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Comparative estimation of fracture resistance of teeth restored with new fiber impregnated composite, short fiber composite, and nanohybrid composite – An in-vitro study

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Abstract
INTRODUCTION. Composite resins, used in restorative dentistry, offer enhanced esthetic and mechanical qualities. Nevertheless, the significant issue of volumetric shrinkage during polymerization remains a concern. Shrinkage-induced stress has the potential to cause marginal defects and enamel and cuspal fractures, especially in high stress-bearing areas. The present study aimed at assessing and comparing the fracture resistance and fracture patterns of teeth restored with new impregnated cubical composite, short fiber reinforced composite, and nanohybrid composite in mesio-occlusal-distal (MOD) cavities.
MATERIALS AND METHODS. This was an in-vitro study comprising 45 extracted premolars cleaned and mounted in resin blocks. The MOD cavities were prepared in all the samples and were divided into three groups; Group I samples restored using ESPE Filtek Z350 XT restorative composite syringe^{TM}, Group II using GC EverX posterior composite^{TM} (4mm), and Group III using Fibrafill cube S. Restorations were finished and polished.
RESULTS. The mean fracture resistance was 844.5 ± 264.8, 1249.7 ± 518.3, and 1240.8 ± 453.3 in Group I, II, and III, respectively. Group II and III fracture resistance was comparable (p = 1.00) but higher than Group I (p = 0.03 with Group II, p = 0.04 with Group III). No significant difference was present in the favourable and non-favourable fracture patterns between the three groups (p = 0.108).
CONCLUSIONS. Short fiber and cubic fiber integrated composites performed similarly in terms of fracture resistance resulting in favourable fracture, however better over conventional nanohybrid composites.

Keywords: composite resin, fiber impregnated, short fiber, nanohybrid

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Сравнительная оценка сопротивления зубов на излом, восстановленных с помощью нового композита, пропитанного волокнами коротковолокнистого композита и наногибридного композита: исследование in vitro

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Резюме
ВВЕДЕНИЕ. Композитные смолы, используемые в реставрационной стоматологии, обладают улучшенными эстетическими и механическими свойствами. Тем не менее, значительная проблема объемной усадки во время полимеризации остается актуальной. Стресс, вызванный усадкой, может привести к краевым дефектам и трещинам эмали и бугров, особенно в областях с высокой нагрузкой. Настоящее исследование было направлено на оценку и сравнение сопротивления на излом и характера трещин у зубов, восстановленных с использованием нового композита, пропитанного кубическими волокнами, композита с короткими волокнами и наногибридного композита в мезиально-окклюзионно-дистальных (MOD) полостях.
МАТЕРИАЛЫ И МЕТОДЫ. В данное in vitro исследование вошли 45 удаленных премоляров, очищенных и установленных в блоки из смолы. Во всех образцах были подготовлены MOD полости, и их разделили на три группы: группа I – восстановление с использованием ESPE Filtek Z350 XT restorative composite syringeTM, группа II – композитом GC EverX posterior compositeTM (4 мм), группа III – композитом Fibrafill cube S. Реставрации были окончательно обработаны и отполированы.
РЕЗУЛЬТАТЫ. Среднее сопротивление на излом составило 844,5 ± 264,8, 1249,7 ± 518,3 и 1240,8 ± 453,3 в группах I, II и III соответственно. Сопротивление на излом в группах II и III было сопоставимым (p = 1,00), но значительно выше, чем в группе I (p = 0,03 для группы II, p = 0,04 для группы III). Значительных различий в благоприятных и неблагоприятных типах трещин между тремя группами не выявлено (p = 0,108).

ВЫВОДЫ. Композиты с короткими волокнами и с интегрированными кубическими волокнами показали схожие результаты по сопротивлению на излом, обеспечивая благоприятные трещины, и продемонстрировали лучшие показатели по сравнению с традиционными наногибридными композитами.

Ключевые слова: композитная смола, пропитанная волокнами, короткие волокна, наногибрид

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INTRODUCTION

Advancements in adhesive techniques and the growing demand on aesthetics have elevated resin composite as the primary option for restoring cavities in posterior teeth [1]. Although the combined restorative materials such as porcelain and composite resins effectively imitates the mechanical characteristics of natural dental tissues, the fracture and volumetric shrinkage remain the paramount concerns with composite resins [2]. Considerable research has been undertaken and continues to be ongoing to tackle these concerns, with a focus on refining composite characteristics by altering filler ratios, particle dimensions, and the chemical composition of the polymer matrix [3]. The dentino-enamel junction (DEJ) acts as a crucial interface between the rigid enamel and the more flexible dentin, forming a mechanically robust unit that absorbs stress in teeth and prevents crack propagation [4]. Maintaining or replicating the properties of DEJ during restoration processes is vital. Restoration techniques, in MOD direct restorations play a pivotal role in maintaining the mechanical integrity of posterior teeth, particularly in cases where the stress-absorbing properties of DEJ are compromised [5]. However, achieving an ideal composite restoration requires awareness of potential risk factors and the types of failure commonly observed in the posterior region such as bulk fracture and secondary caries.

Fiber reinforcement in conventional dental composites aims to increase the fracture resistance by optimizing the diameter and length of fiber to enhance stress transfer from the matrix. Garoushi et al. observed significant improvement in material properties through this method [3]. Since the elastic modulus and mechanical strength of fiber-reinforced composites (FRC) closely resemble dentin [6], research has been conducted to strengthen the reinforcing phase of restorative PFC making it more reliable for use in high-stress environments like posterior teeth. In the year 2013, short fiber reinforced composite (SFRC), consisting of a combination of a resin matrix, randomly orientated E-glass fibers, and inorganic particulate fillers has emerged with an aim to simulate stress absorbing ability of dentin [1; 7]. The SFRC is designed for use as a bulk base in high stress-bearing regions for restoring both vital and non-vital teeth. Its semi-interpenetrating polymer network enhances bonding properties for repairs and increases toughness of polymer matrix. Materials that are used to make fibers include carbon, aramid, polyethylene, and glass [7]. The *in-vitro* investigations revealed enhanced load-bearing strength and fracture toughness in SFRC compared to conventional composite materials [8; 9]. However, findings from studies by Barreto et al. and Frater et al. indicate no significant differences in fracture resistance between SFRC and conventional filler composites. This discrepancy may be primarily attributed to the insufficient reinforcement provided by short fibers within the polymer matrix [10; 11].

The introduction of nanotechnology has advanced composite resin materials, particularly nanohybrid resin composites. Nanohybrid composites enhance filler distribution by combining nanoparticles with submicron particles, resulting in superior mechanical, chemical, and optical properties [12]. The nanofilled materials, due to their high filler content and reduced particle size, offer easy handling, long-term restoration maintenance, and improved mechanical properties. These materials exhibit reduced polymerization shrinkage and enhanced diametral tensile strength, compression strength, and fracture toughness, making them ideal for high-stress areas in the oral environment [13]. Filtek Z350 XT restorative nanohybrid composite comprises a combination of non-agglomerated silica filler of 20 nm and aggregated zirconia/silica clusters with primary particle sizes of 5–20 nm at 78.5% weight [12]. An *in-vitro* study by Bukhari SM demonstrated significantly higher fracture resistance of Filtek Z350 XT composite material in posterior MOD cavities compared to Zirconomer and Cention [14].

Lately, FibraFill CUBE was introduced in restorative dentistry as a microhybrid, light-curable composite with integrated fiber reinforcement that substitutes the dentin layer. Designed to mimic the DEJ and evenly distribute stress, it reduces the risk of fracture between the restorative material and the tooth. It is thus meant for the fabrication of direct restorations as an alternative for the dentine layer [15; 16]. FibraFill comes in pad form with two layers of particulate composite and oriented glass fiber reinforcement. It is available in cube shapes (3mm x 4mm x 3mm), it comes in doses of S (65 ± 5 mg), M (95 ± 8 mg), and L (180 ± 10 mg). The manufacturer indicates that it can be used in dentistry for Class I, Class II, and Class V cavities, as well as large posterior combination cavities, deep cavities in endodontically treated teeth, pre- and post-endodontic restorations, and core restorations[1].

[1] Fibrafill. Available at: https://fibrafill.com/en/instructions/instructions-for-use-fibrafill-cube (accessed: 17.05.2024).

Considering the Fibrafill CUBE material as lately introduced, it is crucial to have a better understanding of its mechanical strength when compared to the widely used Filtek Z350 XT composite material and fiber reinforced EverX posterior composite. In terms of mechanical strength of the restoration, fracture toughness testing is vital to evaluate a material's ability to withstand stress without breaking and to monitor crack propagation before failure. Previous studies suggest that testing bulk fill composites in 4 mm increments is appropriate [3]. Thus, the aim of this *in-vitro* study was to assess and compare the fracture resistance and fracture patterns of teeth restored with new impregnated cubical composite, short fiber reinforced composite, and nanohybrid composite in MOD cavities. The null hypothesis was; teeth restored with the cubical fiber-impregnated composite will exhibit similar mechanical resistance to those restored with nanohybrid and SFRC composites, and that fracture patterns in premolars with MOD cavities will not depend on the type of composite used.

MATERIALS AND METHODS

This was an *in-vitro* study conducted in a dental college of Pune, Maharashtra. The approval for conducting this study was obtained from the Scientific and Institutional Ethical committee of a dental college in Pune, Maharashtra. The sample size was estimated using G* Power 3.1.9.2 software keeping effect size of XX, alpha of 0.05, and power of the study as 80%. A total of 45 extracted two rooted premolars were included using convenience sampling. All the materials, instruments, and equipment used in the study are presented in Fig. 1. The procedural steps are presented in Fig. 2 and 3.

Preparation of samples

All teeth were cleaned using an ultrasonic scaler (Azdent), autoclaved (using Runyes Unicorn DenMart) and stored in a normal saline until use. The teeth were subsequently embedded in resin blocks measuring 2 x 2 x 2.5 cm, with the root portion extending from 2 mm below the CEJ to the apex. MOD cavities were prepared on these mounted teeth using a diamond tapered

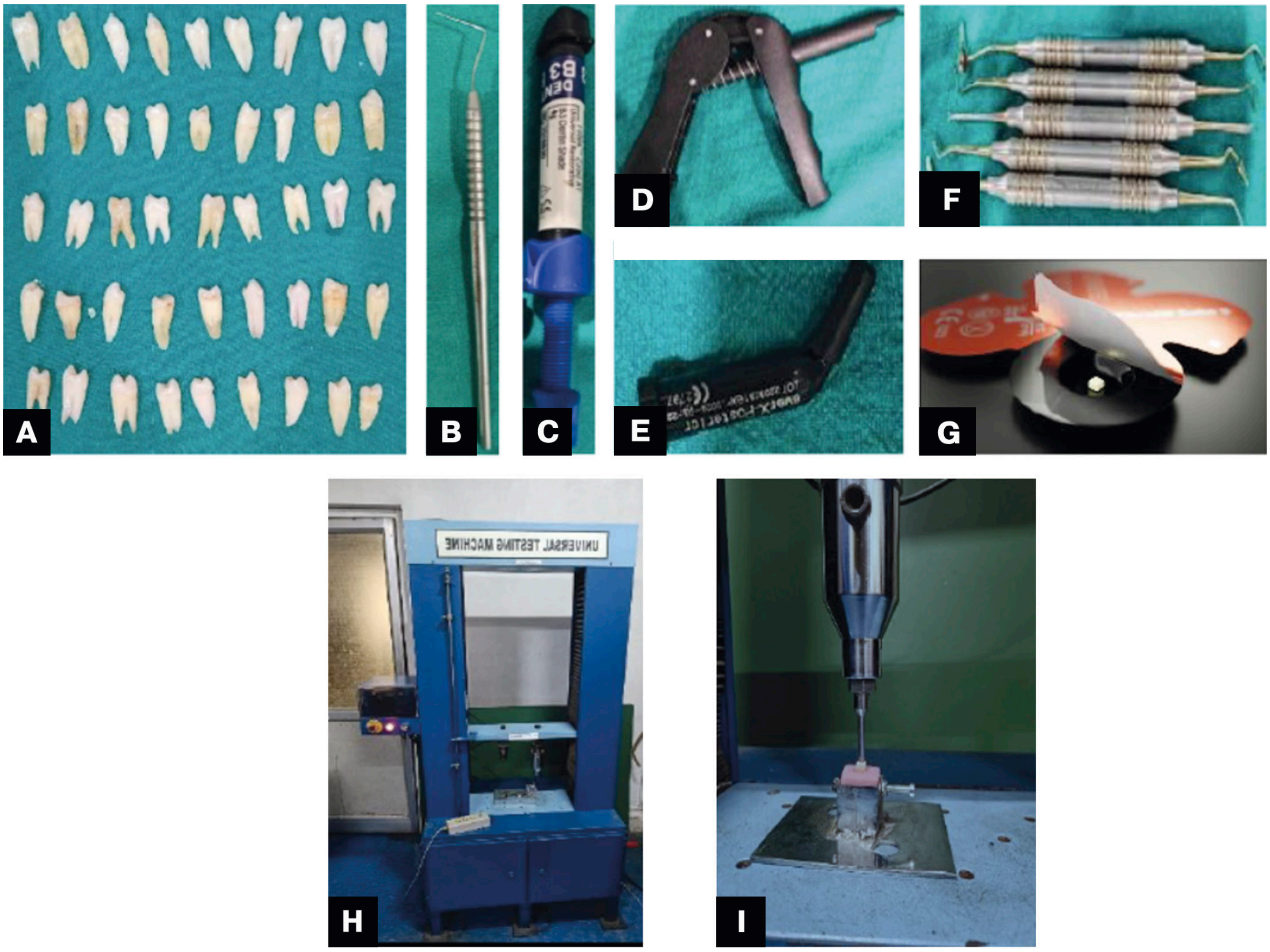

Fig. 1. Materials, instruments, and equipment used in the study: *A* – extracted two rooted premolars; *B* – William's probe; *C* – 3M ESPE Filtek Z350 XT resorative composite syringe.TM; *D*, *E* – compule dispensing gun and GC EverX posterior TM composite; *F* – composite instruments; *G* – Fibrafill CUBE S TM; *H*, *I* – universal testing machine

Рис. 1. Материалы, инструменты и оборудование, использованные в исследовании: *A* – извлеченные двукорневые премоляры; *B* – зонд Вильямса; *C* – шприц с композитом для реставрации 3M ESPE Filtek Z350 XT™; *D*, *E* – композит GC EverX posterior™ и пистолет; *F* – композитные инструменты; *G* – Fibrafill CUBE S™; *H*, *I* – универсальная тестовая машина fissure (TF-13) and an air rotor handpiece (Being Foshan). Bucco-lingually, the cavity was expanded to two-thirds of the bucco-lingual width of the tooth. The proximal box depth on both the distal and mesial aspects was maintained at 1 mm above the CEJ. Verification of measurements was done using a William's probe (GDC) and the unsupported enamel was meticulously removed with an enamel hatchet (GDC).

Tofflemier (GDC) with matrix band was adapted around each tooth. A selective etching protocol was applied, using 37% phosphoric acid (Dental Restorite Etching Gel Prime™) for 15 seconds, followed by rinsing and air-drying. The bonding agent (Single Bond Universal Adhesive 3M ESPE™) was then applied using applicator tip (Oro), agitated, and cured with an LED unit for 10 seconds.

Restoration of the prepared teeth

For restoration, the samples were divided into three groups as below:

Group I (*n* = 15): MOD cavity restored with 3M ESPE Filtek Z350 XT restorative composite syringe™

In Group I, a layer of 2 mm of 3M ESPE Filtek Z350 XT restorative composite syringe™ was cured for 20 seconds. The remaining tooth was restored using layer technique with each layer cured for 20 seconds with continuous intensity by Woodpecker LED.C light curing unit™.

Group II (*n* = 15): MOD cavity restored with GC EverX posterior composite™ + 3M ESPE Filtek Z350 XT restorative composite syringe™

In Group II, the initial layers of 4 mm of GC EverX posterior composite™ were adapted using composite instruments and cured for 20 seconds. The remaining tooth was restored using 3M ESPE Filtek Z350 XT restorative composite syringe™ up to occlusal anatomic surface and cured using Woodpecker LED.C light curing unit™.

Group III (*n* = 15): MOD cavity restored with Fibrafill CUBE S™ Dentapreg + restored using 3M ESPE Filtek Z350 XT restorative composite syringe™

In Group III, cube of Fibrafill CUBE S™ was adapted using composite instruments up to 4 mm and cured for 30 seconds. The remaining tooth was restored using 3M ESPE Filtek Z350 XT restorative composite syringe™ up to occlusal anatomic surface and cured using Woodpecker LED.C light curing unit™.

Finishing and polishing of the restoration

Samples were finished with a yellow band diamond point (TF-21EF) after removing the retainer and matrix band. The final finishing and polishing was done using Shofu Super Snap rainbow discs in a sequence of black (coarse), violet (medium), green (fine) and pink (superfine, based on particle size, using a slow-speed micromotor handpiece (Alegra). All samples were then stored in a humidifier at 35 °C and 80% humidity.

Assessment of outcome parameters

Fracture resistance was assessed by subjecting the MOD restorations from each group to loading via Universal testing machine (INSTRON) at a cross-head speed of 2 mm/min using a stainless-steel stylus 4.8 mm diameter at centre pit of occlusal surface. This was followed by evaluation of fracture patterns.

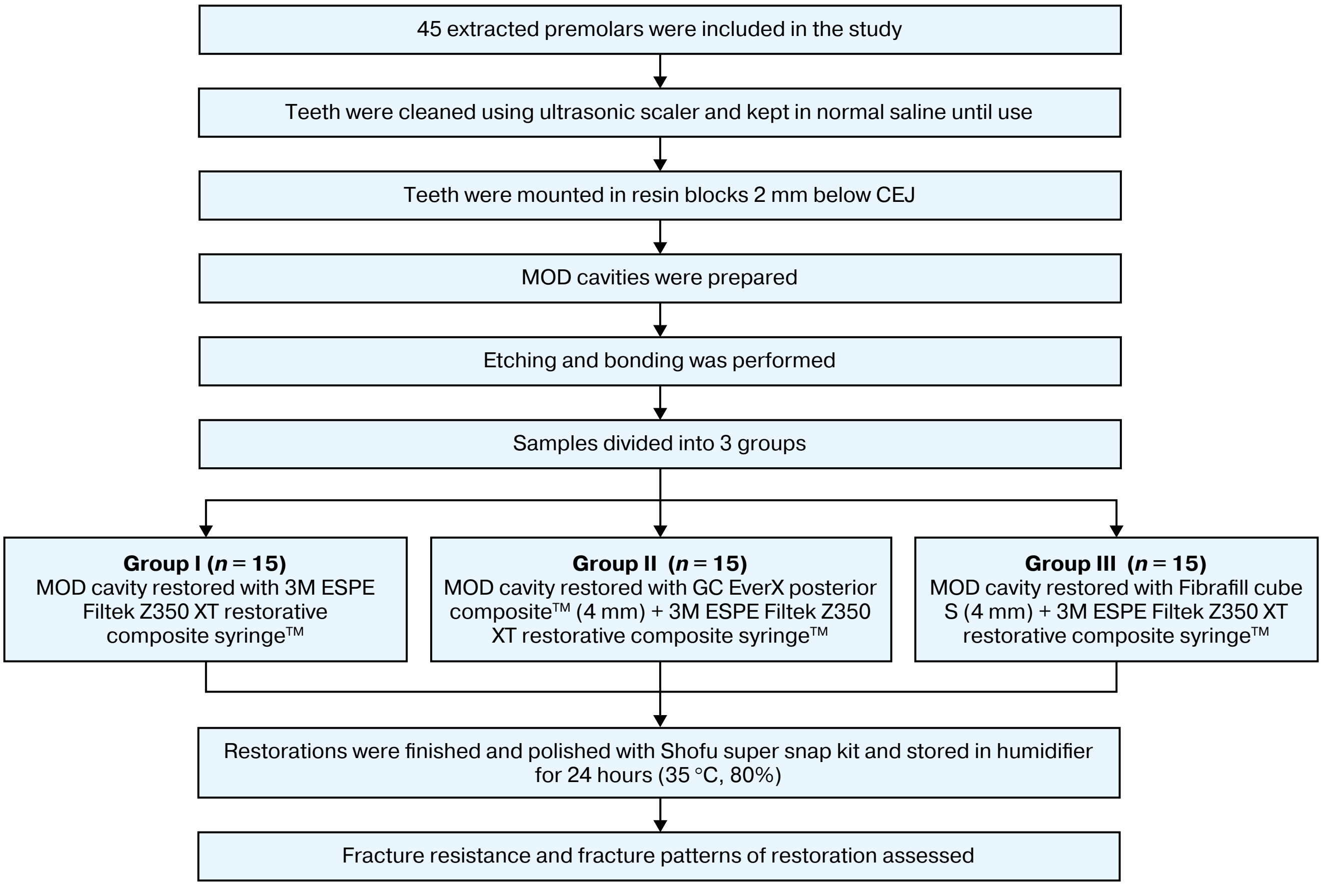

Fig. 2. Flow chart representing procedural steps involved in the study

Рис. 2. Блок-схема, представляющая процедурные шаги, выполненные в ходе исследования

Fracture patterns were evaluated as restorable or non-restorable under dental operating microscope (Carl Zeiss Meditec AG™) with two examiner agreement. The fracture above the CEJ was noted as restorable fracture while the fracture extending below CEJ was noted as non – restorable fracture.

Statistical analysis

All analysis were performed using SPSS version 15.0 (SPSS Inc., Chicago, IL). The data for fracture loads was analysed statistically using one-way ANOVA. Differences between fracture patterns of experimental groups were analysed using Chi-square test. The significance was kept at $p < 0.05$.

RESULTS

The mean fracture resistance in Group I was 844.5 ± 264.8, in group II was 1249.7 ± 518.3, and in Group III was 1240.8 ± 453.3 (Table 1). The comparison of fracture resistance between the groups using one way ANOVA test revealed a statistically significant difference between the groups ($F = 4.427$, $p = 0.018$). The post hoc Tukey test demonstrated a significant difference in fracture resistance between Group I and Group II ($p = 0.038$) and between Group I and Group III ($p = 0.044$). However, the fracture resistance between Group II and Group III was comparable ($p = 1.000$) (Fig. 4).

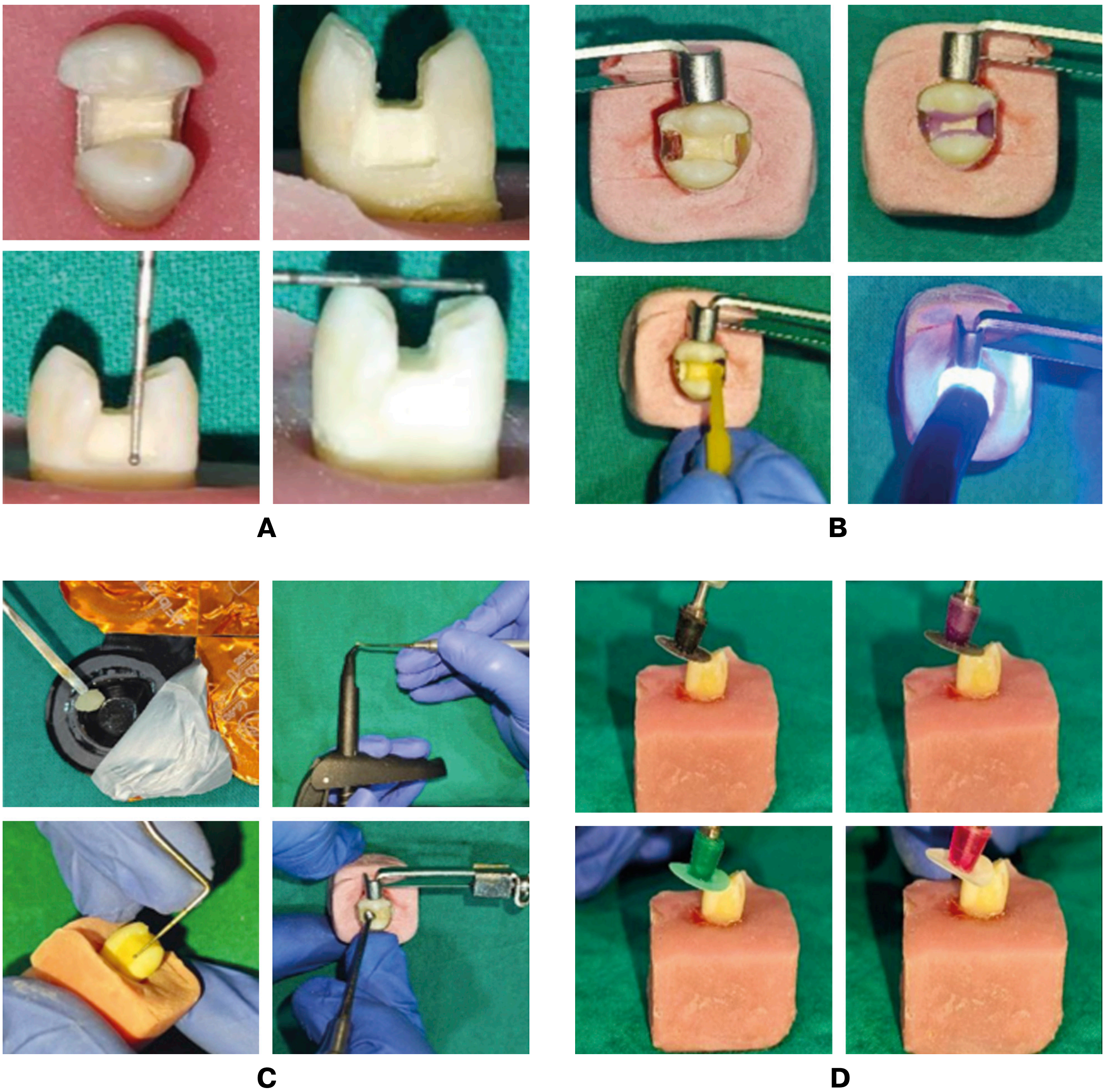

Fig. 3. Preparation of teeth, restoration of MOD cavity, and finishing and polishing of the restoration: *A* – cavity preparation; *B* – tofflemire retainer with matrix band application and etching and bonding; *C* – MOD cavity restoration; *D* – finishing and polishing

Рис. 3. Подготовка зубов, восстановление MOD полости и окончательная обработка и полировка реставрации: *A* – подготовка полости; *B* – установка матричной ленты с использованием фиксатора Тоффлемайра, протравка и нанесение адгезива; *C* – восстановление MOD полости; *D* – окончательная обработка и полировка

Table 1. Comparison of fracture resistance between Group I, II, and III

Таблица 1. Сравнение сопротивления на излом между группами I, II и III

Groups	N	Mean	Standard deviation	F-value	Significance (p)
Group I	15	844.5	264.9	4.427	**0.018***
Group II	15	1249. 7	518.3		
Group III	15	1240.8	453.3		

Note. Significance at $p<0.05$

Примечание. Значимость при $p<0,05$

The fracture patterns in the present study were categorized as favourable and non-favourable fractures. In Group I, 47.8% and 18.2% samples had non-favourable and favourable fracture pattern, respectively. Similarly, group II presented with 26.1% non-favourable and 40.9% favourable fracture patterns. The non-favourable fracture patterns in Group III was revealed in 26.1% samples and favourable patterns in 40.9% samples (Fig. 5). Comparison between favourable and non-favourable fracture patterns between the three groups using Chi-square test revealed no statistically significant ($\chi^2=4.447$, $p=0.108$) difference between the groups.

DISCUSSION

It is widely acknowledged that the success of endodontic therapy depends on both the treatment and the quality of the coronal restoration. Excessive cavity preparation often leads to tooth fragility, causing partial or complete fractures of the cusps or roots in posterior teeth. The loss of the marginal ridge and proximal tooth structure reduces tooth stiffness by 46%, a significant 2.5-fold decrease [17; 18]. As reported in the study by Eakle et al., endodontically treated premolars are particularly prone to fractures, especially under compressive forces, with the lingual cusp being most frequently affected [19]. Hence, in the present study cavities were prepared in two rooted premolar. Further, studies indicate that preparing MOD cavities can reduce tooth fracture strength by up to 54% compared to unprepared teeth. Therefore, in the present study MOD cavities were prepared in the teeth to assess the load-bearing capacity of resin composites with various substructures under worst-case conditions.

In present study, three composites were compared for their fracture resistance. One was Filtek Z350 XT, which is a visible light-activated, nano-filled composite resin with advanced filler technology containing 4–11 nm zirconia, aggregated zirconia/silica clusters, and 20 nm non-agglomerated silica fillers, while the other was GC EverX posterior composite. The third FRC used in the experimental group in the present study was the Fibrafill S cube which is recently introduced. The fracture resistance in the present study was comparable between GC EverX posterior composite™ and Fibrafill CUBE S™ Dentapreg and was significantly higher than the 3M ESPE Filtek Z350 XT restorative composite syringe™.

The higher fracture resistance of GC EverX posterior composite™ and Fibrafill CUBE S™ Dentapreg can be attributed to their structure and fiber composition. The GC EverX posterior composite contains short fibers that prevent fracture propagation and offer fracture toughness comparable to dentin, nearly double that of conventional composites. According to Garoushi et al., the fiber length distribution of EverX Posterior ranged from 0.3 to 1.5 mm. The specific lengths of E-glass fibers embedded in a bis-GMA polymer matrix are crucial because they effectively transfer stress from the polymer to the fibers. This stress transfer is essential for reinforcing the composite material, as the fibers can bear and distribute the load more efficiently, thereby enhancing the overall strength and durability of the composite. Moreover, the fibers are silanized, which enables them to bond chemically with the matrix [7]. According to the present study, a substantial proportion of favourable fractures (40%) define cavities were repaired with EverX posterior composite™ when compared to 3M ESPE Filtek Z350 XT restorative composite syringe™. Similar results were demonstrated for Fibrafill CUBE S™ Dentapreg with 40.9% favourable fractured restored with this material. Frater et al. demonstrated that SFRC has the ability to alter fracture modes to more favorable ones. [1] This is primarily due to the support provided by the SFRC substructure beneath the composite restoration [18].

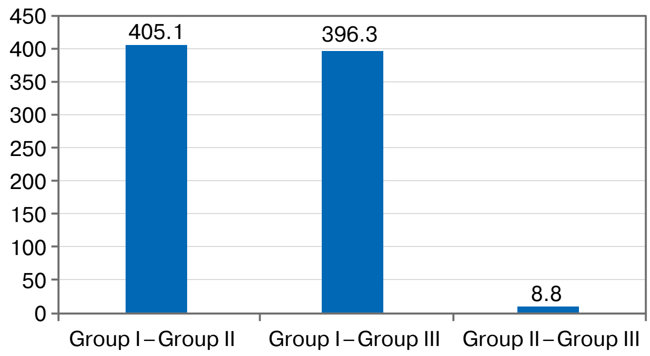

Fig. 4. Bar diagram representing the mean difference in the fracture resistance between the groups

Рис. 4. Столбчатая диаграмма, представляющая среднюю разницу в сопротивлении на излом между группами

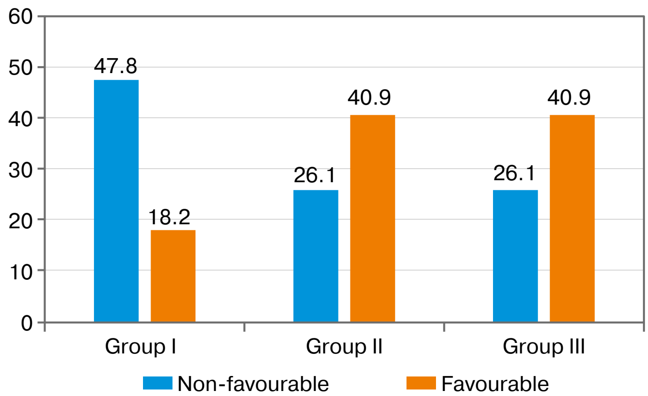

Fig. 5. Bar diagram representing fracture patterns observed in Group I, II, and III

Рис. 5. Столбчатая диаграмма, представляющая типы трещин, наблюдаемые в группах I, II и III

The higher fracture resistance of Fibrafill S cube can be attributed to integrated membrane reinforcement. This material primarily comprises surface-treated continuous glass fibers of special glass. The composition includes silane-treated glass, Isopropylidenediphenol PEG-2 Dimethacrylate (Bis-EMA) and a blend of various resin components including silane-treated silica, Bis-GMA, UDMA, TEGDMA, HEMA, CQ, DMAEMA, and BHT [20].

Furthermore, the material offers a special kind of biomimicry to restore hard tissue, featuring both short scattered fibers and continuous fiber reinforcement. Thus, it makes it ideal for replacing dentin in large posterior applications, minimizing crack development and propagation within dental tissue. This reduces the risk of severe damage to remaining dental tissues, thereby enhancing longevity. Its enhanced fracture toughness as a filling or core build-up material has been demonstrated. Additionally, bulk filling with a cube reduces stress concentration, preserves marginal integrity, and lowers tension during polymerization, resulting in overall robustness and reduced risk of failure [20]. These findings align with the present study, which indicates improved fracture resistance compared to nanohybrid composites, with more favorable fractures observed in FibraFill-filled cavities compared to conventional ones. The structures and features of GC EverX posterior composite™ and Fibrafill CUBE S™ Dentapreg are thus better over the Filtek Z350 XT composite whose diverse nanocluster sizes allow for high filler loading, maintaining strength, fracture resistance, and wear resistance. The resin includes Bis-GMA, UDMA, TEGDMA, and bis-EMA, providing a compressive strength of 360 MPa. Literature reports its fracture toughness comparable to Filtek Supreme XT restoratives and significantly higher than Durafill VS and Renamel Microfill microfills. However, despite changes in filler size and concentration, the resin matrix has not achieved the fracture resistance of a natural tooth [21].

In the present study, a two-step etch-and-rinse adhesive was applied to the tooth structure for all three types of composite resins examined in this study. A research by Tsujimoto A et al. has shown higher bond strength of SFRC to dentin compared to one-step self-etch adhesives [22]. Incremental layering techniques are preferred clinically to reduce polymerization stress and improve mechanical properties. While some studies suggest oblique layering strategies over horizontal ones, no significant differences between various build-up techniques have been found. Therefore, a horizontal layering technique was employed in this study when applying the different composite resins [1].

With respect to the technique adopted for assessing the fracture resistance, a compressive static fracture test was used in the present study. The procedures were performed using Universal Testing Machine [17] and were in accordance with the steps reported by Wu et al. [15] However, the clinical environment, with its dynamic loading conditions, presents differences from earlier in vitro research conducted under static loading conditions. Additionally, variations in factors such as the condition of the teeth, application methods for restorations, and study protocols make it unfair to directly compare the fracture resistance statistics of the current study with those of previous investigations [18]. These factors should be considered as limitations of the present study.

It is important to highlight that, continuous exposure to mechanical and environmental stress on restorations leads to gradual deterioration and the formation of cracks, ultimately resulting in the failure of dental restorations [23]. In extensive class II restorations, cracks can initiate in enamel or dentin, typically at the center of cavity preparations, and progress apically. The lack of visible signs often leads to delayed treatment. Utilizing a dental operating microscope, which provides enhanced magnification, offers valuable insights due to enamel's translucent nature and enables dentists to initiate early treatment, improving prognosis. In the present study, a dental operating microscope was used to assess favorable and unfavorable fractures observed in the experimental samples. This was in accordance with the approach outlined by Scotti et al. [18].

CONCLUSION

FRCs enhance the fracture resistance and strengthen structurally compromised teeth compared to conventional nanohybrid composites. Both short fiber and cubic fiber integrated composites performed similarly in terms of fracture resistance in all experimental groups. Additionally, the use of FRCs prevented further crack propagation, resulting in favorable fractures. These findings suggest that employing membrane-integrated self-assembled glass fiber reinforced composites (SFRCs) as an intermediate layer can improve the fracture resistance of extensive and deep posterior restorations. Future in vivo studies can further explore and support these findings while investigating other physical properties of cubical fiber impregnated composite resin. Future research should concentrate on comparing the flexural strength of the newly introduced fiber-integrated composite resin with flowable composites, supported by clinical investigations to validate the findings.

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