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Research Article

Compressive Strength and Compressive Fatigue Limit behavior of Two Fluoride releasing materials

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ABSTRACT

This study was conducted to evaluate the compressive strength, compressive fatigue limit and the amount of fluoride released from the Smart Dentin Replacement SDR™ restorative material in comparison to another fluoride released from hybrid resin composite material Tetric N Ceram. A total of eighty (80) specimens were used in this study, where forty (40) specimens were used to evaluate the compressive strength and the compressive fatigue limit, while the other forty (40) specimens were used to evaluate the amount of fluoride released from the two tested materials. Each of the forty (40) specimens for the two tests was divided into two groups: where Group (1) represented the Tetric N Ceram material, and Group (2) represented the SDR™. Statistically significant difference was found between the mean of the compressive strength of the specimens in Group (1) and Specimens of Group (2) as they recorded 224 ± 8.4 and 201.6 ± 9.05 respectively. While, no statistically significant difference was found between the mean of compressive fatigue limit of the specimens in Group (1) and Specimens of Group (2) as they recorded 188.5 ± 6.2 and 190 ± 5.02 respectively. Results also revealed that the mean Compressive fatigue limit of the SRD™ caped with 2 mm of Tetric N Ceram was approximately 94.52% from its Compressive bond strength means. Fluoride release test revealed the significant superior results of fluoride released by the SDR™.

Smart dentine replacement caped with hybrid resin composite could be the material of choice when the amount fluoride released is considered in selection of tooth restoration and when the proper functioning in the oral cavity is required for a permanent restoration in stress areas. Also it was concluded that the SDR™ ability to release fluoride was more than the Tetric N Ceram.

Key Words: Compressive strength; Fatigue limit, Fluoride release

INTRODUCTION

The addition of fluoride to restorative materials has attracted the attention of dental researchers and clinicians as for the possibility of using these materials as a source of low fluoride release to the teeth, within long periods. These so-called "intelligent" dental materials have been elaborated with the purpose of reducing secondary caries and neutralizing the pH decrease, especially in high-caries risk patients. Their mechanical and esthetic properties have been improved and most of them can now be used to restore posterior teeth (Gao and Smales, 2001). Thus such restorations are considered to be the material of choice in deep cavities in early erupted permanent molars where the fluoride is needed to reverse the active caries process and to prevent recurrent caries expected in such large and deep cavities.

Where fluoride release profiles of various restorative materials were compared, these materials were not found as successful as they were expected to be in their long-term fluoride releasing ability (Williams et al. 2001)˙ Fluoride release of these materials was initially fast and then, the release became steady with time. Similarly, other studies reported that despite the wide variations in the amounts of fluoride released from dental materials, the pattern of fluoride release was found to begin with an initial high burst of fluoride released during the first 24 hrs followed by a low, prolonged elution (Vermeersch et al. 2001; Attar and Turgut 2003 and Wiegand et al. 2007).

Other important issues about these materials is their mechanical properties like compressive strength. Moreover, their compressive fatigue limit cannot be overlooked as it shows the material behavior under repeated cyclic loading as in the oral cavity especially that it does not correlate to the initial compressive strength (Lohbauer et al. 2003).

Smart Dentine Replacement SDR™ has been introduced to the market as a structure of the Stress decreasing resin that provides low stress to the composite system. The optimized balance of properties exhibited by SDR™ is as a result of the combination of SDR™ resin with fillers and other formulation components. SDR™ combines these features to deliver the first posterior flowable base which can be bulk filled with the great advantage of Fluoride release (Frankenberger 2008).

Thus, this study was performed in order to evaluate the initial amount of fluoride released from the SDR^{TM} restorative material compared to another fluoride release of hybrid resin composite. Moreover, to compare its compressive strength and compressive fatigue limit of SDR^{TM} when capped with hybrid resin composite material to this hybrid resin composite material when used alone. The null hypothesis was that there is no difference among the initial amount of fluoride release, compressive strength and compressive fatigue limit of the different materials tested

Materials and Methods

A total of Eighty (80) specimens was used in this study, where forty (40) specimens were used to evaluate the compressive strength and the compressive fatigue limit, while the other 40 specimens were used to evaluate the amount of fluoride release from the two tested materials. Each 40 specimens for the two tests were divided into two groups: where Group (1) represented the Tetric N ceram (Ivoclar Vivadent, Schaan, Liechtenstein), and Group (2) represented the SDR ^{TM} (DENTSPLY/Caulk, Milford, DE). Table (1) represents the material formulation of both materials used in this study.

The Compressive and Compressive fatigue limit of all specimens were determined using universal testing machine (Model LRX-Plus; Lloyd Instruments Ltd., Fareham, United Kingdom) with a load cell of 5 kN and data were recorded using computer software (Nexygen-MT; Lloyd Instruments Ltd., Fareham, United Kingdom).

The forty (40) specimens were performed in a cylindrical mold of 4 mm diameter and 4 mm length and they were separated into two groups of 20 specimens each : Group (1) 20 specimens of Tetric N Ceram which were packed in the mould and light cured for 30s using Light Bluelex-LED (BlueLex, LD-105, San-Chong city, Taiwan). While the other 20 specimens Group (2); (the first 2 mm was packed with the SDR ^{TM} and light cured for 30s using Light Bluelex-LED (BlueLex, LD-105, San-Chong city, Taiwan) then the outer 2 mm was packed with Tetric N Ceram and again was light cured.

Each group was further divided into two subgroups A and B of 10 specimens each; where in subgroup (A) the specimens were subjected to compressive strength test, while in subgroup (B) the 10 specimens were subjected to compressive fatigue limit test.

For compressive strength test, Specimens of the subgroup (A) from the Group (1) and Group (2) were fixed in the lower fixed component of the Instron machine. The specimens were subjected to a compressive loading in the occlusogingival direction at a crosshead speed of 0.5 mm/min. The load required to fracture each specimen was recorded in Newtons. The obtained values were converted into Mega-Pascal units (MPa), according to the following equation: compressive strength = F/A (N/mm2) or (MPa) where F (the force leading to fracture) in Newton's and A is the cross-sectional surface area of cylindrical specimen in mm^2.

Table 1: Material formulation of Tetric N ceram and SDR TM:

Material	Composition	Company
Tetric N Ceram	Resin: BisGMA, BisEMA(6), UDMA and Procrylat Filler: 50% wt Barium glass 5% wt Ba-Al-Fluorosilicate 5% wt Mixed oxide 1% wt Highly dispersed silica 17% wt Ytterbium Trifluoride	IvoclarVivadent,Schaan, Liechtenstein
SDR TM	Resin: Ethoxylated Bisphenol A dimethacrylate (EBPADMA); Triethyleneglycol dimethacrylate (TEGDMA); Modified urethane dimethacrylate resin; Camphorquinone (CQ) Photoinitiator; Butylated hydroxyl toluene (BHT); UV Stabilizer Filler: Barium-alumino-fluoro-borosilicate glass; Strontium alumino-fluoro-silicate glass; 68% by weight, 44% by vol. Titanium dioxide; Iron oxide pigments	DENTSPLY/Caulk, Milford, DE

For compressive fatigue limit test, Specimens of the subgroup (B) from the Group (1) and Group (2) were fixed (Model LRX-Plus; Lloyd Instruments Ltd., Fareham, United Kingdom) with a load cell of 5 kN and data were recorded using computer software (Nexygen-MT; Lloyd Instruments Ltd., Fareham, United Kingdom) as previously mentioned in the evaluation of Compressive bond strength. The load profile was in the form of a wave at a rate of 1 Hz. Compressive fatigue test for 5000 load cycles or until specimen fractured was determined by testing according to the staircase (up-and-down) method.The first specimen was tested at the approximate value of about 25% of the Compressive bond strength previously evaluated (Marc 2007).

As for the fluoride release measure, a total of forty (40) specimens (20 specimens of Tetric N Ceram and 20 specimens of SDR^{TM}) were prepared to evaluate the amount of fluoride release using a special Teflon mold of 2mm diameter and 2mm thickness. The two fluoride releasing materials were packed in each disc using a load of 1 Kg applied over a glass slab to ensure the uniform packing of the material. The glass slab was then removed and LS was light cured for 30s using Light Bluelex-LED (BlueLex, LD-105, San-Chong city, Taiwan) with constant mode of full intensity 800 mW/cm2 at zero distance from the specimen. Reagents used in performing the test:

a. Two standard fluoride calibration solutions were used for checking the electrode potential and calibrating the Fluoride meter.

- HI 70701 (10 mg/LFl solution) Lot. 1215
- HI 70703 (100 mg/LFl solution) lot. G2603

b. TISAB II (Total Ionic Strength Adjustment Buffer) HI 4010-05 (Lot.3425) was used for measuring fluoride ions in the deionized water as it provides a constant background ionic strength. Each specimen from the two materials was placed in a plastic tube containing 5 ml of deionized water and stored at room temperature. All tubes were properly covered with rubber stoppers to prevent evaporation of the water. Each specimen was removed from its tube after the first day of immersion then at the end of a week to measure the amount of fluoride released. At the time of measurement, each specimen was rinsed with 1 ml of deionized water which was poured over the specimen by small pipette and added to the previously stored deionized water. The specimen was then transferred to a new plastic tube containing 5ml of deionized water till the end of the week for the second measurement. The amounts of fluoride were expressed in part per million (ppm).

The deionized water was analyzed for fluoride with the use of an ion specific electrode (FC301B, Hanna Company, Italy) connected to a microprocessor-based portable fluoride meter (HI98401, Hanna Company). In order to obtain an accurate result, the meter was calibrated at a temperature no more than

20 ± 3°C. A separate stainless steel temperature probe (HI 7662, Hanna Company, Italy) was supplied and connected to the meter. It was used to measure and adjust the temperature of the deionized water. The reading was shown on the lower part of liquid crystal display. A separate reference electrode (HI4663, Hanna Company, Italy) was also supplied and connected to the portable fluoride meter. It was immersed with the fluoride electrode and the temperature probe in the sample solution during measurement of fluoride concentration in order to guarantee an accurate and repeatable measurement every time. The 5 ml storage medium of each specimen plus 1ml of deionized water used for rinsing the specimen were added to 0.6 ml of readymade total ionic strength adjustment buffer solution TISAB II (HI 4010-05) in ratio 10:1 and placed in a specially designed Teflon pot with three holes cover. The Teflon Pot (beaker) was used to hold the three electrodes of an ion meter away from each other and from touching the bottom of the beaker. The three connected electrodes were properly immersed in the solution in order to assure accurate readings of fluoride released into the deionized water. The results were displayed on the upper part of liquid crystal display (LCD) directly in fluoride concentration and expressed in ppm (mg/L).

Statistical Analysis

Statistical analysis was performed using SPSS software, version 17.0 (Statistical Package for Social Sciences, SPSS Inc., Chicago, IL, USA). The means and Standard deviation of compressive strength and compressive fatigue limit and the amount of fluoride release were calculated for all groups. The obtained data were subjected to analysis of variance (one-way ANOVA) and Scheffe post hoc and t-Tests ($p \leq 0.005$) to determine the significant differences among groups. The Student's t-test was used to determine significant differences between Compressive bond strength and compressive fatigue limit also to determine the significant differences in fluoride release between the two examined materials.

RESULTS

Compressive strength and compressive fatigue limit results:

Table (2) represented the statistical analysis of compressive strength and Compressive fatigue limit means obtained for both subgroups A from group (1) and group (2). A significant difference in the compressive strength mean values was found between Groups 1 and 2 ($p \leq 0.005$). The subgroup (A) form group (1) presented the highest value 224(±8.4) MPa while the subgroup (A) from group (2) recorded 201.6±9.05 MPa, respectively. As regards to compressive fatigue limit, subgroups (B) from Group (1) and Group (2) presented no statistical significant difference ($p \leq 0.005$). The subgroup (B) from group (1) recorded 188.5 ± 6.2 MPa while subgroup (B) from group (2) recorded 190 ± 5.02 MPa. Results also revealed that the mean Compressive fatigue limit of the SRD™ caped with 2 mm of Tetric N Ceram was approximately 94.52% from its Compressive bond strength means, while that of Tetric N Ceram alone was 84.1%.

Table 2: Mean values (Mpa) and Standard Deviation of compressive strength and compressive fatigue limits of the two tested groups.

Group	Means and Standard Deviation, MPa		Compressive fatigue /Compressive strength
	Compressive strength	Compressive Fatigue strength	
Tertic N Ceram (Group1)	224 ± 8.4	188.5 ± 6.2	84.1%
SDR™ caped with Tetric N Ceram (Group 2)	201.6 ± 9.05	5.02 ±190	94.52%
t-Test P-Value	0.003*	0.008	* P≤0.005

** ANOVA) and Scheffe post hoc and t-Tests (p ≤0.005)*

Table 3: Mean values and Standard Deviation of the amount of fluoride released by the two tested materials after 24 hours and 1 week.

Duration	Amount of Fluoride release from the two materials Material, ppm		P Value
	Tetric N Ceram ±SD	SDR™ ±SD	
After 24 hours	0.4013± 0.05	0.828± 0.03	*0.000
After 1 week	0.225± 0.1	0.7330±0.6	*0.000

**Significant at P≤0.005*

Fluoride release results

Table (3) represented the descriptive statistics and test of significance of the different amount of fluoride release between the two examined materials. Results revealed that the fluoride released after 24 hours of immersing the specimens of the two materials (Tetric N Ceram and the SDR™) in deionized water was significantly higher for the SDR™ which recorded 0.828± 0.03 ppm than the Tetric N Ceram which recorded 0.4013± 0.05 ppm at $p \leq 0.05$. Same statistical data was obtained for the amount of fluoride released from the two materials after one week as the SDR™ recorded 0.7330±0.6 ppm while the Tetric N Ceram recorded 0.225± 0.1 ppm at $p \leq 0.005$.

DISCUSSION

Fatigue fractures of resins after years of clinical use were found to be a common failure reason. Studies investigating resistance to fatigue are unable to substitute the clinical studies but may provide an estimate of the clinical performance of a material in a short period of time and incurring lower costs. Nevertheless, compressive strength is one of the most important mechanical properties of a core buildup material which restores the structure of a tooth in posterior region (Saygili and Mahmali 2002; Summitt et al. 2006;Van Noort 2007). According to Lohbauer et al., 2003, materials providing high initial compressive strengths do not automatically reveal the best fatigue resistance values (Marc 2007). The development of high performance materials depends on a delicate balance between the type, size, shape and concentration of filler particles, as well as on the critical formulation of the organic phase.

Since the properties of the composites for the restoration of posterior teeth are controversial while clinical and fatigue studies are scarce, the purpose of this study was to determine the compressive strength and compressive fatigue limit of Tetric N Ceram specimens in restoring a bulk of 4 mm and other specimens of SDR™ restoring the first 2mm and caped with the outer 2mm of Tertic N Ceram, as recommended by the manufacturer that SDR™ is designed to be overlaid with a methacrylate based posterior composite with which it is highly compatible for replacing missing occlusal /facial enamel. The two groups of specimens were evaluated and compared regarding their compressive strength and their compressive fatigue limit and the relation of both values to each other.

However, the clinical significance of this study was to introduce the SDR™ as an effectively fluoride releasing flowable base with reasonable compressive strength and compressive fatigue limit when applied under a tooth-colored restoration.

Results obtained in this study revealed a significant different between the compressive strength of the two groups of specimens, where the group of Tetric N Ceram showed higher mean value than that of SDR™ capped with Tetric N Ceram. However, SDR™ capped with Tetric N Ceram showed higher compressive fatigue limit means than that of Tetric N Ceram with no statistical significant difference found between them. Moreover, results of the compressive fatigue limits revealed that the SDR™ caped with the Tetric N Ceram showed a great percentage reached 94.52% of their compressive strength suggesting better performance in the oral cavity under repeated cyclic loading and increase longevity of the restoration.

The compressive fatigue limit for any composite resin containing restorative material depends on many factors such as polymerization shrinkage, water sorption and high sensitivity to contamination during the restoration and incomplete polymerization especially in light cure composite resins which light does not reach to the deep parts of the cavity. All of these factors will affect the mechanical properties, clinical performance and longevity of the composite restorations and lead to premature failure than with amalgam restorations.

It seems that there are other factors like degree of conversion, filler matrix bond in mouth environment, type of polymerization, polymerization shrinkage and many other factors which affect the mechanical properties of composite resins (O`Brien 2002).

The polymerization pattern of composite resin is important in mechanical properties too. In this study we used Dentsply's new restorative SDR ^{TM} is based on the "Stress Decreasing Resin" technology. This means that a substance described as a "polymerization modulator" is chemically embedded in the backbone of the polymerizable resin. Thanks to the significantly reduced polymerization stress, SDR™ has the required physical and mechanical properties for use as a posterior bulk-fill flowable base. Moreover, the integration of these modifications in the well-proven methacrylate chemistry makes SDR™ compatible with methacrylate-based adhesives and composites, which are widely used in dental practice (Lohbauer et al. 2003).

Low concentrations of fluoride have a beneficial effect on dental hard tissues and in the prevention of caries. However, after topical fluoride treatments, salivary fluoride concentrations decrease to very low levels within a few hours. Fluoride releasing dental materials can be alternative systems not only to maintain the long-term fluoride release in the oral environment but also to reverse active caries lesions (Powers and Sakaguci 2006 ; Albers 2002). Thus, another aim in this study was to evaluate the initial amount of fluoride release; immediately and one week after of SDR^{TM} compared to Tetric N ceram since 90 % of the fluoride is released during the first week, the remaining 10 % might be released more slowly and could be sufficient to reduce the prevalence and severity of demineralization (Albers 2002).

However, the results showed that this was true for Tetric N Ceram only where, the highest values of fluoride release were observed in the first 24 hours for both materials; Tetric N Ceram and the SDR ^{TM} then slowly decrease in fluoride release was observed during the first week with the Tetric N Ceram. While for the SDR^{TM} the level of fluoride release remained constant during the first week indicating greater ability to reverse the active caries process and enhanced effect on remineralization for longer duration. Moreover, a significantly higher amount of fluoride released in the deionized water was obtained for SDR^{TM} compared to Tetric N Ceram. Tetric N Ceram is a hybrid composite resin with fine filled particles and there are just a few studies on fluoride release by this material (Burgess 2001). The monomer matrix is composed of Bis-GMA, urethane dimethacrylate, and triethylene glycol dimethacrylate (TEGDMA).

The inorganic fillers contain barium glass, ytterbium trifluoride around 15%, Ba-Alfluorosilicate glass, highly dispersed silicon dioxide, and spheroid mixed oxide (Mattick et al. 2001). It's worth mentioning that a limitation of the study was the use of only two standard fluoride solutions to calibrate the fluoride meter to measure the amount of fluoride release.

In this study, the SDR ^{TM} caped with 2mm of Tetric N Ceram showed lower statistical significant mean of compressive strength than specimens made from 4 mm Tertic N Ceram only. This finding was in disagreement with Xu and Burgess in 2003, who mentioned that materials with high fluoride release have lower compressive strength because of the voids that are left after the soluble fluoride salt leaches out and concluded that in order to enhance the fluoride recharge capability without increasing porosity, the polymer matrices that have fluoride 'exchange capability' are highly desirable. Now Naom et al 2011 mentioned that fluoride containing resin composites and especially those containing 'pre-reacted glass ionomer fillers' could be employed to get benefit in treating high caries risk patients in situations where glass ionomers may be unsuitable; particularly in high load bearing or aesthetically critical locations.

This capability raises the possibility of fluoride-containing composites exhibiting a lower incidence of recurrent caries than non-fluoride containing composites. And also the 'mechanical properties' of such composite 'did not diminish' with aging and fluoride release over the testing period. Thus we can conclude from this study that SDR^{TM} capped with resin composite maximize the benefit from the higher fluoride release of this bulk fill flowable base with its stress reduction ability in the deep portions of cavities as well as maximize the benefit from placement of a compatible adhesive composite with less fluoride release and better mechanical property. Thus, this combination offers better overall clinical performance, tolerance for occlusal forces and consequently longevity of restoration (Naoum et al. 2011).

Finally, it is important to mention that the depth of cure of SDR™ could reach up to 4 mm when packed as bulk restorations that makes it possible to be used in deciduous teeth where the mastication forces are limited than the permanent teeth and moisture control is difficult, so further investigations are still needed to evaluate the SDR™ to be used as a final restoration in deciduous teeth.

CONCLUSIONS

Smart dentine replacement caped with hybrid resin composite could be the material of choice when amount fluoride release is considered in selection of tooth restoration and when the proper functioning in the oral cavity is required for a permanent restoration in stress areas.

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