ORIGINAL ARTICLE

Fracture Resistance of Endodontically Treated Molars Restored with Composite Resin after Insertion of Titanium Mesh and Polyethylene Fiber: An in Vitro Study

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ABSTRACT

Background: Direct composite resin restorations are conservative method for replacing lost tooth structure but often face issues like polymerization shrinkage and stress. Although incremental layering helps minimize these effects, it can be time-consuming and increase the risk of defects or contamination. Incorporating fiber reinforcement and titanium mesh may strengthen restorations, improve stress distribution, and preserve more natural tooth structure in endodontically treated teeth.

Method: This in vitro study evaluated the fracture resistance of endodontically treated mandibular molars restored with composite resin reinforced by titanium mesh or polyethylene fiber. Thirty extracted molars were divided into three groups (n=10).Group A - composite only, Group B - titanium mesh, and Group C - polyethylene fiber. After root canal treatment and restoration, samples were tested for fracture resistance using a universal testing machine. Data were analyzed using ANOVA, unpaired t-test, and Chi-square test, with significance set at p<0.05.

Result: It was found that the mean fracture resistance of teeth restored with only composite resin (Group A) was 761N whereas the mean load to fracture Group B and Group C was 1451.7N and 1218N respectively. While comparing these two reinforced groups to the composite resin alone, statistical analysis revealed a significantly greater fracture resistance (<0.05). The highest favorable fracture rate was observed in the polyethylene fiber group (70%).

Conclusion: Compared to composite restorations, the titanium mesh and polyethylene fiber reinforced composite restoration significantly increase the fracture resistance of Endodontically treated tooth (ETT).

Keywords: Endodontically treated tooth; Composite resin; Polyethylene fiber; Titanium mesh; Fracture resistance.

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INTRODUCTION

Traditionally root canal treated teeth are restored by porcelain fused to metal (PFM) or a full-ceramic crown. This procedure may be invasive both in the crown and in the root of the teeth. In case of failure, the invasive nature of such procedures often excludes the possibility of a re-intervention due to the poor quantity of the remaining dental tissues. In addition, it exposes the tooth to a higher risk of irreversible fractures.[1] The emergence of newer and more reliable restorative materials has pushed clinicians to shift the thought process from mandatory crown coverage to an innovative approach of restoring endodontically treated teeth with advanced restorative materials and techniques.[2]. In comparison to alternative restorative materials, direct restoration with composite resin offers greater resistance to tooth fracture and intra-coronal strengthening.[3]

However, one of the factors influencing the outcome of a final restoration is the contraction of vast composite restorations during polymerization. It has previously been proposed to utilize a low viscosity intermediate resin as an "elastic buffer" between the bonding agent and the composite resin.[4] When flowable resin was used in root-filled molar teeth with Mesio-Occluso-Distal cavities, the fracture strength of the teeth was not increased.[5] However, the fracture strength of the teeth was increased when a Leno Weave Ultra High Modulus (LWUHM) polyethylene fiber was placed into the bed of flowable resin. It is therefore suggested to insert fibers against the cavity walls to prevent failure due to the mode of failure of composite and weakened walls in ETT. New techniques and materials may assist the practitioner to approach old issues from a new angle and produce fresh and distinctive solutions that cusp movement reduce and fracture strength improve if fibers

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were applied against the dentinal surface.[5] Additionally, fibers were said to have an impact on C-factor reduction and improved micro tensile bond strength.[5] The occlusal vertical loading-induced lateral forces may be absorbed by the wallpapering technique that places fibers circumferentially in contact with vertical walls. Decrease failure rates or, if they do occur, repair most damages so that they are not catastrophic. If the remaining cavity walls are thinner than 2 mm, there is a higher chance for catastrophic failure.[6] To reduce polymerization shrinkage stress effects, it is recommended that conventional Resin based composite restorations should be placed and cured in 2 mm increments to allow adequate conversion of the unpolymerized RBC resin.[7] So, several increments are required to fill the cavity of endodontically treated tooth because of the large volume of restoration, which is time consuming, increases the risk of contamination between layers, and may include voids in the restoration.[8]

The excellent stiffness, low density, non-toxicity, corrosion resistance and good biocompatibility of titanium mesh make it a popular choice in oral implantology. It can be bent into several shapes because of its flexibility. Titanium particles have no discernible impact on the relative growth rate of human cells.[9] A mature male person can generate an occlusal force that typically ranges on molar sites, from 45 to 68 kg (441.3-666.8 MPa). In contrasting the values for titanium mesh's maximum flexural strength is (503-900) Mpa.[10]

Ribbond (Ribbond, Seattle, WA, USA) is a leno woven, ultra-high-molecular-weight polyethylene fiber. The weaved network enables the resin to be infused into the fibers and wet the strands. At the interface between the enamel and the composite and adhesive materials, a polyethylene fiber network efficiently modifies the stress dynamics and permits efficient force transmission.[11]

Therefore, this in vitro study was conducted to assess if titanium mesh and fiber reinforcement within composite resin could rule out the necessity of crown coverage for posterior teeth that have undergone root canal treatment with a class 1 cavity.

MATERIALS & METHODS

This in vitro quasi experimental study was performed in the Department of Conservative Dentistry and Endodontics, Faculty of Dentistry, Bangladesh Medical University (BMU), Shahbag, Dhaka and Department of Materials and Metallurgical Engineering, BUET, Dhaka.

Sample Selection

Thirty (30) freshly extracted humans first and second molars which were extracted due to periodontal reasons was collected for this study from the department of Oral and Maxillofacial Surgery. The collected teeth were preferably be free of caries and without any fracture lines or cracks and confirmed by pre operative radiograph and transillumination.

Endodontic procedure

Standard access cavity were prepared in all teeth maintaining 1.5 mm diameter of tooth structure using high speed handpiece and round bur (no 4) and an Endo-Z bur with cool water spray. The patency of the file was verified by using a size 10k file into the canal until the tip of the file become visible at the apical foramen. The determination of working length was measured manually by subtracting 1mm from this measurement. Root canal instrumentation was performed in a crown-down manner using copious irrigation of 2 ml of 5.25% NaOCl between each two files. The canals were instrumented in the following sequence: SX, S1, and S2, F1, F2 (Pro Taper Gold File system) which corresponds to #25/.08. Once instrumentation is completed, the final irrigation was done using 5.25 percent NaOCL and 17% EDTA but not simultaneously Prior to sealing, the root canals were dried using appropriate-sized paper points. Single cone obturation was then done with Pro Taper Gold conform fit gutta-percha cones (Dentsply Sirona) and epoxy-amine resin sealer (AH plus sealer).

Sampling Method:

Three experimental groups (10 teeth in each group) were selected by random sampling (lottery method) according to the post endodontic restoration. Three group are named as following

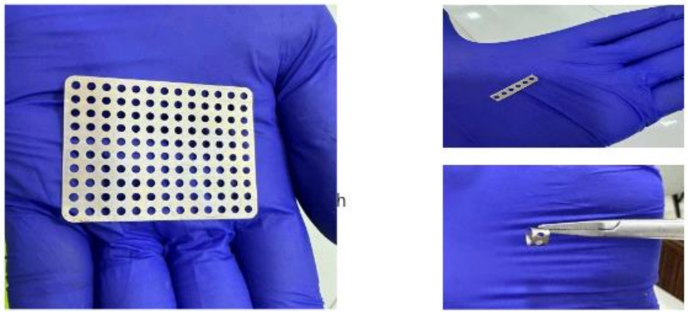
Group A: ETT restored with composite resin.

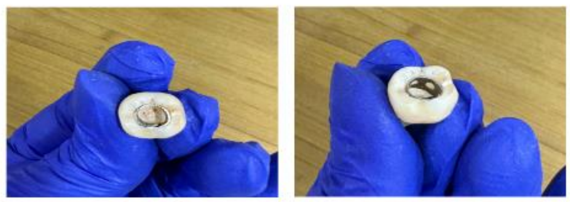
Group B: ETT restored with composite resin after insertion of titanium mesh.

Group C: ETT restored with composite resin after insertion of polyethylene fiber.

Restorative procedure

Group A: The cavity was cleaned and dried. Then, the surface was conditioned with 37% phosphoric acid (B&E Etch-37) for 15 seconds and rinsed with water for 15 seconds. After drying the cavity surface, a bonding agent (G Premio BOND, GC corporation, Tokyo, Japan) was applied with a micro brush and light cured for 10 seconds. After the priming and bonding procedure, the





Circular titanium mesh was coated with adhesive resin first and later placed into the cavity filled with flowable resin

Two pieces of Ribbond Fibers placed in wallpapering technique in the bed of flowable resin cavity surfaces were coated with a layer of low-viscosity resin composite (Filtek Supreme, 3M ESPE, St. Paul, USA). Then, the cavity was restored with nano hybrid composite resin (Filtek™ Z350 XT, 3M ESPE,St. Paul, USA) using an incremental technique and light cured with a LED unit/light-emitting diode unit (DTE O-LIGHT II Curing Light) with an irradiance of 500 mW/cm² for 40 seconds.

Group B: After etching and bonding as described in Group A, the cavity surfaces were coated with flowable composite. Before curing, a piece of titanium micro-mesh plate (0.2 mm thick, 10 mm long) (Medicon, Tullingen, Germany)was cut and shaped into a circular form with the help of Adam's plier. The cut piece was coated with adhesive resin and placed circumferentially into the cavity filled with uncured flowable composite (Filtek Supreme, 3M ESPE, St. Paul, USA). After curing for 20 seconds, the cavity will be restored with nano-hybrid composite (Filtek™ Z350 XT,3M ESPE, St. Paul, USA)using an incremental technique and light-cured for 40 seconds.

Group C: After etching and bonding as described in Group A, the cavity surface was coated with flowable composite (Filtek Supreme, 3M ESPE, St. Paul, USA). Before curing, two pieces of LWUHMW Polyethylene Fiber (8 mm long and 4 mm wide) (Ribbond: Ribbond Inc., Seattle, WA, USA) were coated with adhesive resin. Excess material was blotted off, and the cut fibers were embedded inside the flowable composite circumferentially at the prepared cavity. The first piece of ribbond was carefully adapted to the buccal wall, while the second was positioned against the lingual wall, allowing for an overlap at the proximal surface to enhance structural integrity. The Ribbond pieces were overlapped at the proximal surfaces, each terminating at an imaginary DEJ line in the coronal region and folding down onto the axial pulpal floor in the cervical region. After a curing period of 20 seconds, the cavity was filled using a Nano-hybrid Composite (Filtek™ Z350 XT,3M ESPE,St. Paul, USA) in an incremental manner, with a light curing duration of 40 seconds.

Then finishing and polishing was done in all using Wismed Micromotor and Sofu's Super snap kit. Next, using custom made molds (size 24*12*1), all of the teeth from each group were placed in self-curing acrylic resin block. Up to the cementoenamel junction, the teeth were fully entrenched in the resin. To prevent the teeth from drying, they were placed in an incubator at 37°C for 24 hours until they were subjected to fracture resistance.

Fracture test:
All the teeth were tested for resistance to fracture using a universal testing machine (UTM model 2716-020 50 KN, Illinois Tool Works Inc., USA) with a 6-mm diameter round tip, which was placed parallel to the long axis of the teeth until the bar slightly contacted the occlusal surface. The compressive load applied was at a speed of 0.5 mm/min, and the fracture resistance values were recorded in Newtons for each sample.

Following a visual inspection of each specimen with 3.5X magnification loupes, the fracture mode was identified. As per Ramirez-Gomez et al. (2024), the fracture mode was classified as favorable if fractures occurred only in the composite resin or extended up to 1 mm apical to the Cemento Enamel Junction, and unfavorable if the fracture extended more than 1 mm apical to the CEJ.

Data Collection and statistical analysis:
A clinical checklist were used to record the data. All data were organized in the orderly tabulated form according to pre-determined assessment criteria. Collected data were analyzed by using Statistical Package for Social Science (SPSS)- Version 26. The findings were displayed as needed in tables, figures, diagrams, and graphs. ANOVA and unpaired T test were performed for estimating the significant difference between three groups to assess the fracture resistance. The differences between the fracture mode in respect to CEJ were assessed by the Chi-square test. A p-value was used to indicate the significance of the result, and a value less than 0.05 was regarded as significant.

RESULTS

Table-I compares the fracture resistance of endodontically treated molars restored with three different materials: composite resin (Group A), composite resin and titanium mesh (Group B), composite resin and polyethylene fiber (Group C). The mean fracture resistance in Group A was 761.7±187.3 N, with a range of 425.5 to 975.4 N. Group B showed a significantly higher mean fracture resistance of 1451.7±512.2 N, ranging from 835.0 to 2093.0 N. Group C had a mean fracture resistance of 1218.0±320.5 N, with values ranging from 895.0 to 1669.0 N. There was a significant difference in fracture resistance among the three groups ($p<0.001$), with composite resin and titanium mesh (Group B) demonstrating the highest fracture resistance, followed by composite resin and polyethylene fiber (Group C), and composite resin (Group A) having the lowest.

Table-I: Comparison of fracture resistance of endodontically treated molar among three groups (n=30)

Groups	**Fracture Resistance (Newton)** Mean±SD Range (min-max)
Group A (n=10)	761.7 ± 187.3 (425.5 – 975.4
Group B (n=10)	1451.7 ± 512.2 (835.0 – 2093.0)
Group C (n=10)	1218.0 ± 320.5 (895.0 – 1669.0)

P<0.001 (for ANOVA)
Group A: ETT restored with Composite resin
Group B: ETT restored with Composite resin and Titanium mesh
Group C: ETT restored with Composite resin and Polyethylene Fiber

Table-II shows the comparison of fracture strength of ETT between the three post endodontic restoration groups: Composite resin (Group A), Composite resin and Titanium mesh (Group B), and Composite resin and Polyethylene fiber (Group C). Group A had a mean fracture strength of 761.7±187.3 N, Group B had 1451.7±512.2 N, and Group C had 1218.0±320.5 N. The comparison between Group A (Composite fiber) and Group B (Composite resin and Titanium mesh) showed a highly significant difference (p<0.001), indicating that titanium mesh significantly increases fracture strength compared to composite fiber. The comparison between Group A and Group C (Composite resin and Polyethylene fiber) also showed a statistically significant difference (p=0.028), suggesting Polyethylene fiber provides better fracture strength than composite fiber. However, the difference between Group B (Titanium mesh) and Group C (Polyethylene fiber) was not statistically significant (p=0.492), indicating similar fracture strength between these two groups. Overall, titanium mesh and Polyethylene fiber reinforcement in composite restoration appear to enhance fracture strength more effectively than composite resin alone.

Table-II: Comparison of fracture resistance between two groups (n=30)

Groups	**N**	**Fracture Resistance** Mean±SD Range (min-max)	***p*-value for Unpaired t-test**		
			Group A vs Group B	**Group A vs Group C**	**Group B vs Group C**
Group A: Composite resin	10	761.7 ± 187.3 (425.5 - 975.4)	<0.001	0.028	0.492
Group B: Composite resin and Titanium mesh	10	1451.7 ± 512.2 (835.0 - 2093.0)			
Group C: Composite resin and Polyethylene fiber	10	1218.0 ± 320.5 (895.0 - 1669.0)			

Group A: ETT restored with Composite resin
Group B: ETT restored with Composite resin and Titanium mesh
Group C: ETT restored with Composite resin and Polyethylene Fiber

Table-III shows the association of fracture modes (favorable vs. unfavorable) among the three groups: Composite resin (Group A), Composite resin and Titanium mesh (Group B), and Composite resin and Polyethylene fiber (Group C). In Group A (Composite resin), 20% of fractures were favorable, while 80% were unfavorable. In contrast, Group B (Composite resin and Titanium mesh) had a higher proportion of favorable fractures, with 60% being favorable and only 40% unfavorable. Group C (Composite resin and Polyethylene fiber) showed the highest percentage of favorable fractures at 70%, with only 30% being unfavorable.

Table-IV shows the association of fracture modes (favorable vs. unfavorable between each pair of groups: Composite resin (Group A), Composite resin and Titanium mesh (Group B), and Composite resin and Polyethylene fiber (Group C). In the comparison between Group A and Group B, 20% of fractures in Group A were favorable compared to 60% in Group B, with a p-value of 0.067, indicating that the difference is not statistically significant but suggests a trend towards more favorable fractures with titanium mesh. Between Group A and Group C, there was a statistically significant difference (p=0.025), with Group C showing a higher proportion of favorable fractures (70%) compared to Group A (20%). This indicates that composite resin with polyethylene fiber significantly improves the favorable fractures compared to composite resin alone. In the comparison between Group B (Composite resin and Titanium mesh) and Group C (Composite resin and Polyethylene fiber), the difference was not statistically significant (p=0.639), suggesting similar fracture modes between these two groups. Overall, Group C (composite resin with polyethylene fiber) appears to offer a significant advantage over Group A (composite resin) in terms of promoting favorable fracture outcomes.

Table-III: Percentage of fracture mode relation among three groups (n=30)

Fracture mode	Group A (n=10)	Group B (n=10)	Group C (n=10)
Favourable	2(20.0%)	6(60.0%)	7(70.0%)
Unfavourable	8(80.0%)	4(40.0%)	3(30.0%)
Total	10(100.0%)	10(100.0%)	10(100.0%)

p<0.05, Chi-square test
Group A: ETT restored with Composite resin
Group B: ETT restored with Composite resin and Titanium mesh
Group C: ETT restored with Composite resin and Polyethylene Fiber

Table-IV: Association of fracture mode between two groups (n=30)

Fractur mode	Group A (n=10)	Group B (n=10)	Group C (n=10)	Group A vs Group B	Group A vs Group C	Group B vs Group C
				p-value	p-value	p-value
Favourable	2(20.0%)	6(60.0%)	7(70.0%)	0.067	0.025	0.639
Unfavourable	8(80.0%)	4(40.0%)	3(30.0%)			
Total	10(100.0%)	10(100.0%)	10(100.0%)			

Chi-square test was applied to assess the level of significant
Group A: ETT restored with Composite resin
Group B: ETT restored with Composite resin and Titanium mesh
Group C: ETT restored with Composite resin and Polyethylene Fiber

DISCUSSION

In this study, the fracture resistance of endodontically treated molars restored with composite resin was increased after insertion of titanium mesh and polyethylene fiber. The results found in the present study exhibited both similarities and dissimilarities with those of previous studies. In agreement with the study by Hiremath et al.[12], which indicated that titanium mesh and fiber-reinforced composite could eliminate the need for endodontically treated molars to undergo the necessary crown implantation process, they found the mean fracture resistance of titanium mesh and polyethylene fiber to be 836.7 N and 701.7 N, respectively. In our present study, the fracture strengths were 1451.7 N and 1218 N, respectively. There are certain reasons behind these differences. Depending on the size of the inserted materials, values can vary significantly across different studies. The mechanical properties of titanium mesh, which currently range from 0.1 to 0.6 mm, are directly related to its thickness. In most cases, titanium mesh measuring 0.2 mm is appropriate.[10] Hiremath et al.[12] used titanium mesh with a width of 0.1 mm, whereas we used a variety measuring 0.2 mm. Furthermore, we also employed a wallpapering approach (Abdulamir& Majeed, 2023) along with ribbond fibers, which may have contributed to the higher mean score of fracture resistance.[13] This can also be explained by the fact that composite materials and tooth structure can work in strain harmony when ribbon-like fibers are positioned against cavity walls, acting similarly to the dentino-enamel complex.[14] Additionally, a significant reduction in the volume of composite resin between the tooth structure and the ribbond fiber may be achieved by adapting and polymerizing the ribbond fibers to the contours of the remaining tooth structure. This would protect the remaining walls from stress caused by occlusal load and polymerization shrinkage.

In our present study, the fracture resistance of nano hybrid composite resin is 761N when used in endodontically treated tooth. However, Belli et al.[5] found that the strength of hybrid composite was 729.34N and 786.48N in endodontically treated tooth respectively. It is therefore difficult to compare the results with that of previous studies because most of the previous author used hybrid/micro hybrid composite in their studies but in our study nano-filled composite used as a final restorative material. Hegde et al.[15] used the nano-hybrid-composites and found compressive strength of 312-417 MPa. However, according to Rajeesh et al. [16] although the hybrid composite resin was better than that of nano-hybrid-composites, but the nano-filled composite possesses better results than that of nano-hybrid-composite. So, the differences of results may be not due to the restorative materials only but for the instrumentation technique and irrigation protocol. As per example, Xu et al.[17] showed that NaOCl caused destruction to the root canal wall and intratubular surface, allowing EDTA to demineralize the exposed underlying dentine and thus reducing the root's mechanical strength. The higher the NaOCl concentration, the greater the effects. Furthermore, using hand files instead of rotary files results in a higher load needed to fracture teeth, as they seem to remove less dentine, thereby altering the strength of the tooth.[18]

Cavity dimensions and polymerization shrinkage may also interfere with the fracture strength of composite resin restoration because the contraction stresses produced at the bonding contact increase with the strength of the adhesion between the resin composite and dentin. Belli et al.[5] experimented with combining polyethylene fibers in root-filled molars within a MOD cavity, and investigated if this reinforcement may boost the molars' resistance to fracture. Fracture resistance of the polyethylene fiber groups was 958.64 and 926.88 N, respectively which is differ from our present study (1218 N). It may be due to the fact that class 1 cavity was used in the present study. Moreover, it can be assumed that the cavity also had better supporting tooth tissue, the interaxial dentin, the pulp chamber roof, the marginal ridges, and the remaining number of cusps is responsible for better results which are also supported by Goel et al.[19] Reeh et al.[20] indicated that the interaxial dentin and marginal ridges are the two that affect it the most, but it is vital to understand that these are all interrelated. There is a 20% loss of stiffness with a Class I cavity; this rises to 40% if one of the marginal ridges is destroyed, and to 60% if MOD.

Another important issue is the presence of high C factor in class I cavity. Feilzer et al.[21] proposed an in vitro model in which restorations with a C-factor smaller than 1 are the only ones likely to resist polymerization shrinkage strains, and he highlighted the effect of bonded to unbonded surface area ratios on the development of polymerization stresses with CRs. The micro tensile test was initially used by Yoshikawa et al.[22] to assess the resin-dentin bond in class I cavities. They discovered that all adhesive systems evaluated under high C-factors had lower bond strength. Under and extensive composite restoration, embedding a LWUHM polyethylene fiber into a of flowable resin strengthens the micro tensile binding to dentin.[5] It is thought that the ribbond fiber added to the flowable resin during composite restoration strengthens the dentin's microtensile bond and fracture strength. However, it decreases microleakage in cavities with a high C-factor.[5]

In the current study, Group-A (composite resin) had a mean fracture resistance of 761 N and Group-C (composite resin and polyethylene fiber) had a mean fracture resistance of 1218 N and there is significant difference between them. In comparison to the other groups, composite resin had lowest fracture resistance since they were replaced by using direct composite resin only. The Poisson's effect allows the compression forces to be separated into tensile and shear forces. It could cause a crack to start by spreading to the cavity's floor and walls. Because composite resin is inherently less tough than other materials, crack propagation might result in catastrophic failure.[23] Depending on the position of fracture line, the failure modes were categorized as favorable or unfavorable; concerning the cemento-enamel junction, which is helpful in forecasting the future state of a repaired tooth in terms of failure.[24]

In present study, the group with only composite restoration had shown low fracture resistance in comparison to other two groups and the majority of failures (80%) were unfavorable. Application of titanium mesh was advantageous in relation to fracture resistance but unfavorable fracture patterns (60%) were dominant. The polyethylene fiber group produced remarkably significant fracture pattern than another two groups (70% favorable). It makes sense because of the differences of modulus of elasticity. When a system comprising dentin (18.3 Gpa) and pure titanium (120 Gpa) is loaded, the denser material can withstand under higher forces without deforming, transferring the stresses to the less rigid tooth structure and resulting in intra-radicular stress concentrations that can lead to unfavorable fractures.[25] According to Scully, normal masticatory load of human tooth in molar region is 500-700 N. Even in bruxism patient, it is as high as 1000N. According to present study we can say that, though titanium mesh offers unfavorable fracture dominantly, but it can be withstand under 1451.7N pressure which is higher than the maximum masticatory load. On the other side, the ribbond fiber group with a modulus of elasticity of 23.6 Gpa, exhibits the favorable mode of fracture (70%) most. LWUHMWPE ribbon's locked stitch interwoven framework structure, which has nodal crossings that enable intrinsic stress and an energy-absorbing mechanism.[5] The ability of polyethylene fibers to conform to the shape of teeth is enhanced by their structure.[5] The polyethylene ribboned fiber slows the spread of cracks and boosts the load-bearing capability of restorative material.[26] Furthermore, this material's adherence to composite resins is increased by using cold gas plasma during production.[27] The density of the fixed nodal intersections of ribbond fibers preserves the integrity of the restoration and efficiently distributes the stresses across it along well-defined routes. [28]

Conclusion

The fracture resistance of endodontically treated molars are greatly enhanced after incorporating titanium mesh and polyethylene fiber within composite resin. Moreover, Polyethylene fiber-reinforced composite restorations appear to be a more dependable restoration method since they demonstrated a favorable fracture pattern under occlusal loading.

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