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Evaluation of the effect of different fiber reinforced composite resins on the flexural strength of Bulk Fill composite resin

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ABSTRACT

Aims: The aim of this study was to evaluate the effect of reinforcing a Bulk Fill composite resin material with different fiber reinforced composite resins (FRCRs) on flexural strength.

Methods: For the flexural strength test, 60 specimens were prepared using 4x4x8 mm polymethyl methacrylate (PMMA) blocks in accordance with the standards and the specimens were divided into four study groups [Bulk Fill composite resin (group 1), Bulk Fill composite resin+glass fiber in braided structure (group 2), Bulk Fill composite resin+polyethylene fiber in leno woven structure (group 3), Bulk Fill composite resin+short glass fiber reinforced composite resin (group 4)]. The specimens were soaked in distilled water at 37°C for 24 hours and subjected to three-point bending test with Universal Test device. Data were statistically analyzed using Mann-Whitney U and Kruskal Wallis-H tests.

Results: The average bending resistance values were 654.72 Newton (N), 682.33 N, 643.87 N and 1003.91 N in groups 1, 2, 3 and 4, respectively. The effect of short glass fiber reinforced composite resin+Bulk Fill composite resin group on bending resistance was statistically significantly higher than all other groups ($p>0.05$). There was no statistically significant difference between the other groups in terms of flexural strength.

Conclusion: Within the limits of this in vitro study, it was concluded that short glass fiber reinforced composite resin increases the flexural strength of Bulk Fill composite resin as a base material.

Keywords: Excessive material loss, Bulk Fill composite resin, FRCR, fiber, three-point bending test

INTRODUCTION

Dental caries is one of the most common oral diseases in pediatric dentistry.[1] It is known that the most caries-prone tooth surfaces in permanent dentition are the pits and fissures of the first and second molars and the buccal and palatinal pits of the first molars, respectively.[2]

It is possible to maintain the function of permanent posterior group teeth with excessive loss of material for a long time with success in restorative treatment. It is important to restore function, phonation and aesthetics.[3] Composite resins, which started to be used in dental applications in the 1960s, are still frequently preferred in the treatment of teeth with excessive loss of material. Composite resins, which were used only in anterior teeth for many years, are also widely used in posterior teeth as a result of increased aesthetic expectations and developments in materials.[4]

In order to facilitate and accelerate the placement of composite resins in large layers in the posterior region, manufacturers have produced Bulk Fill composite resins that can be placed in single layers or thicker layers. The biggest advantage of Bulk Fill composite resins is that they can be placed as a single layer with a thickness of 4-6 mm, shortening the clinical working time and showing low polymerization shrinkage.[5,6] The lifetime of composite resin restorations is inversely proportional to the size of the restoration. In large restorations where the amount of remaining tissue in the tooth is insufficient, the resistance of the composite restoration to masticatory force decreases.

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However, failure of these restorations due to fracture is also frequently observed.[7,8]

Since the resistance of composite resins to compressive and bending forces is not sufficient, fiber reinforcement has been introduced to improve their physical properties. The properties of fibers such as flexibility, resistance to pressure, translucency, low specific gravity, resistance to corrosion and ability to bond with adhesive technique make them preferred for reinforcing composite resins and improving their mechanical properties. Fiber-reinforced composite resins (FRCRs) are formed as a result of the fiber structure and polymer matrix forming a whole. The stresses occurring in the matrix structure are transmitted to the fibers, thus preventing fracture development in the restoration or tooth. The mechanical properties of FRCR are affected by the type of fibers, the way they are saturated, their density, their arrangement, the content of the matrix structure or the bonding of the fibers to the matrix.[8,9]

FRCR consists of prefabricated and networked fibers of different structures and shapes added to the matrix.[10] The most preferred fibers today are glass and polyethylene fibers in woven mesh form, which are networked according to their types. Polyethylene fibers can be woven, leno woven, pigtail and unidirectional in structure. Ribbond® (Ribbond Inc, Seattle, WA, USA), on the other hand, is a polyethylene fiber material consisting of a multidirectional cross-locked loop-style leno weave.[11] Recently, a barium glass-filled short glass fiber reinforced composite resin has been introduced GC EverX Posterior® (GC, Tokyo, Japan). This material is a combination of a resin matrix with non-continuous electrical (E) glass fibers and inorganic fillers. This combination results in a semi-interpenetrating polymer network during polymerization, which gives the material good bonding and fracture toughness.[12,13]

The clinical success of a restorative material is directly related to its physical and mechanical properties. Determination of the mechanical and physical properties of the materials used and their stress and strain under functional forces is important for a successful restoration.[14] Mechanical tests are used to determine the mechanical properties of the material, which are defined as bending, compression, elasticity and hardness, which determine the clinical success of the material. ISO (International Organization for Standardization) standards have been accepted as the standard test technique to determine the physical and mechanical properties of the material. Among these tests, the three-point bending test is widely used in accordance with ISO 4049 standards and is one of the most preferred methods.[9]

The aim of this study was to evaluate the strengthening of a Bulk Fill composite resin with different FRCR by three-point flexural testing.

METHODS

The study was approved by the Dicle University Faculty of Dentistry Clinical Researches Ethics Committee (Date: 30.11.2022, Decision No: 2022-42). All procedures were carried out in accordaance with the ethical rules and the principles of the Declaration of Helsinki. All patients signed the free and informed consent form.

In order to investigate the strength of Bulk Fill composite resin reinforced with different FRCR by three-point bending test, blocks made of polymethyl methacrylate (PMMA) with 4 mm width, 4 mm depth and 8 mm length were prepared in accordance with ISO 4049 standards. The molds were designed and created with CAD/CAM in digital environment. A total of 60 specimens prepared from this mold, 15 specimens in each group, were divided into the following four study groups;

- **Group 1:** Bulk Fill composite resin
- **Group 2:** Bulk Fill composite resin+glass fiber in weave structure
- **Group 3:** Bulk Fill composite resin+polyethylene fiber in leno woven structure
- **Group 4:** Short glass fiber reinforced composite resin+Bulk Fill composite resin

The materials used in our study are given in Table 1. The following steps were applied to each test group:

Group 1: The mold was placed on a glass coverslip on a flat surface. Vaseline was first applied to the rectangular cavities on the PMMA mold with an applicator to prevent the composite resin from adhering to the material. Then, 4 mm Bulk Fill composite resin was placed into the cavities with the help of cement spatula and fulvar. The overflowing part of the Bulk Fill composite resin from the mold was removed with a spatula and the upper surface was flattened. In order to achieve an equal distance standard for each composite resin sample and to obtain the best polymerization depth, the tip of the light device was positioned in direct contact with the molds and at right angles. Bulk Fill composite resin specimens were polymerized for 20 seconds with the Woodpecker LED-F Light Device (Woodpecker, Foshan, China) in accordance with the company's recommendation, with light applied only on the top surface (Figure 1). After each sample model was polymerized, it was removed from the mold and placed in light-proof containers.

Group 2: A 2 mm Bulk Fill composite resin was placed on the substrate of the molds on the glass coverslip and no light was applied. The pre-saturated braided glass fiber was cut according to the prepared mold (7 mm in length) with scissors. The fiber was carefully placed on the Bulk Fill composite resin with the

Table 1. Materials used in the study

	Material	Feature	Producer company
1	Biolnfinity sirius dental composite	Bulk Fill composite resin	Avrupa Implant (Umg Uysal) Istanbul, Turkiye
2	Interlig	Glass fiber in braided structure	Angelus, Londrina, PR, Brazil
3	Ribbond	Polyethylene fiber in leno woven structure	Ribbond Inc., Seattle, WA, USA
4	EverX posterior	Short glass fiber reinforced composite resin	GC, Tokyo, Japan
5	Clearfil liner bond F	Binding agent	Kuraray, Okayama, Japan

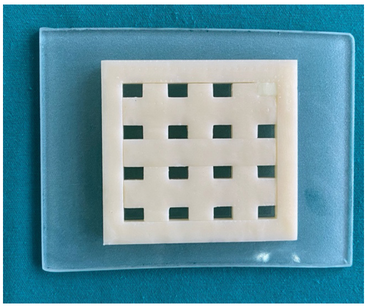

Figure 1. Image of Bulk Fill composite resin before polymerization

help of a press and polymerized for 20 seconds (Figure 2). Bulk Fill composite resin was placed into the remaining cavity with the help of a spatula and fulvar and polymerized for 20 seconds.

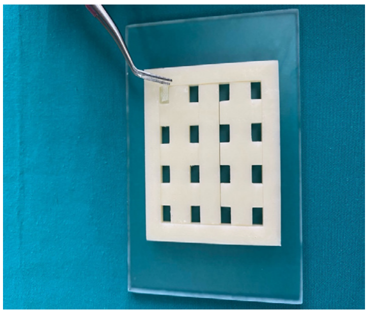

Figure 2. Placement of the cut braided glass fiber on the composite resin

Group 3: As in group 2, 2 mm Bulk Fill composite resin was placed on the bottom layer of the mold and no light was applied. Leno woven polyethylene fiber was cut with the help of special Ribbond scissors in 2x7 mm dimensions according to the prepared mold. The bond in the Kuraray Clearfil Liner Bond F dental bonding agent kit was used to pre-saturate the fiber material (Figure 3). After saturation with resin, the prepared fiber bulk fill was placed on the composite resin and polymerized with light for 40 seconds. After this process, the remaining upper part of the mold was placed on the bulk fill composite resin with the help of a spatula and fulvar and polymerized for 20 seconds.

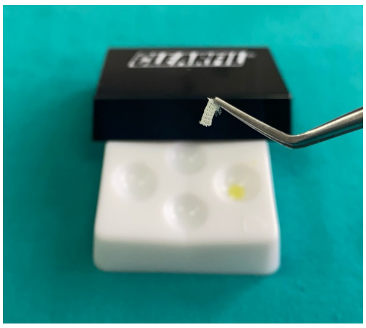

Figure 3. Fiber material and bond agent cut according to mold dimensions before saturation process

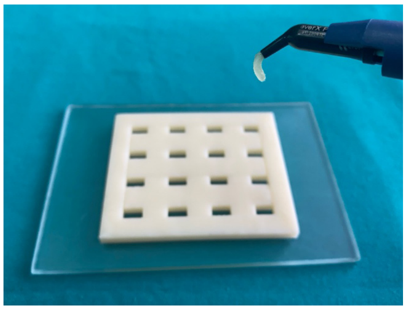

Figure 4. Short glass fiber reinforced composite resin placed in the substrate of the mold

Group 4: Short glass fiber reinforced composite resin was placed on the bottom layer of the molds on the glass coverslip as a 3 mm base material (Figure 4). It was polymerized with light for 20 seconds according to the manufacturer's recommendation. The remaining upper part of the mold was filled with Bulk Fill composite and polymerized with light for 20 seconds. After each sample model was polymerized, it was removed from the mold and placed in light-proof containers.

All specimens (60 specimens in total) were placed in distilled water at 37 0C for 24 hours and then subjected to three-point bending test. The three-point bending test was performed in the laboratory of the Department of Prosthodontics, Faculty of Dentistry, Van Yüzüncü Yıl University, Van Yüzüncü Yıl University, using a Universal Testing Machine (AG- 50 kNG, Shimadzu, Japan).

The crusher tip, which will perform the fracture, was connected to the upper part of the Universal Testing Machine moving downwards. In order to adjust this crushing tip to the exact midpoint of the samples, the exact midpoint of the samples was previously determined with a digital micrometer. The Universal Testing Machine was then operated at a speed of 1 mm/minute and force was applied to the samples. The device was stopped when a breakage occurred in the sample.

RESULTS

The conformity of the fracture values of the 4 groups used in our study with the three-point bending test to the statistical normal distribution was tested according to Shapiro Wilk's and/or Kolmogorov Smirnov methods. Mann-Whitney U and Kruskal Wallis-H tests were used for intergroup comparisons because the variables were not from normal distribution. In case of significant differences in Kruskal-Wallis-H test, post-hoc multiple comparison test was used to determine the groups with differences.

In the study in which the effect of fiber-reinforced composite resins on the flexural strength of Bulk Fill composite resin was comparatively examined, the average flexural strength values of groups 1, 2, 3 and 4 were determined as 654.72 N, 682.33 N,

Table 2. Results of the analysis related to the difference between group 1 and group 2 in terms of bending resistance

	Bending resistance						Mann-Whitney U test		
	n	Mean	Median	Min	Max	SD	Mean rank	z	p
Group 1	15	654.72	613.4	275	1056	213.14	14.67	-0.518	0.604
Group 2	15	682.33	655.1	155.8	964	242.84	16.33		

Min: Minimum, Max: Maximum, SD: Standard deviation

643.87 N and 1003.91 N, respectively, as a result of three-point bending test. There is a statistically significant difference between the groups in terms of bending resistance (p<0.05).

The highest flexural strength value obtained was observed in the short glass fiber reinforced composite resin+Bulk Fill composite resin group, while the Bulk Fill composite resin+leno woven polyethylene fiber group was tested to have the lowest value. The effect of group 4 on bending resistance was statistically significantly better than all other groups (Tables 3, 4 and 5) (p<0.05). No statistically significant difference was found between the other groups in the study (Tables 2, 6 and 7) (p>0.05).

DISCUSSION

It is possible for permanent posterior teeth that have suffered excessive loss of material due to caries or anomalies to maintain their functions for a long time with success in restorative treatment.[4] Since tissue loss is high in large restorations, the resistance of the remaining tooth tissue and the durability of the composite material used against occlusal forces are also reduced and thus fractures are seen in the restorations in the long term. For this reason, composite resins have been continuously developed. In order to reduce the failures of composite resins, it is recommended to use FRCR with these restorations, considering that it increases the support of the restorations and dental tissues they support.[15]

Table 3. Analysis results for the difference between group 1 and group 4 in terms of bending resistance

	Bending resistance							Mann-Whitney U test	
	n	Mean	Median	Min	Max	SD	Mean rank	z	p
Group 1	15	654.72	613.4	275	1056	213.14	10.33	-3.215	0.001
Group 4	15	1003.91	943	616.6	1800	297.4	20.67		

Min: Minimum, Max: Maximum, SD: Standard deviation

Table 4. Analysis results for the difference between group 2 and group 4 in terms of bending resistance

	Bending resistance							Mann-Whitney U test	
	n	Mean	Median	Min	Max	SD	Mean rank	z	p
Group 2	15	682.33	655.1	155.8	964	242.84	11.07	-2.758	0.006
Group 4	15	1003.91	943	616.6	1800	297.4	19.93		

Min: Minimum, Max: Maximum, SD: Standard deviation

Table 5. Analysis results for the difference between group 3 and group 4 in terms of bending resistance

	Bending resistance							Mann-Whitney U test	
	n	Mean	Median	Min	Max	SD	Mean rank	z	p
Group 3	15	643.87	582.5	290	1091	193.39	9.73	-3.588	0.001
Group 4	15	1003.91	943	616.6	1800	297.4	21.27		

Min: Minimum, Max: Maximum, SD: Standard deviation

Table 6. Analysis results for the difference between group 1 and group 3 in terms of bending resistance

	Bending resistance							Mann-Whitney U test	
	n	Mean	Median	Min	Max	SD	Mean rank	z	p
Group 1	15	654.72	613.4	275	1056	213.14	15.67	-0.104	0.917
Group 3	15	643.87	582.5	290	1091	193.39	15.33		

Min: Minimum, Max: Maximum, SD: Standard deviation

Table 7. Analysis results for the difference between group 2 and group 3 in terms of bending resistance

	n	Mean	Median	Min	Max	SD	Mean rank	z	p
Group 2	15	682.33	655.1	155.8	964	242.84	16.67	-0.726	0.468
Group 3	15	643.87	582.5	290	1091	193.39	14.33		

Min: Minimum, Max: Maximum, SD: Standard deviation

Since the restorative material is exposed to masticatory forces in clinical use, high flexural strength of the material is a desirable feature.[9] Flexural strength test is one of the tests that most closely mimics the forces to which restorative materials in the mouth are exposed. It allows determination of the material's resistance to fracture. It also provides an idea about whether the materials will be successful under pressure.[16,17]

It has been determined that there is a positive correlation between the high ratio of inorganic filler in the matrix structure of the restorative material used and the mechanical properties of the material. Therefore, the restorative material to be used in clinical studies should have high filler content and thus high flexural strength.[18,19] One of the methods to increase flexural resistance is fiber reinforcement of composite resins. It is claimed that appropriately placed and designed fibers increase the flexural resistance of the composite resin to which they are added.[20-22] Fibers improve the physical properties of the material by acting as fracture stoppers. The most preferred fiber types for this purpose are networked polyethylene and glass fibers.[23]

Braided glass fibers are pre-saturated fibers. Being pre-wetted eliminates the steps to be applied by the clinician. In addition, it is claimed that they have high bending resistance due to their higher fiber content compared to non-presaturated fibers.[9] Glass fibers are claimed to have high tensile strength and increase the flexural and impact resistance of composite resins.[24]

Leno woven polyethylene fibers are pre-saturated fibers and must be cut with special scissors and saturated in resin before use. These fibers can easily take shape during use and thus adapt to the cavity walls. Due to the gas-plasma treatment they are exposed to during their production, they easily absorb water, reducing the surface tension of the fiber and providing a good chemical adhesion with composite resins.[25]

Newly developed short-fiber reinforced composite resins, recommended for use in high-stress areas, contain silanated e-glass fibers optimized in size and length to provide maximum strengthening effect. These composite resins have many advantages in the restoration of teeth with excessive material loss. Their elastic modulus is similar to dentin, their tensile strength is high, they are cost-effective and suitable for single-session treatment. When short fiber reinforced composite resins are used as a substructure under conventional composite resins, the durability of the restoration is significantly increased and when the restoration is loaded to the fracture point, the fracture path changes and repairable fractures occur.[26]

In our study, the effect of short glass fiber reinforced composite resin on the flexural strength of Bulk Fill composite resin was statistically significantly better than all other groups. Garoushi et al.[27] compared the fracture and bending resistance of short glass fiber reinforced composite resin and different Bulk Fill composite resins in large posterior restorations and found that short glass fiber reinforced composite resin showed higher fracture and bending resistance. In an in vitro study by Garlapati et al.[28] comparing the fracture resistance of hybrid composite resin, leno woven polyethylene fiber+conventional composite resin and short glass fiber reinforced composite resin+conventional composite resin in endodontically treated teeth, it was shown that short glass fiber reinforced composite resin increased fracture resistance at a high rate. In addition, it was stated that the short fiber in the composite resin can be supported by filler particles and composite layers, thus preventing the progression of cracks. In the study of Rajaraman et al.[29] in which they compared the fracture resistance of short glass fiber reinforced composite resin with Class I cavity and intact teeth with a universal tester, it was found that the average fracture resistance of short glass fiber reinforced composite resin was close to that of intact teeth, but not statistically significant. They attributed the higher fracture resistance observed in intact teeth to the absence of material loss. In a 2.5-year clinical follow-up study by Tanner et al.[30] in which they treated 36 posterior teeth with short glass fiber reinforced composite resin, it was observed that short glass fiber reinforced composite resins had high fracture resistance properties. After follow-up, the survival rate of the restorations was 97.2% and the success rate (not requiring repair) was 89.9%.

The results obtained in our study are similar to the previous studies. It is thought that higher bending resistance values are obtained by micromechanical interlocking of the protruding short fibers in the short glass fiber reinforced composite resin with the composite.

In a study, Vallittu[31] investigated the flexural strength of acrylic resin reinforced with unidirectional and braided glass fibers. According to the results of this study, unidirectional glass fibers have higher bending resistance, but braided glass fibers increase the resistance at fracture in all polymer materials and this is clinically important. In an in vitro study by Candan et al.[9] in which the effect of using different substrate materials on the flexural resistance of nanofilament composite resin was evaluated, it was reported that only the nanofilament composite resin control group had the lowest flexural resistance, and the highest flexural resistance value was reported in the sample group in which glass fiber was used in mesh structure together with flowable composite resin. In the same study, it was reported that the use of flowable composite resins in the substrate of restorations increases the bending resistance of the restorations, reduces the harmful effects of occlusal forces and eliminates irregularities at the base of the cavity. Although there was no statistically significant difference between the group that placed braided glass fiber on fluid composite resin and covered with nanofil composite resin and the group that placed braided glass fiber directly on the mold base without using fluid composite resin and covered with nanofil composite, the bending resistance was found to be higher. Studies have been conducted on the placement of the fiber in which part of the specimens to be tested in bending tests. Chung et al.[32] examined the effect of adding glass fiber to the autopolymerizable acrylic base material used for the construction of temporary fixed prostheses on bending resistance and placed the unidirectional fiber in four different ways in a 9 mm high mold. According to the results of the study, the highest bending resistance value was observed in the lower 1/3 of the mold, while the lowest value was observed in the upper and middle parts of the mold. Kanie et al.[33] examined the effect of the position of the braided glass fiber placed in acrylic resin on bending resistance and reported that the highest bending resistance was found when the fiber was placed in the lower part of the mold where the tensile stresses were the highest. Similarly, Lassila and Vallittu,[34] in their study where they placed the fiber between the composite layers, found that the highest bending resistance was found in the samples placed at the bottom of the composite.

In our study, it was observed that the braided glass fiber increased the flexural strength of Bulk Fill composite resin, although not statistically significant. We think that this may be related to the fact that we placed the braided glass fiber in the middle layer instead of the substrate in our study and used Bulk Fill composite resin instead of flowable composite resin as the base material.

In our study, the effect of leno woven polyethylene fiber on the flexural strength of Bulk Fill composite resin was found to be lower than that of Bulk Fill composite resin and braided glass fiber, although not statistically significant. Pereira et al.[35] compared the flexural strength of non-fiber reinforced hybrid, microfill and hybrid+microfill composite resin combinations and hybrid composite reinforced with polyethylene fiber in leno woven structure. According to the results of this study, they found that reinforcement with polyethylene fiber in leno woven structure showed higher bending resistance than microfill, hybrid+microfill composite resin combination and lower bending resistance than hybrid composite resins, but this difference was not statistically significant. Bae et al.[36] applied three-point bending test to their composite resin samples prepared by adding leno woven polyethylene fiber, polyaramide and three different glass fibers. As a result of the test, they found that all samples with fiber addition significantly increased the flexural strength compared to the group containing only composite resin. However, they found that the bending resistance of polyaramide and glass fibers was significantly higher than that of leno woven polyethylene fibers. Türkeş et al.,[15] in their in vitro study in which they examined the resistance of the restoration against compressive forces when leno woven polyethylene fiber material was placed in composite resin in different configurations with a universal test device, found that there was no statistically significant difference between the resistance values of the group in which only composite resin was used compared to the group in which polyethylene fiber was applied with fluid composite resin on the base. Tezvergil et al.,[37] Belli et al.[38] and Lassila et al.[39] used leno woven polyethylene fiber with flowable composite resin in their studies similar to this study. In composite resin restorations, it was reported that placing a leno-woven polyethylene fiber with a thin layer of flowable composite resin in the cavity positively affected the adhesion between the fiber and the composite resin and reduced the effect of shrinkage by acting as a buffer against the stresses occurring under occlusal forces and stresses occurring during polymerization of the flowable composite resin. They also reported that the use of fibers together with the flowable composite resin in cavities with a large surface area allows the flowable composite resin to penetrate better between the fibers of the fiber, creating a stable and high bonding resistance. In our study, unlike other studies, the leno woven polyethylene fiber was placed directly into the Bulk Fill composite resin instead of being placed into the fluid composite resin which is a base material. This may be related to the fact that Bulk Fill composite resin does not penetrate between the fibers of the fiber as well as the flowable composite resin, resulting in adhesive failure. At the same time, the in vitro nature of our study, the fact that the leno-woven polyethylene fiber was not pre-saturated, the time interval and ambient conditions expected during saturation, the volumetric size formed in the cavity after saturation, and the placement of the fiber mesh in the middle of the Bulk Fill composite resin layers may have caused the low bending resistance values.

CONCLUSION

Within the limitations of this study, the following conclusions can be drawn:

- The highest flexural strength value was found in the short glass fiber reinforced composite resin+Bulk Fill composite resin group.
- There was no statistically significant difference between the glass fiber in braided structure, Bulk Fill composite resin and polyethylene fiber in leno woven structure groups.
- It may be more meaningful to use FRCR with flowable composite resin as a base material to increase the flexural strength of Bulk Fill composite resins.
- Since our study was conducted under in vitro conditions, the intraoral environment cannot be mimicked exactly. In addition, restorative materials are not only subjected to forces in the vertical direction in the mouth but are also subjected to forces in many directions.
- This study should be supported by the results of different in vitro and clinical studies.

ETHICAL DECLARATIONS

Ethics Committee Approval

The study was carried out with the permission of the Dicle University Faculty of Dentistry Clinical Researches Ethics Committee (Date: 30.11.2022, Decision No: 2022-42).

Informed Consent

In this study, no biological material was used, no personal data are available. Therefore, informed consent is not required.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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