ASDJ
AINSHAMS DENTAL
JOURNAL

Print ISSN 1110-7642
Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
September 2024 • Vol. 35

Effect Of Various Types, Placement Techniques and Aging of Composite Resin on The Fracture Resistance of Upper Premolars

Monica Bassem Bertie[1], *Hanan Abdel Aziz Niazi*[2], *Mohamed Amr Kamel*[3]

Aim: to assess the influence of multiple composite resin types, application methods, and aging on the fracture resistance of premolars with Mesio-occlusal-distal (MOD) cavities.

Materials and methods: Forty sound upper premolars with standardized MOD cavities, were randomly distributed into two main groups (n=20) according to the type of resin composite. Then, each group of them was distributed into two subgroups (n=10) according to the application methods. Each subgroup was further distributed into two divisions (n=5) according to the effect of aging.

G-premio adhesive system was applied in accordance with the guidelines provided by the supplier. Restorations were grouped: Group 1 (Incremental G-aenial posterior), Group 2 (Bulk-fill EverX posterior), Group 3 (Incremental G-aenial Injectable), and Group 4 (Bulk-fill EverX flow).

Half the number of each of the 4 groups (n=20) was randomly chosen and underwent 5000 cycles of thermocycling (between 5 and 55 °C). The specimens were affixed to a 5 kN load cell on an Instron 3345 computer-controlled material testing apparatus.

Results: Group 4 gave the greatest fracture resistance value in the aged groups and Group 2 gave the greatest fracture resistance value in the non-aged groups. While Group 1 gave the least value of fracture resistance in the aged groups.

Conclusions: The bulk-fill short fiber reinforced composites, used as restoration of premolars with MOD cavities, could have a significant reinforcing effect on the treated teeth more than the incremental conventional technique.

.

Keywords: Bulk fill composite, fiber reinforced composite, injectable composite, thermocycling.

1- Demonstrator, Operative Dentistry Department, Ain Shams University.
2- Professor of Operative Dentistry Faculty of Dentistry, Ain Shams University.
3- Associate Professor of Operative Dentistry Faculty of Dentistry, Ain Shams University.
Corresponding author: Monica Bassem Bertie, email: monicasidhom@dent.asu.edu.eg

Introduction

Composite restorations are widely used worldwide.[1] Conservative dentistry aims to replace lost hard tooth structure with restorative materials that are biologically and mechanically similar to the surrounding tissues.[2] Resin composites have gone through a number of developments, including advancements in filler technology.[3]

The two most serious drawbacks of resin composite fillings are polymerization shrinkage stresses, in addition to insufficient fracture resistance in comparison to the dentin.[4] Fractures are linked to the mechanical qualities of the materials, cavity configuration, amount of the remaining tooth structures and the patient's occlusion.[5] Stresses at the boundary between a tooth and a filling are created by polymerization shrinkage as the composite's elastic modulus increases during curing. Signs of stress include bond failure, cuspal flexure, and enamel cracking. Restoration failure and the need for repair can result from these signs.[6]

Flowable composites are usually weaker than conventional composites and contain less fillers. A novel type of highly filled flowable composite was developed. It stands out for having a high viscosity and superior mechanical qualities than traditional composite restorative materials. [7,8]

This composite is called an "injectable composite" because of its consistency and 69 weight percent load of nano-sized filler particles. Compared to traditional paste-type composites, the highly filled flowable resin composition includes nano-sized fillers where it could be used in stress-loading restorations.[7,9]

In order to mimic dentine's stress-absorbing characteristics, short fiber-reinforced composites (SFRCs) were introduced to the market in 2013. Furthermore, advancements in SFRCs' handling characteristics have allowed them to eventually enter the field of restorative materials on a larger scale. SFRCs are found in both consistencies, packable and flowable.[10] The SFRC material is intended to be used as a bulk base for both vital and non-vital teeth restorations in high-load bearing areas. It is composed of inorganic particle fillers, e-glass fibers that are dispersed at random, and a resin matrix.[2] Comparing SFRC to traditional particle filler restorative composite resins, marginal microleakage was reduced due to the considerable control of polymerization shrinkage stresses by fiber orientation as well as enhanced fracture toughness.[11]

Fracture resistance, which is based on the material's ability to withstand the spread of cracks caused by internal faults which may cause bulk breakages within the restoration or tiny fractures around the edges of the filling.[12] When evaluating the aging of various dental materials, the clinical procedure of aging is usually recreated in the lab utilizing artificial aging approaches.[13]

Accordingly, this study intended to investigate the impact of various composite resin types, application techniques, and aging regarding the upper premolars with MOD preparations' resistance to fracture.

Materials and methods

Sample size calculation

A power analysis was designed to have adequate power to apply a statistical test of the null hypothesis that there was no difference would be found between different groups regarding fracture resistance. The predicted sample size (n) was a total of (40) samples (i.e.10 samples per group). Sample size calculation was performed using G*Power version 3.1.9.7. [14]

Specimens grouping

According to the kind of composite resin restoration, 40 teeth were distributed at random into two main categories (n = 20). Then, according to the method used for applying the resin composite restoration, each of them was distributed into 2 subcategories (n=10). Then, according to the outcome of thermocycling, each subgroup was further distributed into two groups (n=5). {Figure 1}

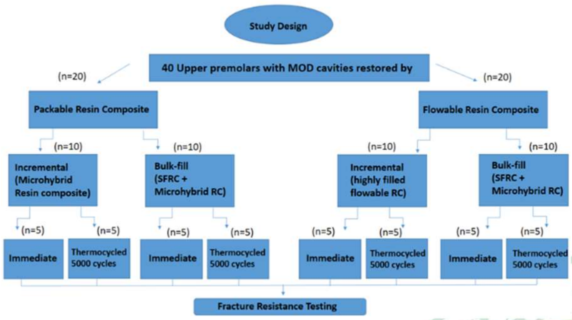

Figure 1: illustration of the study design

Sample selection

Guided by the rules of the ethical committee of the faculty of dentistry Ain shams university with ethical approval code (FDASU-Rec EM012211), a total of 40 human upper premolars that had been extracted for periodontal or orthodontic reasons were chosen at random from a range of individuals between the ages of 18 and 65. The samples were chosen with a rough resemblance in crown size, length, and shape in order to achieve standardization. Their measurements were 7 ± 0.5 mm for mesio-distal width and 8 mm ± 0.5 mm for bucco-lingual width. Using a digital caliper, all dimensional measurements were made at the proximal cementoenamel junction level.

The teeth were inspected to ensure that the measurements of the buccolingual, mesiodistal, and anatomic crown length were around uniform. The absence of visible caries or cracks in the roots, as well as the lack of any prior endodontic treatment, posts, crowns, or resorptions, were the criteria for inclusion.

Samples preparation

The samples were immersed in 5.25% NaOCl for five minutes, the samples were placed in a 0.9% saline until they were utilized.[4] Using self-curing acrylic resin, each premolar was placed into plastic Teflon molds at a level 3 mm below their cemento-enamel junction and parallel to their identified root long axis. Silicon indices were done to the occlusal aspects of the samples and an occlusal stamp was taken using flowable resin composite for the purpose of occlusal surface anatomy and cuspal inclinations reproduction standardization.

Standardized Tooth Preparation

The same skilled operator performed standardised MOD cavity preparation on the teeth, measuring 2.5 mm in width and 5 mm in depth from the cavo-surface boundary, as detailed by Forster et al.[15] In order to standardize cavity preparation, a pencil was used to mark a line on each tooth's two proximal surfaces at the cemento-enamel junction. Two lines were then marked to indicate the inter-cuspal distance, starting from the tip of the cusps and ending at the cemento-enamel junction. The cavity's measurements were as follows: the buccolingual width was 2.5 mm, and the occluso-cervical depth was 5 mm.

A fissure carbide bur with a rounded tip (Healthico, USA) was utilized for the preparation. It was first placed at the midline of the teeth's occlusal surface and used in a high-speed handpiece (sirona, Dentsply, USA) with copious water coolant. Once every four preparations, the carbide bur was replaced with a new one. After the cavity walls were created parallel to the tooth's long axis, the cavity borders were finished using a high-speed finishing stone with a yellow coded (Healthico, USA). A periodontal probe was used to measure the cavity's depth from the cavo-surface margin. The cavity width was (2.5 mm) while the depth was (5 mm).

Cavities restoration

Following the preparation, each cavity went through the same adhesive procedure and was washed with water and allowed dried using a 3-way syringe. A Tofflemire matrix band (Tofflemire, kerr, UK) was applied. The enamel was rinsed with water and allowed to air dry after being selectively acid-etched for 15 seconds using 37% phosphoric acid (Eco-Etch, Ivoclar Vivadent). As directed by the manufacturer, universal adhesive (G-Premio Bond (GPB) GC Corp. Tokyo, Japan) was placed, left untouched for 10 sec, dried for 5 sec at maximum air pressure, then photopolymerized for 10 sec. The Radii Plus, SDI LED photo-polymerization unit was utilized, and it ran at 1500 mW/cm² of light intensity. Radiometer (X LED Light Curing Meter (5600029) – SDI) was used to assess the light intensity output every ten seconds. Restoring the preparations was as following:

Group 1 (Control Group) (n=10): By applying (G-aenial Posterior, GC Japan) in 1 mm increments to the approximate walls of the matrix, the cavity was converted into a class I utilizing the centripetal method. For 20 seconds, this increment was light-cured. (G-aenial Posterior, GC Japan) was applied in sequential 2 mm thick oblique incrementations to reconstruct the middle portion of the cavity. For the last occlusal layer, before curing, a piece of teflon tape was placed on the occlusal aspect and the occlusal stamp was reseated over the occlusal surface to reconstruct the original occlusal anatomy of the tooth that was existing before cavity preparation. The occlusal stamp was removed, and initial photopolymerization was done for 5 seconds before removal of the Teflon tape. After that, curing resumed for 15 seconds. Photopolymerization for 20 sec was done to the mesial and distal surfaces after the tofflemire matrix was removed.

Group 2 (n=10): The middle portion of the cavity was filled with 3 mm bulk of packable SFRC (everX posterior, GC Europe) after the approximate portion had been rebuilt in the same manner as group 1. The composite was then photopolymerized for 20 seconds. (G-aenial Posterior, GC Japan) was applied occlusally in 2 mm-thick oblique incrementations using the occlusal stamp as previously mentioned in group 1. The mesial and distal aspects, following matrix removal, were photopolymerized as previously described.

Group 3 (n=10): The cavity became a class I following the centripetal method when (G-aenial Universal Injectable Flow, GC Japan) was inserted to the approximate walls of the matrix in a single increment. For 20 seconds, this layer was light-cured. Oblique incrementation was done using 2 mm layers of (G-aenial Universal Injectable Flow, GC Japan) (GUF). For the final occlusal portion, application of final oblique GUF layer using the occlusal stamp as previously mentioned in group 1. The mesial and distal aspects, following matrix removal, were photopolymerized as previously described.

Group 4 (n=10): The middle portion of the preparation was filled using a bulk application (3 mm) of flowable SFRC (everX Flow Bulk, GC Japan) after the approximate portion had been restored as group 1. The composite was then photopolymerized for 20 seconds. The occlusal part was rebuilt using (G-aenial Posterior, GC Japan) same as described in group 2. The mesial and distal aspects and each layering, following matrix removal, were photopolymerized as previously described.

Finishing was done by a yellow coded high speed flame finishing stone (Healthico, USA) and were polished using Sof-Lex™ discs (3M ESPE, USA) in a low-speed handpiece. Before being subjected to mechanical testing, every specimen was kept for a full day in distilled water.

Thermocycling

Half the number of each restored group of the 4 groups (n=5), a total of (n=20) was randomly chosen and thermocycled for 5000 cycles (between 5 and 55 °C with a dwell time of 30 s and a transfer time of 15 s) reflecting six months of clinical function according to Gale and Darvell.[16]

Fracture resistance testing

Every sample was mounted separately on an Instron 2710-115 computer-controlled universal material testing apparatus. Each specimen had an occlusal load cell affixed to it, and computer software was used to record the data. Samples were fastened to the testing machine's lower fixed compartment by tightening screws. The fracture resistance test was conducted using a metal shaft with a rounded end (4 mm diameter) connected to the top adjustable chamber of the testing device machine.

This shaft makes a compressive axial loading that comes in contact with the palatal slopes of the buccal cusp and buccal slopes of the palatal cusp at a crosshead speed of 1 mm/min.[3] An audible crack indicated the load at failure, and a computer program was used to record the load-deflection curve, which showed a steep decline. The load which was needed to break was added in newton (N).

Statistical analysis

Values of the mean and standard deviation (SD) were used to present numerical data. They were examined for normality using the Shapiro-Wilk test and the data distribution. Three-way ANOVA was used to analyze the data, which had a parametric distribution. The three-way model's pooled error term was used to compare basic effects. P-values were modified using the Bonferroni modification to account for multiple comparisons. A significance threshold of $p<0.05$ was applied. R statistical analysis software, version 4.3.1 for Windows, was used to conduct the statistical analysis.

Results

Fracture variables on the fracture resistance ($p=0.004$). The study's findings demonstrated that the bulk-fill flowable SFRC (EverX flow) had the highest fracture resistance value (1504.92±5.46) N in the aged groups and the bulk-fill packable SFRC (EverX posterior) had the highest fracture resistance value (1129.83±112.15) N in the non-aged groups. While (group 1), showed the least value of fracture resistance (681.68±51.15) N in the aged groups. (Tables 1,2) {Figure 2}

Table 1: Effect of different variables and their interactions on fracture strength (N)

Variable	Sum of Squares	df	Mean Square	f-value	p-value
Material consistency	184548.15	1	184548.15	13.39	**<0.001***
Application technique	1369061.42	1	1369061.42	99.36	**<0.001***
Aging	1735.52	1	1735.52	0.13	**0.725ns**
Material consistency *application technique	183142.90	1	183142.90	13.29	**<0.001***
Material consistency *aging	513687.27	1	513687.27	37.28	**<0.001***
Application technique*aging	82336.93	1	82336.93	5.98	**0.020***
Material consistency *application technique*aging	132643.36	1	132643.36	9.63	**0.004***

df =degree of freedom*; significant (p≤ 0.05) ns; non-significant (p>0.05)

Table 2: Intergroup comparisons, mean and standard deviation values of fracture strength (N) for samples with and without aging.

Material consistency	**Application technique**	**Fracture strength (N) (mean±SD)**		**p-value**
		Non-aged	**Aged**	
Packable	**Bulk-fill**	1129.83 ±112.15	891.92± 179.44	**0.036***
	Incremental	870.72± 167.09	681.68± 51.15	**0.042***
Flowable	**Bulk-fill**	1059.19 ±143.00	1504.92 ±5.46	**<0.001***
	Incremental	759.76± 105.41	793.67± 57.74	**0.546ns**

*; significant (p≤0.05) ns; non-significant (p>0.05)

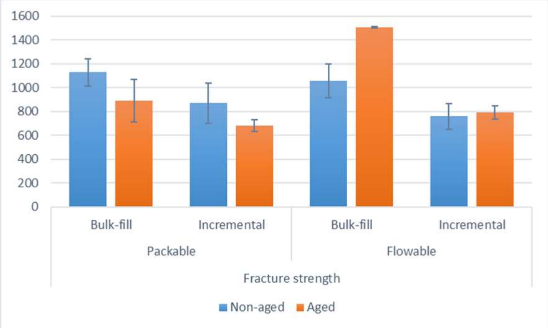

Figure 2: Bar chart with mean and standard deviation values of fracture strength (N) for samples with and without aging

Discussion

The choice of the optimum material and method for the restoration of deep MOD cavities in upper premolars depends on the functional needs and the amount of tooth structure that remains.[2]

The usage of composite materials in big cavities has increased since the introduction of fiber-reinforced composite technology. The vendor of two recently released SFRCs (everX posterior and everX flow, GC) claims that the short fiber structure of this material produces a level of hardness that is comparable to dentin when coated with a layer of universal restorative composite. It also shrinks very little, which keeps fractures from happening.[17]

In order to minimize microleakage and polymerization stress, incremental methods have been recommended as the best way to reconstruct a big cavity using composite.[18] A bulk-fill composite should have adequate mechanical characteristics because bulk filling is primarily required in the posterior, stress-bearing parts.[19] Flowable composites were formerly thought to be unsuitable for repairing these areas; as a result, questions have been raised, particularly regarding the flowable base bulk-fill composites.[20] Strength, toughness, and wear resistance are important features in the posterior region of composites, even if there is little association between these attributes and their clinical performance.[21]

According to Siso et al. [22], the loss of marginal ridges in MOD preparation without restoration resulted in a 50% reduction in tooth strength when compared to healthy premolar teeth. To further replicate the worst clinical scenario, the MOD cavity in this study was constructed in relation to the teeth measurements.

Therefore, this study examined using a variety of composites (highly filled flowable composite, packable micro-hybrid composite, packable and flowable fiber-reinforced composite), application techniques (incremental and bulk-fill), and the impact of aging through thermocycling to check their influence on upper premolars fracture resistance.

Regarding the effect of various types and consistencies of composite resin, the packable resin composite (RC) materials (everX posterior and g-aenial posterior) had higher fracture resistance than the flowable RC materials (everX flow, g-aenial universal) in the non-aged groups, yet the difference wasn't significant. On the other hand, the flowable RC materials in the aged groups had significantly higher fracture resistance than the packable RC materials. Some flowable composites have higher fracture resistance ratings than others. This could be because these materials contain more resin matrix, which, as suggested by Bonilla et al.[23] may reduce the high stress at the crack tip by plastic deformation.

The bulk-fill flowable SFRC (everX flow, GC) and {G-aenial Universal Injectable, GC} (GUF) were the flowable resin composite materials employed in our investigation. GUF is appropriate for direct restorations without further covering because it includes 69 weight percent filler. To give the best viscosity and handling qualities for restorations, the universal flowable composite matrix's composition and the filler surface's pretreatment are altered.[24] The filler content of GUF includes nanoparticles. The greatest findings for GUF were reported by Lazaridou et al.[25], who noted that new flowable materials with higher filler volumes had better wear resistance than some conventional composites.

Furthermore, our outcomes agree with the clinical conclusions made by Lawson et al. [26]. It should be noted that the flowable composite they utilized in their trial had a smaller cavity (class I) and that, after two years of usage, its clinical efficacy was comparable to that of a conventional composite.

The new flowable micrometer size SFRC (everX Flow), bulk-fill flowable SFRC (everX flow, GC), demonstrated noticeably greater fracture resistance than the other groups. This is consistent with research by Garoushi et al.[27], which found that bulk-fill flowable SFRC covered with very little composite had substantially higher fracture resistance than filling with conventional composite.

New technologies have been developed, such as bulk-fill composites made of resin-based material that could cure in one step at a thickness increase of 4 to 5 mm. Moreover, by lowering the polymerization shrinkage, they are made to lessen cuspal flexure.[28,29]

From the results of this study, regarding the effect of application technique of resin composite, the bulk-filled materials had a substantially greater fracture resistance value than the incrementally filled materials in all groups. This was consistent with the findings of an investigation by Rossato et al.[28] Where when molars were incrementally restored using traditional composite as opposed to bulk-fill composites, they discovered noticeably lower values. Bulk-fill composites may be responsible for this, as they improve fracture resistance while reducing cusp deformation, post-gel shrinkage, and shrinkage stresses.

In a prior investigation, Garoushi et al. demonstrated how short fiber fillers might halt the spread of cracks and boost the resin composite's resistance to fracture.[30] This was consistent with research by Lassila et al. and Shouha et al., in contrast to traditional particulate filler resin composites, they reported that the experimental short fiber reinforced flowable resin composite had improved fracture toughness and flexural properties.[31,32]

Every day, while consuming food and beverages, restorative materials undergo thermal cycling. The usage of 500 thermal cycles between 5°C and 55°C is appropriate to model the short-term aging of dental materials, according to ISO 11405 standards.[33] The effect of thermocycling on composites can actually be more detrimental than that of water alone because of the increased destruction of the polymeric network brought on by hydrothermal ageing.[34] The thermal cycling in this investigation was 5000 cycles, which, according to Gale and Darvell, corresponds to six months of clinical function.[16]

Based on the results of our study, the non-aged packable resin composite samples had a significantly higher value of fracture resistance than aged samples. Additionally, the bulk-fill flowable SFRC had significantly higher fracture resistance value after aging. It is known that water uptake influences the polymer's elastic modulus; this, along with hygroscopic expansion, may help to ease the internal tensions caused by limited shrinkage.[35]

The restorative material's dimensional stability is impacted by water sorption where low water sorption is preferred.[36] Bis-MEPP based flowable resin composites as (G-ænial Universal Injectable and everX-Flow) have low water sorption, where bis-MEPP is considered a rigid monomer which is more hydrophobic [37] compared with bis-GMA monomer and dimethacrylate co-monomers in everX posterior and G-aenial posterior composite respectively. Therefore, the low water sorption of the bis-MEPP based flowable resin composites may be the cause for their increased fracture resistance after aging.

The impact of thermocycling on the degree of conversion (DOC); the post-curing effect and its association with the mechanical characteristics of the flowable composite resin; could also account for the rise in fracture toughness of the flowable composite resin after aging. The release of unreacted monomers, which rises with heat shocks and storage duration, could be the reason why the DOC rises gradually.[34]

Finally, the null hypothesis was refused, as the various types, placement techniques and aging did affect the fracture resistance and the highest fracture strength values were obtained with the bulk-fill flowable SFRC group.

Conclusions

Within the limitations of this study, it could be concluded that:

1. The flowable resin composite materials had a higher value of fracture resistance than the packable resin composite materials after aging.
2. The bulk-filling technique, especially with short fiber reinforced composites, showed improved fracture resistance values than the incremental conventional technique.
3. Thermocycling at (5000 cycles) deteriorates the fracture strength of packable composite resin materials while it enhanced the fracture strength of the flowable composite resin materials.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare no conflict of interest

References

1. Kaisarly D, Gezawi ME.: Polymerization shrinkage assessment of dental resin composites: a literature review. Odontology. 2016 Sep;104(3):257-70. doi: 10.1007/s10266-016-0264-3. Epub 2016 Aug 19. PMID: 27540733.

2. Garoushi S, Gargoum A, Vallittu PK, Lassila L. : Short fiber-reinforced composite restorations: A review of the current literature. J Investig Clin Dent. 2018 Aug;9(3):e12330. doi: 10.1111/jicd.12330. Epub 2018 Feb 25. PMID: 29479830.

3. Farahanny, Wandania & Dennis, Dennis & Sihombing, Desilia.: Fracture Resistance of Various Bulk-fill Composite Resins in Class II MOD Cavity on Premolars: An In Vitro Study. World Journal of Dentistry. (2019) 10. 166-169. 10.5005/jp-journals-10015-1637.

4. Fráter M, Sáry T, Vincze-Bandi E, Volom A, Braunitzer G, Szabó P B, Garoushi S, Forster A.: Fracture Behavior of Short Fiber-Reinforced Direct Restorations in Large MOD Cavities. Polymers (Basel). 2021 Jun 23;13(13):2040. doi: 10.3390/polym13132040. PMID: 34201423; PMCID: PMC8271361.

5. Veloso SRM, Lemos CAA, de Moraes SLD, do Egito Vasconcelos BC, Pellizzer EP, de Melo Monteiro GQ. : Clinical performance of bulk-fill and conventional resin composite restorations in posterior teeth: a systematic review and meta-analysis. Clin Oral Investig. 2019 Jan;23(1):221-233. doi: 10.1007/s00784-018-2429-7. Epub 2018 Mar 28. PMID: 29594349.

6. Kwon Y, Ferracane J, Lee IB.: Effect of layering methods, composite type, and flowable liner on the polymerization shrinkage stress of light cured composites. Dent Mater. 2012 Jul;28(7):801-9. doi: 10.1016/j.dental.2012.04.028. Epub 2012 May 9. PMID: 22575738.

7. Jang JH, Park SH, Hwang IN.: Polymerization shrinkage and depth of cure of bulk-fill resin composites and highly filled flowable resin. Oper Dent 2015; 40:172–180.

8. Nazari A, Sadr A, Saghiri MA, et al.: Non-destructive characterization of voids in six flowable composites using swept-souce optical coherence tomography. Dent Mater 2013;29:
278–286.

9. Sabbagh J, Ryelandt L, Bacherius L, et al.: Characterization of the inorganic fraction of resin composite. J Oral Rehabil 2004; 31:1090–1101

10. Keulemans F, Garoushi S, Lassila L.: Fillings and core build-ups (Book Chapter). In: Vallittu P, Özcan M, eds. A Clinical Guide to Principles of Fibre Reinforced Composites (FRCs) in Dentistry. Duxford: Woodhead Publishing; 2017:131-163.

11. Garoushi S, Vallittu PK, Watts DC, Lassila LVJ. Polymerization shrinkage of experimental short glass fiber reinforced composite with semi-inter penetrating polymer network matrix. Dent Mater . 2008; 24:211–5.

12. Moosavi H, Zeynali M, Pour ZH.: Fracture resistance of premolars restored by various types and placement techniques of resin composites. Int J Dent. 2012; 2012:973641. doi: 10.1155/2012/973641. Epub 2012 May 14. PMID: 22666255; PMCID: PMC3359818.

13. Mohamed M. Abdul-Monem; Ibrahim L. El-Gayar; Fayza H. Al-Abbassy.: Effect of aging on the flexural strength and fracture toughness of a fiber reinforced composite resin versus two nanohybrid composite resin. Alexandria Dental Journal, 41, 3, 2016, 328-335. doi: 10.21608/adjalexu.2016.58048

14. Faul, Franz, et al. "G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences." Behavior research methods 39.2 (2007): 175-191.

15. Forster A, Braunitzer G, Tóth M, Szabó BP, Fráter M.: In Vitro Fracture Resistance of Adhesively Restored Molar Teeth with Different MOD Cavity Dimensions. J Prosthodont. 2019 Jan;28(1):e325-e331. doi: 10.1111/jopr.12777. Epub 2018 Mar 5. PMID: 29508474.

16. Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. J Dent. 1999 Feb;27(2):89-99. doi: 10.1016/s0300-5712(98)00037-2. PMID: 10071465.

17. Ozsevik AS, Yildirim C, Aydin U, Culha E, Surmelioglu D. Effect of fibre-reinforced composite on the fracture resistance of endodontically treated teeth. Aust Endod J. 2016 Aug;42(2):82-7. doi: 10.1111/aej.12136. Epub 2015 Nov 27. PMID: 26611674.

18. S-H Han, S-H Park; Incremental and Bulk-fill Techniques With Bulk-fill Resin Composite in Different Cavity Configurations. Oper Dent 1 November 2018; 43 (6): 631–641. doi: https://doi.org/10.2341/17-279-LR.

19. Leprince JG, Palin WM, Vanacker J, Sabbagh J, Devaux J, Leloup G.: Physico-mechanical characteristics of commercially available bulk-fill composites. J Dent 2014; 42:993-1000.

20. Moszner N, Fischer UK, Ganster B, Liska R, Rheinberger V. Benzoyl germanium derivatives as novel visible light photoinitiators for dental materials. Dent Mater 2008; 24:901-907.

21. Ferracane JL.: Resin-based composite performance: Are there some things we can’t predict? Dent Mater 2013; 29:51-58.

22. Siso, S. H., Hürmüzlü, F., Turgut, M., Altundaşar, E., Serper, A. and Er, K. Fracture resistance of the buccal cusps of root filled maxillary premolar teeth restored with various techniques. Int endo j. 2007; 40(3):161–168.

23. Bonilla ED, Yashar M, Caputo AA. Fracture toughness of nine flowable resin composites. J Prosthet Dent. 2003 Mar;89(3):261-7. doi: 10.1067/mpr.2003.33. PMID: 12644801.

24. Sumino N, Tsubota K, Takamizawa T, Shiratsuchi K, Miyazaki M, Latta MA, et al. Comparison of the wear and flexural characteristics of flowable resin composites for posterior lesions. Acta Odontol Scand. 2013; 71:820–7.

25. Lazaridou D, Belli R, Petschelt A, Lohbauer U. Are resin composites suitable replacements for amalgam? A study of two-body wear. Clin Oral Investig. 2015; 19:1485–92.

26. Lawson, N.C.; Radhakrishnan, R.; Givan, D.A.; Ramp, L.C.; Burgess, J.O. Two-year Randomized, Controlled Clinical Trial of a Flowable and Conventional Composite in Class I Restorations. Oper. Dent. 2015, 40, 594–602

27. Garoushi, S.; Sungur, S.; Boz, Y.; Ozkan, P.; Vallittu, P.K.; Uctasli, S.; Lassila, L. : Influence of short-fiber composite base on fracture behavior of direct and indirect restorations. Clin. Oral Investig. 2021, 1–10.

28. Rosatto CM, Bicalho AA, Veríssimo C, Bragança GF, Rodrigues MP, Tantbirojn D, Versluis A, Soares CJ.: Mechanical properties, shrinkage stress, cuspal strain and fracture resistance of molars restored with bulk-fill composites and incremental filling technique. J Dent. 2015 Dec;43(12):1519-28. doi: 10.1016/j.jdent.2015.09.007. Epub 2015 Oct 9. PMID: 26449641.

29. Sengun, A., Cobankara, F. K. and Orucoglu, H. Effect of a new restoration technique on fracture resistance of endodontically treated teeth. Dental Traumatology. 2008; 24(2):214–19

30. Garoushi S, Vallittu PK, Lassila LVJ. Short glass fiber reinforced restorative composite resin with semi-interpenetrating polymer network matrix. Dent Mater. 2007; 23:1356–62.

31. Lassila L, Keulemans F, Säilynoja E, Vallittu PK, Garoushi S. Mechanical properties and fracture behavior of flowable fiber reinforced composite restorations. Dent Mater. 2018;34:598–606.

32. Shouha P, Swain M, Ellakwa A. The effect of fiber aspect ratio and volume loading on the flexural properties of flowable dental composite. Dent Mater. 2014; 30:1234–44.

33. International Organization for Standardization. ISO/TS 11405 Dentistry -- Testing of adhesion to tooth structure. 3rd ed. Geneva: International Organization for Standardization; 2015.

34. Gonçalves L, Filho JD, Guimarães JG, Poskus LT, Silva EM. Solubility, salivary sorption and degree of conversion of dimethacrylate-based polymeric matrixes. J Biomed Mater Res B Appl Biomater. 2008 May;85(2):320-5. doi: 10.1002/jbm.b.30949. PMID: 17973246.

35. Alshabib A, Algamaiah H, Silikas N, Watts DC. Material behavior of resin composites with and without fibers after extended water storage. Dent Mater J. 2021 May 29;40(3):557-565. doi: 10.4012/dmj.2020-028. Epub 2021 Mar 18. PMID: 33731541.

36. Heintze SD, Zimmerli B. Relevance of in vitro tests of adhesive and composite dental materials, a review in 3 parts. Part 1: Approval requirements and standardized testing of composite materials according to ISO specifications. Schweiz Monatsschr Zahnmed. 2011;121(9):804-16. Dutch, English. PMID: 21987305

37. Hibino Y, Nagasawa Y, Eda Y, Shigeta H, Nakajima H. Effect of storage conditions on mechanical properties of resin composite blanks for CAD/CAM crowns. Dent Mater J. 2020 Sep 29;39(5):742-751. doi: 10.4012/dmj.2019-202. Epub 2020 May 16. PMID: 32418950.