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EFFECT OF USING FIBER REINFORCEMENT RIBBOND® SYSTEM ON MARGINAL ADAPTATION OF FLUORIDE RELEASING RESTORATIONS: AN *IN VITRO* STUDY

Yasser Abdelaziz Abed* *and* Ahmed Gamal Abdelwahed**

ABSTRACT

Aim: To assess the impact of using Ribbond® fibers on the marginal adaptation of three Giomer restorative materials at the gingival margin in class II restorations.

Materials and Methods: Three Giomer restorative materials were evaluated; BEAUTIFIL II (SHOFU INC., Kyoto, Japan), BEAUTIFIL II LS (SHOFU INC., Kyoto, Japan), BEAUTIFIL-Bulk Restorative (SHOFU INC., Kyoto, Japan). Sixty human mandibular molars were collected. Standardized occluso-mesial box-only cavities were prepared. The cavities were allocated into 6 groups (n = 10) according to the type of restorative material; Group 1: Nanohybrid Giomer: BEAUTIFIL II (BE), Group 2: Low-shrinking nanohybrid Giomer: BEAUTIFIL II LS (BLS), Group 3: Bulk-fill Giomer: BEAUTIFL-Bulk Restorative (BBR), Group 4: Nanohybrid Giomer: BEAUTIFIL II + Fiber Reinforcement Ribbond® System (BE+R), Group 5: Low-shrinking nanohybrid Giomer: BEAUTIFIL II LS + Fiber Reinforcement Ribbond® System (BLS+R), Group 6: Bulk-fill Giomer: BEAUTIFL-Bulk Restorative + Fiber Reinforcement Ribbond® System (BBR+R). All restorations were thermocycled for 10,000 cycles between 5°C-55°C. Scanning electron microscope (SEM) was used to analyze the gingival margins of the restorations at 50× magnification to determine the length of the gap (non-continuous) margin. Shapiro-Wilk test, two way analysis of variance (ANOVA) test and Sidak's multiple comparisons test were used to analyze the results statistically.

Results: The mean percentage of non-continuous margins for the groups was as follows: BE (29.47±1.88), BLS (28.59±1.74), BBR (12.30±1.43). BE+R (15.44±1.31), BLS+R (10.70±0.92), BBR+R (15.20±0.99).

Conclusions: The use of Ribbond® fibers improves the marginal adaptation at the gingival margins of class II of incrementally-packed Giomer restorative materials.

KEYWORDS*:* Ribbond® - Giomer - Marginal adaptation

* Associate Professor, Conservative Dentistry, Faculty of Dentistry, October 6 University, Giza, Egypt
* Assistant Professor, Conservative Dentistry, Faculty of Dentistry, October 6 University, Giza, Egypt

INTRODUCTION

Resin composites have seen tremendous rise in their use for direct and indirect restoration of posterior teeth[1]. They have grown in popularity due to the increasing demand for esthetics in addition to improved mechanical properties, and bonding characteristics to enamel and dentin[2,3]. Continuous development has been made, resulting in significant advances in optical characteristics, biocompatibility, physical properties and wear resistance[4,5].

Several in vitro studies and clinical trials have proved the clinical efficacy of glass ionomers and resin-modified glass ionomers[6-10]. The main advantage of these materials is related to their fluoride releasing ability, which reduces the probability of developing new carious lesions adjacent to restorations (CAR)[11]. A new trend has emerged in the dental industry to develop hybrid restorative materials combining the main advantages of resin composite (excellent esthetics and optimum bonding to tooth) and glass ionomer (fluoride releasing and recharging ability) [12]. A new group of these hybrid restorative materials known as Giomers was introduced[13]. The term "Giomer" is derived from combining the words "glass ionomer" and "resin composite"[14]. Giomers differ from glass ionomers and resin modified glass ionomers in having surface salinized prereacted glass (S-PRG) fillers incorporated within the resin matrix[15,16]. The addition of S-PRG fillers improves the physical and mechanical properties and increases fluoride releasing and recharging over time[17,18].

Despite the significant modifications in the composition and formulations, volumetric contraction of the restoration due to polymerization shrinkage develops stresses at the tooth-restoration interface, which is still an obstacle limiting the clinical longevity of resin-based restorative materials[19]. These introduced stresses might develop marginal gaps, which can eventually lead to marginal leakage and failure of restoration[20]. The number of monomers that convert into polymers is the main determinant of the amount of polymerization shrinkage[21]. Various factors determine the magnitude of shrinkage stress. These factors include the amount and type and of fillers, resin matrix formulation, technique and time of curing and the geometry of the prepared cavity[22-24]. Several strategies, such as increasing filler load, applying low-shrinkage materials, incremental packing technique, sandwich technique, guided polymerization, and modified curing modes, have been proposed for reducing polymerization shrinkage stresses[25-28].

Direct resin composites are usually applied in increments of no more than 2 mm-thickness. This increases the risk of air bubbles entrapment between increments and prolongs the time of application, especially in deep posterior cavities[29]. To overcome these problems, bulk-fill restorative materials were developed to allow applying the resin composite in one increment up to 4-5 mm and polymerization in one step[30,31].

Over the past few decades, restorative dentistry has continuously progressed from conventional macromechanical retention towards adhesion. The concept of biomimetic dentistry has emerged, aiming to introduce restorative materials that can mimic the structure and integrity of natural teeth[32]. Biomimetic dentistry strategies mainly target two goals: maximizing bond durability and reducing stresses[33]. Among the stress-reduction methods are the insertion of reinforcing fibers in resin composite restorations[34,35]. Ribbond® (Ribbond, Seattle, WA, USA) is a non-impregnated bondable reinforcement polyethylene fiber ribbon that has been reported to enhance the durability of resin composite restorations[36]. It allows efficient force transmission, resulting in improved flexural strength of the resin composite restorations[37]. Previous researches showed that the insertion of polyethylene fiber under the resin composite restorations in endodontically treated teeth had a stress altering effect that increased the fracture strength of the restorations[38-40].

Marginal leakage frequently occurs at the gingival floor in deep proximal cavities due to difficulties faced regarding accessibility and attaining efficient light curing[41]. Therefore, achieving adequate bonding to dentin in the gingival floor is still one of the challenges in restoring class II cavities[42]. It was supposed that the use of reinforcement polyethylene fiber ribbon could control shrinkage of resin-based restorative materials during polymerization, thus improving the marginal adaptation at the gingival floor in class II[43]. Therefore, this study aimed to evaluate the effect of using reinforcement polyethylene fiber ribbon on the marginal adaptation of three Giomer restorations at the gingival floor of class II. The two null hypotheses tested were the following: (1) the use of reinforcement polyethylene fiber ribbon would improve the marginal adaptation, (2) no differences would be between conventional and low-shrinking incrementally-packed, and bulk-fill Giomer restorative materials.

MATERIALS AND METHODS

Three fluoride-releasing restorative materials were evaluated in this study: a nanohybrid Giomer (BEAUTIFIL II, SHOFU INC., Kyoto, Japan), a low-shrinking nanohybrid Giomer (BEAUTIFIL II LS, SHOFU INC., Kyoto, Japan), and a bulk-fill Giomer (BEAUTIFIL-Bulk Restorative, SHOFU INC., Kyoto, Japan). The technical characteristics are presented in Table (1)

This in vitro study was carried out in compliance with the rules of the Research Ethics Committee – Faculty of Dentistry – October 6 University (Approval date: July 4, 2022 – Approval No. RECO6U/19-2022). Following obtaining informed consent, sixty freshly extracted human mandibular molars were collected from participants. The teeth were extracted for periodontal reasons. To overcome the variations in width and shape of the natural molars, the teeth were selected with a maximum of ± 0.5 mm as an accepted variation

TABLE (1) Technical characteristics of the investigated materials according to manufacturers

Product	Abbreviation	Specification	Composition		Filler Wt% (Vol%)	Shade	Polymerization time (sec.)	Lot Number	Manufacturer
			Resin matrix	Fillers					
BEAUTIFIL II	BE	Nanohybrid Giomer	Bis-GMA TEGDMA	S-PRG based on fluoroboroaluminosilicate glass	83.3% (68.6%)	A3	10	012240	SHOFU INC., Kyoto, Japan
BEAUTIFIL II LS	BLS	Low-shrinking nanohybrid Giomer	Bis-GMA TEGDMA Bis-MPEPP	S-PRG based on fluoroboroaluminosilicate glass	82.9 % (68.6 %)	A3	10	052134	SHOFU INC., Kyoto, Japan
BEAUTIFIL-Bulk Restorative	BBR	High viscosity bulk-fill Giomer	Bis-GMA UDMA TEGDMA Bis-MPEPP	S-PRG based on fluoroboroaluminosilicate glass	87% (74.5%)	U	10	072155	SHOFU INC., Kyoto, Japan

Abbreviations: ***BIS-GMA, Bisphenol A Dimethacrylate; TEGDMA, Triethylene Glycol Dimethacrylate; Bis-MPEPP, Bisphenol A polyethoxy methacrylate, UDMA, Urethane Dimethacrylate; AUDMA: Aromatic Urethane Dimethacrylate; AFM, Addition Fragmentation Monomers, 1,12-Dodecane-DMA*** in the dimensions of the teeth. The molars were cleaned by a periodontal scaler, then stored in 0.5% chloramine T solution. Each molar was mounted vertically in self-curing acrylic resin (Acrostone Cold Cure, Acrostone, Cairo, Egypt) up to 2 mm below the cemento-enamel junction.

Standardized conservative class II cavities (proximal box-only) were prepared on the mesial surfaces of the selected teeth with the following dimensions: 4 ± 0.3 mm bucco-lingual, 2 ± 0.3 mm mesiodistal, and 4 ± 0.3 mm occlusoginigival. None of the cavity margins were beveled. One operator (Y.A.A) prepared all the cavities using a round end straight fissure bur (MANI, INC., TOCHIGI, Japan) rotating in a high-speed hand piece (Dentsply Sirona T4, Sirona Dental Systems GmbH, Fabrikstraße, Germany) under profuse water coolant. Every 4 cavity preparations, a new bur was used. All cavity dimensions were checked with a periodontal probe.

The prepared cavities were randomly divided into 6 groups (n = 10) according to the type of restorative material:

Group 1: Nanohybrid Giomer: BEAUTIFIL II (BE)

Group 2: Low-shrinking nanohybrid Giomer: BEAUTIFIL II LS (BLS)

Group 3: Bulk-fill Giomer: BEAUTIFL-Bulk Restorative (BBR)

Group 4: Nanohybrid Giomer: BEAUTIFIL II + Fiber Reinforcement Ribbond® System (BE+R)

Group 5: Low-shrinking nanohybrid Giomer: BEAUTIFIL II LS + Fiber Reinforcement Ribbond® System (BLS+R)

Group 6: Bulk-fill Giomer: BEAUTIFL-Bulk Restorative + Fiber Reinforcement Ribbond® System (BBR+R)

The prepared cavities in all groups were etched using 37% phosphoric acid etching gel (Meta Etchant, META BIOMED, Chungcheongbuk-do, Republic of Korea), then a self-etching bonding agent (BeautiBond Universal, SHOFU INC., Kyoto, Japan) was applied onto the entire cavity surfaces and left undisturbed for 10 seconds, air-dried for 3 seconds, and light-cured for 10 seconds at 1200 mW/cm^2 using premium plus™ (Premium Plus Dental Supplies Inc., NY, USA).

In groups 1 (BE) and 2 (BLS), the restorative materials were applied in two increments of 2 mm each. Each increment was cured for 10 seconds, while in group 3 (BBR), the restorative material was applied in one increment and cured for 10 seconds.

In groups 4 (BE+R) and 5 (BLS+R), a 2 mm piece of fiber reinforcement Ribbond® (Ribbond Inc., WA, USA) of 3 mm width was cut with the specific scissors of the Ribbond® kit. Ribbond® fibers were soaked in a bonding agent (GLUMA® Bond 5, Kulzer GmbH, Hanau, Germany) for 2 minutes before use. Excess bonding agent was gently removed by tapping dry micro brushes on the fibers. The fibers were applied in close contact against the gingival floor, and then a 2 mm increment of the restorative materials was applied. This combination was light-cured for 10 seconds. Another 2 mm increment of the restorative material was applied and light-cured for 10 seconds.

In group 6 (BBR+R), a 2 mm layer of the bulk-fill Giomer was applied, and then Ribbond® fibers were applied and gently placed through the uncured resin composite. Another 2 mm of the bulk-fill Giomer was applied and then the whole restorative material was cured for 10 seconds.

After finishing and polishing, all restorations were exposed to 10,000 thermal cycles between 5°C-55°C with a dwelling time of 30 seconds and a 10 second transfer time using a thermocycling machine (SD Mechatronic Thermocycler, Germany).

All samples were sectioned along the center of the restorations in a buccolingual direction. The gingival floor was analyzed at 50× magnification using a scanning electron microscope (SEM)

(Prisma E SEM, Thermo Fisher Scientific Inc., MA, USA). The total length of the gingival margin was measured by the in-built ruler of scanning electron microscope. The length of the gap (non-continuous) margin was then determined. A margin is classified as a "gapped margin" if the gap was greater than 1 µm wide. The marginal adaptation values were presented as a percentage of the gap over the total margin length of the gingival margin.

Data management and statistical analysis were performed using GraphPad Prism software (version 8.0). Numerical data was presented as mean ± standard deviation (SD) values. Data were explored for normality by checking the data distribution using Shapiro-Wilk test. Comparisons between groups were performed using two way analysis of variance (ANOVA) test followed by Sidak's multiple comparisons test. The significance level was set at $p<0.05$.

RESULTS

The images of SEM of the restorations were analyzed to determine the mean percentage of non-continuous margins for each group. Figure (1) represents an example of the method of calculation continuous margins.

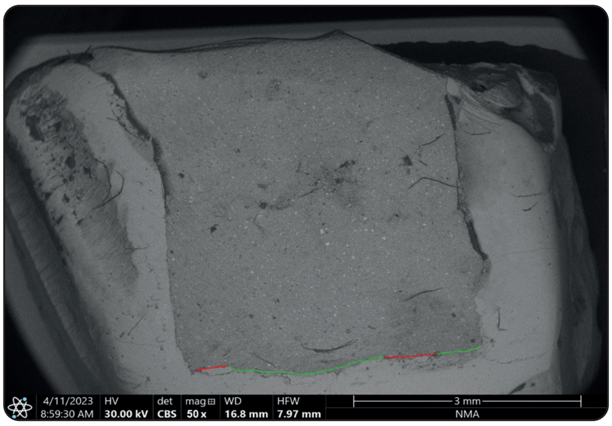

Fig. (1) SEM image (50×) and an example of the quantitative margin analysis. The green lines indicate continuous margin segments, and the red lines indicate non-continuous margin segments

Effect of using Ribbond®

The results of intergroup comparisons are presented in Table (2) and Figure (2). The results showed no significant differences in the gap percentage between the groups with Ribbond® and those without Ribbond® for all restorative materials. BEAUTIFIL II without Ribbond® (BE) showed statistically significant higher gap percentages (29.47±1.88) than with Ribbond® (BE+R) (15.44±1.31) and BEAUTIFIL II LS without Ribbond® (BLS) showed statistically significant higher gap percentages (28.59±1.74) than with Ribbond® (BLS+R) (10.70±0.92), while BEAUTIFL-Bulk Restorative without Ribbond® (BBR) showed statistically significant lower gap percentages (12.30±1.43) than with Ribbond® (BBR+R) (15.20±0.99).

TABLE (2) Intergroup comparisons for marginal gap (%) with and without Ribbond®

	Without Ribbond®	With Ribbond®	p-value
BEAUTIFIL II	29.47±1.88	15.44±1.31	<0.001*
BEAUTIFIL II LS	28.59±1.74	10.70±0.92	<0.001*
BEAUTIFL-Bulk Restorative	12.30±1.43	15.20±0.99	<0.001*

Significance level (p<0.05), *significant

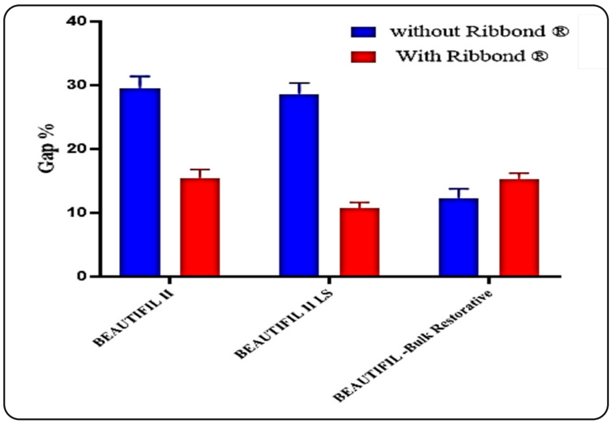

Fig. (2) Bar chart showing average marginal gap (%) with and without Ribbond®

Effect of restorative material

The results of intergroup comparisons are presented in Table (3) and Figure (3). Among without Ribbond® groups, BEAUTIFIL II (BE) recorded the highest gap percentage (29.47±1.88) followed by BEAUTIFIL II LS (BLS) (28.59±1.74). However, the difference between the two groups was statistically non-significant. The least gap percentage was recorded for BEAUTIFL-Bulk Restorative (BBR) (12.30±1.43). Among with Ribbond® groups, BEAUTIFIL II (BE+R) recorded the highest gap percentage (15.44±1.31) followed by BEAUTIFL-Bulk Restorative (BBR+R) (15.20±0.99). However, the difference between the two groups was statistically non-significant. The least gap percentage was recorded for BEAUTIFIL II LS (BLS+R) (10.70±0.92).

TABLE (3) Intergroup comparisons for marginal gap (%) for different restorative materials

	BEAUTIFIL II	BEAUTIFIL II LS	BEAUTIFL-Bulk Restorative	p-value
Without Ribbond®	29.47±1.88^A	28.59±1.74^A	12.30±1.43^B	<0.001
With Ribbond®	15.44±1.31^A	10.70±0.92^B	15.20±0.99^A	<0.001

Different superscript letters indicate a statistically significant difference within the same horizontal row; *significant (p<0.005)

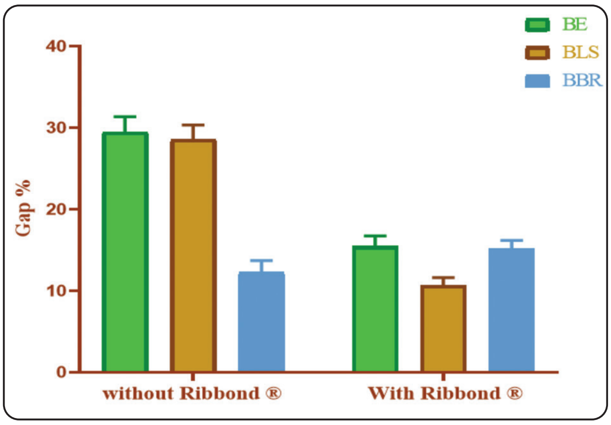

Fig. (3) Bar chart showing average marginal gap (%) for different restorative materials

DISCUSSION

For the past two decades, polyethylene fiber ribbons have been utilized to reinforce restorations in large posterior cavities. One example of these commercially available polyethylene fiber ribbons is the Ribbond® system. The Ribbond® system is formed from a dense network of intersection fibers which may increase fracture toughness, flexural stresses and stop any cracks in the restorations[44]. Several studies have assessed the effects of using the Ribbond® system on the performance of large resin composite restorations[45]. However, as far as we know, this is the first research to investigate the effect of adding the Ribbond® fibers on the marginal adaptation of three Giomer restorative materials.

Usually, polyethylene fiber ribbons are inserted using the "wallpapering" technique. The term "wallpapering" describes the clinical technique of applying the fibers to cover the lateral walls of the prepared cavity, especially in class I because the risk of debonding is higher at the cavity walls due to a high C factor ratio[33]. However, this study was carried out to assess the marginal adaptation at the gingival floor in class II cavities, therefore, the Ribbond® system was only applied to the gingival floor. Improper adaptation at the tooth/restoration interface is due to the formation of multiple stresses induced by polymerization shrinkage, thermal fluctuation, and occlusal load[33].

The marginal adaptation of the gingival margins of the restorations was assessed using SEM and expressed in terms of percentage of gapped margin/ total margin. This method was chosen because it is reliable and truly quantitative method as it avoids the shortcomings of the classical microleakage assessment methods[19, 43].

Randomized controlled clinical trials are regarded as the best way to evaluate the quality of new restorative materials and techniques. Nonetheless, there are several restrictions that prevent this type of research from being used on a regular basis. Difficulties in standardization due to operator variability and patient differences, noncompliance of patients with recall visits, time consumption, and high cost are among these restrictions[46-48]. Therefore, in vitro simulation continues to be a useful method for predicting of the performance of restorative materials. Thermal cycling is a commonly used procedure to simulate the ageing process that occurs clinically[49]. In the current investigation, all restorations were thermocycled for 10,000 cycles between 5°C-55°C which equates to one year of intraoral ageing[50,51].

Despite the continuing advances in resin-based restorative materials, polymerization shrinkage remains a main problem[52]. Polymerization shrinkage creates stresses that can deteriorate the bond between the restoration and cavity walls, leading to marginal leakage, postoperative sensitivity, staining, and recurrent caries[53]. These complications are commonly encountered problems, specially at the gingival margin of Class II restorations[54]. This is accordance with the findings of this study, that revealed that marginal leakage was unavoidable for all tested restorative materials. However, the findings of this study showed that integrating polyethylene fibers ribbon within the restoration improved the marginal adaptation except for BBR, which showed an increase in the gap percentage with the use of the Ribbond® system; therefore, the first null hypothesis was partially accepted.

During polymerization, light activation of resin based restorative materials causes free radical polymerization of the organic matrix[55]. This transforms the pre-gel phase of the resin matrix into a more viscous state. Until this stage, the material is capable of relieving contraction stresses[56]. However, with further polymerization, the material transforms into a post-gel phase, where it becomes a hard mass with a higher modulus of elasticity, so volumetric contraction stresses cannot be relieved[57, 58].

Clinically, after the activation of restorative material by a light curing device, the restoration hardens almost immediately, and a little time is available to relieve pre-gel shrinkage stresses[56]. Several modifications in the photoactivation protocols were developed to reduce polymerization shrinkage stresses by slowing the polymerization rate and thus allowing additional time for pre-gel shrinkage. These modifications involved the soft-start and pulse-delay curing modes. However, none of these modifications succeeded in achieving the required effects[59, 60]. Another approach reducing the overall shrinkage of restoration was to reduce the bulk of restorative material by applying a liner under the restorative material. Several liners were proposed, including flowable resin composite, resin-modified glass ionomer, and calcium silicate[61-63]. Some authors advocated the use of inserts to reduce the bulk of restorative material[60, 64, 65]. Despite the improvement in marginal sealing that was reported with the use of inserts, concerns about the bonding between these inserts and the organic resin composite matrices have limited their use[19]. The current study examined a new method of integrating inserts. The Ribbond® fibers was used as an insert[66].

Bulk-fill resin composites can be cured sufficiently up to 4-5 mm without an increase in polymerization shrinkage stresses, which could be gained through their enhanced light transmission[67, 68]. This allows proper bond strength to the gingival margin of the restoration and reduces the marginal gaps[69, 70] which could explain the significantly better adaptation of the bulk-fill group in comparison to the other groups before application of the Ribbond® fibers.

The incremental filling technique for resin composite restorations is a well-established technique[30, 71]. To attain adequate polymerization of resin composite restorations, zero distance between the restoration and the light curing tip is required[72]. In this study, at least 4 mm existed between the light curing tip and the bottom of the first layer, which may jeopardize the degree of polymerization[72-74], and consequently the bond strength to gingival margins, and this could explain the significant worst results of the BEAUTIFIL II and BEAUTIFIL II LS groups in comparison to the BEAUTIFIL-Bulk Restorative group. The slightly better performance of BEAUTIFIL II LS than BEAUTIFIL II is expected according to the manufacturer's recommendation.

The capability of the Ribbond® system to enhance the marginal adaptation at the gingival margin in Class II restorations could be explained in three aspects. First, the insertion of the Ribbond® fibers into the restorative material caused a reduction in the restorative material's mass. The reduced restorative material mass contains a smaller amount of the shrinkable organic matrix, leading to a decrease in the total amount of volumetric shrinkage[54, 75]. Second, the integration of the fibers with the first layer of the restorative material forms a single mass that resists pulling away from the floor[54,76]. Third, the close adaptation of the fiber ribbon against the floor results in a thin "bond line" between the fiber ribbon and the cavity surface that acts as an energy dissipating mechanism, mitigating the mechanical loading[19, 45].

These findings agreed with the previous studies[33,43]. These studies affirmed that the use of Ribbond® fibers improved the marginal adaptation of the restoration. However, the marginal adaptation of bulk-fill Giomer (BEAUTIFIL-Bulk Restorative) did not improve. Rather, the gap ratio significantly increased. This could be explained by a reduction in transparency. The existence of gaps that might scatter or absorb light may cause reduced transparency. Furthermore, if two perfectly transparent materials are combined into a composite restoration and their refractive indices are not identical, their refraction, reflection, and scattering effects will differ, resulting in a loss of visual clarity and transparency, which is the basis of proper polymerization[67, 68, 76]. As a result, a weak bond to the gingival margins is expected[69, 70]. In contrast to these results, *O'Brien et al., 2014*[76] showed that polymer-polymer composite provide good transparency. This may be because they used a monofilament polymer ribbon while a dense network of intersection fibers was used in this study.

With the use of the Ribbond® system, the low-shrinking nanohybrid Giomer (BEAUTIFIL II LS) showed better marginal adaptation than the two other restorative materials. Therefore, the second null hypothesis was rejected. The lowest marginal gap ratio recorded with BEAUTIFIL II LS could be attributed to the inclusion of a novel steric repulsion structure (SRS) monomer. SRS reduces polymerization shrinkage by molecular steric repulsion, leading to a more stable and durable restoration microstructure. In addition, the balance between the SRS monomer and the multi-filler phase produces a sculptable paste that can adapt easier to the cavity walls. All the abovementioned structural modifications in BEAUTIFIL II LS result in less volumetric shrinkage of 0.85% in comparison to 2%–5% of conventional resin composites, according to the manufacturer's claims[77]. These findings agreed with some previous studies[78-80] that reported improved adaptation and less marginal leakage values with the use of BEAUTIFIL II LS.

CONCLUSIONS

Within the constraints of this investigation, it is possible to conclude that:

1- The Ribbond® system could significantly improve the marginal adaptation of incrementally-packed Giomer restorative material at the gingival margins of class II cavity preparations.

2- Bulk-fill Giomer provides better adaptation at the gingival margins in comparison to incrementally-packed Giomer in class II cavity preparations.

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