD cavity was prepared in each tooth. The prepared cavities were 4 mm in depth and half of the intercuspal distance in width. The cavities were cut with a flat fissure plain cut [long head (FG 57L)] at high speed with water coolant. The bur was replaced every five preparations.[49]

II. Grouping of the specimens:

Cavities were randomly divided into four groups (n=20) according to the tested material, **(Table 1)** i.e., SDR (DENTSPLY) (Group I), Sonic Fill (Kerr) (Group II), Filtek Bulk Fill (3M ESPE) (Group III) and Fuji II LC (GC Corporation) (Group IV). Each group was further divided into two subgroups (n=10), Subgroup A; No thermal cycling was applied, and Subgroup B; was subjected to thermal cycling. **(Table 2)** The subgroups that assigned for thermal cycling were thermocycled in water between 5 ± 2 ºC and 55±2 ºC for 1000 cycles (with 60 seconds dwell time).[48,50,51]

All the restorative procedures were made by the same operator to ensure standardization. An individual metallic matrix (Metafix, Kerr, Bioggio, Switzerland) was utilized to contain the restoratives and aid in the proximal wall build-up. The cavity surfaces were prepared for the application of the GC Fuji II LC by being conditioned using GC cavity conditioner (GC Corporation, Tokyo, Japan) for 10 seconds which was then thoroughly rinsed with an air/water spray for 10 seconds and lightly dried. The other three tested RBC bulk-fill materials were preceded by three steps total-etch adhesive system using Optibond FL (Kerr Co, Orange, CA, USA). A single adhesive was used in the current research to minimize the variables and hence accentuate the influence of restoratives. The used

TABLE (1) Materials details and compositions and manufacturers' names.

Material	Principal components	Manufacturer
SDR, light curing composite	**The resin matrix:** SDR patented urethane di-methacrylate resin, Di-methacrylate resin, and Di-functional diluent. **The filler:** (68% by weight) Barium and Strontium alumino-fluoro-silicate glasses.	DENTSPLY, DeTray GmbH, Germany
SonicFill, nanohybrid composite restorative	**The resin matrix:** (1-methylethylidene) bis (4, 1-phenyleneoxy-2, 1-ethanediyloxy-2, 1-ethanediyl) bismethacrylate. (1-methylethylidene) bis [4, 1-phenyleneoxy (2-hydroxy-3, 1-propanediyl)] bismethacrylate. 2, 2'-rthylenedioxydiethyl dimethacrylate. **The filler:** (83.5% by weight) Glass, oxide, and Silicon dioxide.	Kerr Corporation, Orange, CA, USA
Filtek Bulk Fill, Posterior Restorative	**The resin matrix:** AUDMA, UDMA, and 1, 12-dodecane-DMA. **The filler:** (64.5% by weight) Non-agglomerated/non-aggregated 20nm silica filler, a Non-agglomerated/non-aggregated 4 to 11 nm zirconia filler, an aggregated zirconia/silica cluster filler (20nm silica and 4 to 11nm zirconia particles), and ytterbium trifluoride filler consisting of agglomerate 100 nm particles.	3M ESPE, St. Paul, USA
GC Fuji II LC Dual-cured resin-modified glass ionomer restorative	**Capsule Liquid:** 20-30 WT% Distilled water, 20-30 WT% Polyacrylic acid, 30-35WT% 2-Hydroxyethylmethacrylate, <10 Urethanedimethacrylate and <1 Camphoroqunone. **Capsule Powder:** 100 WT% (Fluoro) Alumino silicate glass.	GC Corporation, Tokyo, Japan

TABLE (2): Samples' grouping:

	Groups (Dentin substitutes)			
	Group I SDR (DENTSPLY)	**Group II** Sonic Fill (Kerr)	**Group III** Filtek Bulk Fill (3M ESPE)	**Group IV** Fuji II LC (GC Corporation)
Subgroups (Thermal cycling)	**Subgroup A:** No thermal cycling (n=10)	**Subgroup A:** No thermal cycling (n=10)	**Subgroup A:** No thermal cycling (n=10)	**Subgroup A:** No thermal cycling (n=10)
	Subgroup B: Thermal cycling (n=10)	**Subgroup B:** Thermal cycling (n=10)	**Subgroup B:** Thermal cycling (n=10)	**Subgroup B:** Thermal cycling (n=10)
Total	80 samples			

adhesive is considered as a gold standard total-etch one, providing satisfactory adhesion to tooth substances.[25] Cavity surfaces were etched for 15 seconds with 37.5% phosphoric acid (Gel Etchant, Kerr Corporation, Orange, CA, USA), which was then thoroughly rinsed with an air/water spray for 10 seconds and lightly dried. Subsequent application and curing of the adhesive were performed following manufacturer's instructions. The four tested materials, all with A2 shade, were then applied into the prepared cavities according to manufacturers' instructions as one bulk. The restoration surfaces were then topped with a celluloid strip (K-Dent – Quimidrol, Joinville, Brazil) and photoactivated using Elipar S10 (3M/ESPE, USA) for 20 seconds continuous curing so that the light curing tip came in contact with the celluloid strip. To ensure a constant value of 600 mW/cm^2, the intensity of the light curing unit was measured after every ten specimens with a radiometer (SDS Demetron, Orange, CA, USA). Afterwards, the samples were finished and polished with Al_2O_3 abrasive disks (Sof-Lex Pop-on, 3M-ESPE, USA).

III. Gap width analysis:

Each tooth was sectioned, using a low-speed diamond disc with proper coolant, through the center of the restoration vertically in a mesiodistal direction.[52] Three descending orders of the sof-lex discs were used to polish the sectioned teeth, which were then cleaned ultrasonically. Gap formation along both mesial and distal gingival interfaces was tested using Environmental scanning electron microscope (Quanta 200, FEI, Netherland). The gap present in the image was divided into several points, each of which was measured in μm, and then the mean of the measured gap widths was calculated.

IV. Statistical analysis

Data were presented as mean and standard deviation (SD) values. Checking data distribution, histograms, calculating mean and median values and finally using Shapiro-Wilk and Kolmogorov-Smirnov tests of normality were performed to explore data for normality. Gap distance data showed parametric distribution; so two-way Analysis of Variance (ANOVA) was used in testing significance for the effect of dentin substitute, thermal cycling and their interactions on mean gap distance. Pair-wise comparison between the groups was performed using Bonferroni's post-hoc test when ANOVA test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM® SPSS® Statistics Version 20 for Windows.

RESULTS

Two-way ANOVA results

The results showed that dentin substitute, thermal cycling and the interaction between the two variables had a statistically significant effect on mean gap distance. Since the interaction between the two variables is significant, so the variables (Dentin substitute and thermal cycling) are dependent upon each other. So we compared the different levels within each variable. **(Table 3)**

Effect of dentin substitute

Regardless of thermal cycling; Fuji II showed the statistically significantly highest mean gap distance. Sonic Fill showed statistically significantly lower mean value. No statistically significant difference was found between SDR and Filtek Bulk Fill; both showed the statistically significantly lowest mean gap distance. **(Table 4, Figure 1)**

Without thermal cycling, Sonic Fill showed the statistically significantly highest mean gap distance. No statistically significant difference was found between Filtek Bulk Fill, SDR, and Fuji II; all showed the statistically significantly lowest mean gap distances. **(Table 5, Figure 2)**

While with thermal cycling, the highest statistically significantly mean gap distance was found with Fuji II. Sonic Fill showed statistically significantly lower mean value. There was no

TABLE (3): Two-way ANOVA results for the effect of different variables on mean gap distance.

Source of variation	Type III Sum of Squares	df	Mean Square	F-value	P-value
Dentin substitute	708.3	3	236.1	250.3	<0.001*
Thermal cycling	839.1	1	839.1	889.5	<0.001*
Dentin substitute * Thermal cycling interaction	775.3	3	258.4	273.9	<0.001*

df: degrees of freedom = (n-1), *: Significant at $P \leq 0.05$

TABLE (4): Descriptive statistics and results of comparison between gap distance of the four dentin substitutes regardless of thermal cycling

SDR	Sonic Fill	Filtek Bulk Fill	Fuji II	P-value
Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
16.3 ± 1.5 [c]	23.4 ± 4.3 [b]	17.5 ± 1.7 [c]	26.6 ± 12.6 [a]	<0.001*

****: Significant at $P \leq 0.05$, Different superscripts in the same row are statistically significantly different***

TABLE (5): Descriptive statistics and results of comparison between gap distance of dentin substitutes with and without thermal cycling

Thermal cycling	SDR	Sonic Fill	Filtek Bulk Fill	Fuji II	P-value
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
No thermal cycling	15.3 ± 0.9 [b]	19.4 ± 1.2 [a]	16.1 ± 1.0 [b]	14.6 ± 0.7 [b]	<0.001*
Thermal cycling	17.4 ± 1.2 [c]	27.3 ± 0.9 [b]	18.9 ± 0.7 [c]	38.5 ± 0.9 [a]	<0.001*

****: Significant at $P \leq 0.05$, Different superscripts in the same row are statistically significantly different***

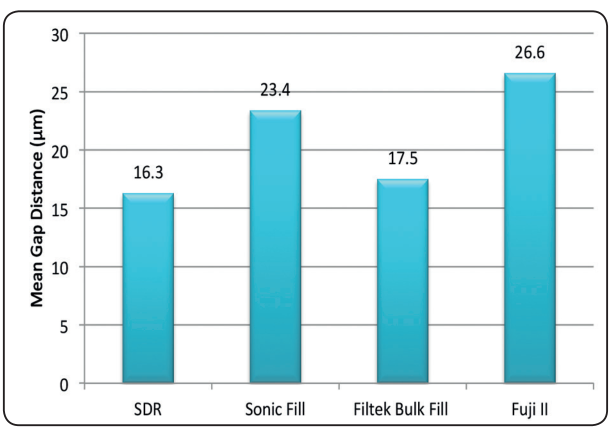


Fig. (1): Column chart representing mean of gap distance in the different Dentin substitute groups

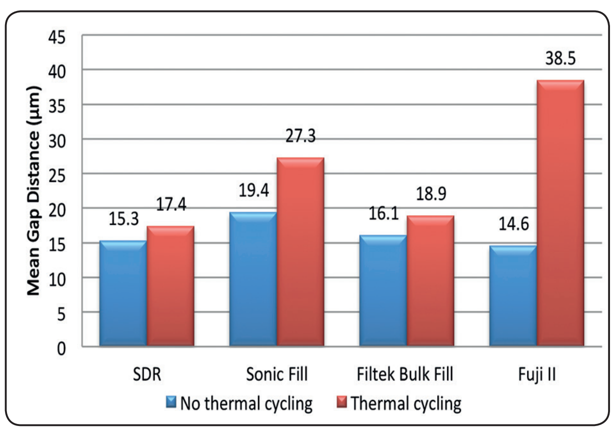


Fig. (2): Column chart representing mean of gap distance in the different Dentin substitute groups with and without thermal cycling statistically significant difference between SDR and Filtek Bulk Fill; both showed the statistically significantly lowest mean gap distance. **(Table 5, Figure 2)**

Effect of thermal cycling

Regardless of dentin substitute; thermal cycling showed statistically significantly higher mean gap distance than no thermal cycling. **(Table 6, Figure 3)** With all types of dentin substitutes; thermal cycling showed statistically significantly higher mean gap distance than no thermal cycling. **(Table 7, Figures 4,5)**

TABLE (6): Descriptive statistics and results of comparison between gap distance with and without thermal cycling regardless of dentin substitute

No thermal cycling	Thermal cycling	P-value
Mean ± SD	Mean ± SD	
16.4 ± 2.1	25.5 ± 8.7	<0.001*

: Significant at P ≤ 0.05

TABLE (7): Descriptive statistics and results of comparison between gap distance with and without thermal cycling using each dentin substitute

Dentin substitute	No thermal cycling	Thermal cycling	P-value
	Mean ± SD	Mean ± SD	
SDR	15.3 ± 0.9	17.4 ± 1.2	0.002*
Sonic Fill	19.4 ± 1.2	27.3 ± 0.9	<0.001*
Filtek Bulk Fill	16.1 ± 1.0 [b]	18.9 ± 0.7	<0.001*
Fuji II	14.6 ± 0.7	38.5 ± 0.9	<0.001*

: Significant at P ≤ 0.05

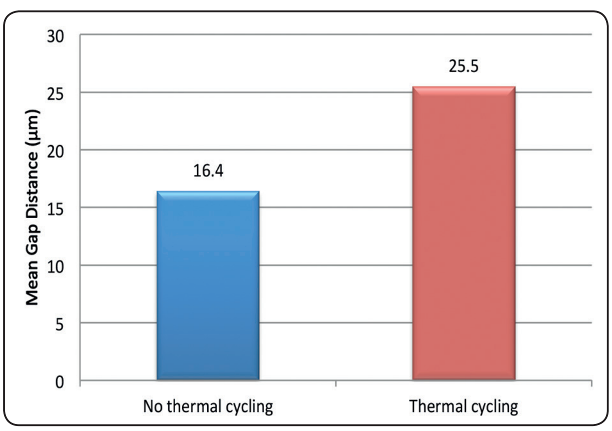


Fig. (3): Column chart representing mean of gap distance with and without thermal cycling

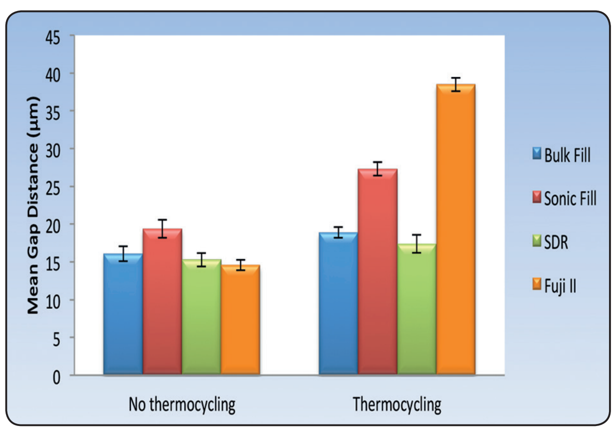
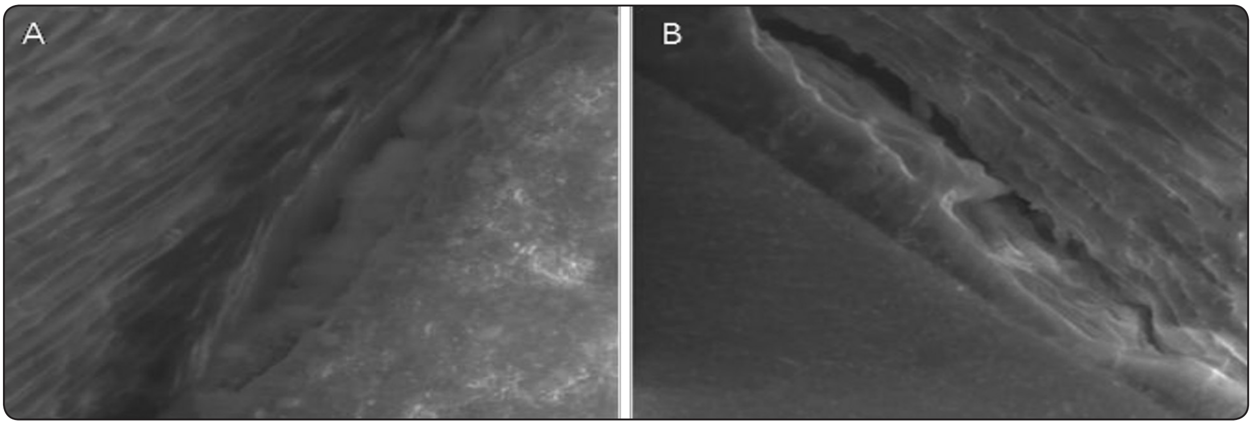


Figure (4): column chart representing mean and standard deviation values (error bars) of gap distance in the different groups



A) Without thermal cycling, B. With thermal cycling

Fig. (5): Photomicrograph of gaps at tooth/restoration interface for SDR (2000X)

DISCUSSION

The recently introduced ''bulk-fill'' RBC restoratives were always accompanied with questions related to the effect of polymerization shrinkage stresses as the whole mass polymerizes at the same time rather than in small increments, unlike the conventional composite restoratives filled with incremental technique.[1]

The early attempts of ''bulk-fill'' RBC restoratives were suffering from several shortcomings like the inefficiency of light curing to composite resin restorations with greater than 2 mm depths,[53-55] preparation design challenges on the C factor,[56,57] and inevitable complications resulting from polymerization shrinkage with subsequent gap formation,[15,56,58] which was presented clinically as discomfort on biting, due to accumulation of fluid within the gap and its movement within the tubules.[59,60] However, ideally bulk fill restoratives would be placed into a high C-factor preparation and yet show very slight polymerization shrinkage stress while assuring a high degree of cure through the entire restoration.[10,61]

This study aimed to assess the marginal seal of new dentin substitutes (SDR, DENTSPLY; Sonic Fill, Kerr; Filtek Bulk Fill, 3M ESPE; and Fuji II LC, GC Corporation) along pulpal dentin interface using environmental SEM and also evaluate longevity of the seal as a result of thermal stresses in MOD cavities (4 mm depth and half of the intercuspal distance width).

Regarding the effect of Dentin substitute, Fuji II showed the statistically significantly highest mean gap distance. Sonic Fill showed statistically significantly lower mean value. There was no statistically significant difference between Filtek Bulk Fill and SDR; both showed the statistically significantly lowest mean gap distance. This was in accordance with Agarwal et al., 2015,[1] Scotti et al., 2014,[48] Roggendorf et al., 2011,[25] and Armiliana et al., 2016,[62] who agreed that the bulk fill flow RBCs, especially the Surefill SDR, have low modulus of elasticity,[63] and low viscosity which facilitates their plastic flow during the early phases of polymerization resulting in better adaptation,[64] thus reducing microleakage in dentin.[48] This was also in agreement with Moorthy et al., 2012,[10] whose findings suggest no detrimental outcome in using the bulk-fill flowable RBC bases on the tooth/RBC restoration interface. Better marginal seal was shown with Bulk Fill and SDR compared to Sonic Fill, which may be due the presence of UDMA in the composition of the first two materials, as it has high molecular weight, which results in smaller polymerization shrinkage.[65]

However, this was not in accordance with Abbas et al., 2003,[21] and Juloski et al., 2013,[66] who assessed the extent of cervical microleakage in bulk filled RBCs and identified dye penetration into the pulp chamber from the pulpal floor, suggesting that the bulk fill RBCs could not be efficiently irradiated to 4 mm for the times recommended by the manufacturers.

Regarding the Fuji II that showed the statistically significantly lowest mean gap distances without thermal cycling, this was in agreement with Koubi et al., 2010,[67] and Besnault et al., 2003,[68] who stated that Fuji II LC provided a better dentinal seal than composites as being less sensitive to parameters, such as temperature and relative humidity. Furthermore, Koubi et al., 2010,[67] claimed that dual-curing resin-modified glass ionomer (RMGI) restoratives could be placed in bulk, as it bypasses all the clinical limitations related to light curing. Also, they polymerize more slowly,[69] resulting in a lower polymerization shrinkage stress,[70] thus improving the marginal and internal adaptation of such restorations.[71]

Regarding the effect of thermal cycling, thermal cycling showed statistically significantly higher mean gap distance than no thermal cycling. With all types of dentin substitutes; thermal cycling showed statistically significantly higher mean gap distance than no thermal cycling.

This was in accordance with Wahab et al., 2003,[47] Scotti et al., 2014,[48] and Versluis et al., 1996,[72] who agreed that mismatch between the coefficients of thermal expansion for the restorative material and the natural tooth structure results in thermally induced stresses, which may lead to gap formation and microleakage.

Fuji II showed the statistically significantly lowest mean gap distance without thermal cycling, while with thermal cycling it showed the statistically significantly highest mean gap distance among all the tested groups. This may be explained because glass ionomers are very sensitive to moisture to which they are exposed. Shanthala and Xavier, 2013,[73] found that RMGI absorbed high amounts of water in a very high rate, leading to its diffusion through the restoration matrix causing an alteration of its properties. Therefore water along with increased temperature difference during thermal cycling caused a relative decrease in physical properties of Fuji II LC,[74] which may have led to this significant increase in gap distance.

Finally, a limitation of this study is that it was carried out in-vitro, not taking into consideration neither the effect of pulpal pressure on the used adhesive systems, nor the possible biological effect of the curing units used, thus more clinical evaluations should be carried out as such type of laboratory studies does not eliminate the need for clinical ones.

CONCLUSIONS

Under the test conditions, Filtek Bulk Fill and SDR provided an adequate marginal seal, concerning gap distance, when compared to Sonic Fill and Fuji II. Meanwhile, thermal cycling significantly increases gap distance in all tested dentin substitutes, thus affecting longevity.

CLINICAL IMPLICATION

''Bulk-fill'' RBC restoratives can be considered as adequate dentin substitute in large cavities as final filling material or core build-up material under extra-coronal restorations.

DISCLOSURE

The authors report no conflicts of interest in this work.

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