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Assessment Of Non- Thermal Atmospheric Plasma on The Push Out Bond Strength of Fiber Reinforced Post in Root Canal System- an in vitro study.

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Abstract:
Objective: To measure the effect of Non-Thermal Atmospheric Plasma (NTAP) on the push out bond strength of fiber reinforced post luted to root dentin, using two separate luting agents; Multilink (dual cure composite resin) and Glass ionomer cement (GIC).
Methodology: 64 extracted human teeth samples were prepared. Root canal treatment was performed, and post space preparation was done in all the samples. This was followed by exposure of half the samples with NTAP and the remaining half samples were not NTAP treated. Fiber post was luted with Multilink composite and GIC to the samples accordingly. Push out bond strength was measured in all the samples under Universal Testing Machine and the values were recorded in Newton.
Results: The push out bond strength in all the samples that were surface treated with NTAP was significantly higher than the samples which were not surface treated.
In case of luting agents Multilink showed a statistically higher value than GIC and the push out bond strength of all the samples were significantly higher in the coronal one third when compared to middle one third.
Conclusion: NTAP surface treatment of root dentin is helpful in achieving a superior bond strength of fiber post to root canal walls and gives favourable outcomes.
Key Words: CAAP (cold atmospheric air plasma), NTAP, Universal testing machine, push pout bond strength, multilink adhesive, GIC.

Introduction

The restoration of teeth that have undergone endodontic treatment is a highly complex procedure which requires careful planning to ensure optimal outcomes over long term.(1,2) The conventional and approved approach is to use a post and core restoration, which has a crown placed on top.(3)

The use of a post is crucial for constructing a core material when there is significant loss of tooth structure.(4,5)

Fiber posts are most commonly used and are crafted by embedding pre-stretched fibers into a resin matrix. These fibers can be made from materials like carbon, glass/silica, and quartz, while epoxy and bis-GMA are commonly used resin matrixes. The structure of the resin matrix is crucial as it allows the fiber post to possess an elastic modulus similar to dentin (around 30 GPa), which isn't so with a metallic post (about 108.6 GPa). Consequently, stress is absorbed and distributed more evenly throughout the root structure, diminishing the likelihood of irreparable fractures.(6)

Fiber posts are cemented to inter-radicular dentin by adhesive cementation which creates micromechanical bond that is formed by hybrid bonds and resin tags. The interdiffusion of liquid resin, which replaces the hydroxyapatite crystals lost during the etching process, occurs in demineralized dentine collagen fibers to form the hybrid bond. The adhesion of root canal cement is obtained through an adhesive bond formed between a fiber post and resin cement by polymerization process of matrix resin.(9,10)

However, the most common problem encountered is post debonding from the root dentin. In order to facilitate better penetration and absorption of bonding agent different techniques of dentine surface treatments have been advocated.

In particular, cold-atmospheric plasma (CAP) has garnered interest as a successful surface alteration technique.

Since a lot is still not known about the effect of cold plasma on dentin surface treatment hence the **objective of our study is to observe the effect of Non-Thermal atmospheric plasma on the push out bond strength of fiber reinforced in root canal system.**

Materials and methodology

- A total of 64 extracted maxillary central incisors (11 and 21) teeth were collected for this study which were having periodontal disease. All selected teeth had similar dimensions (confirmed using a digital calliper).
- **Inclusion criteria**:

1. Single rooted anterior teeth.
2. Teeth free of visible cracks.
3. Caries free teeth.

- **Exclusion criteria**:

1. All teeth with root caries
2. Previous restorations
3. Endodontically treated teeth
4. Fractured teeth
5. Teeth with Open apex
6. Teeth with Calcified canal

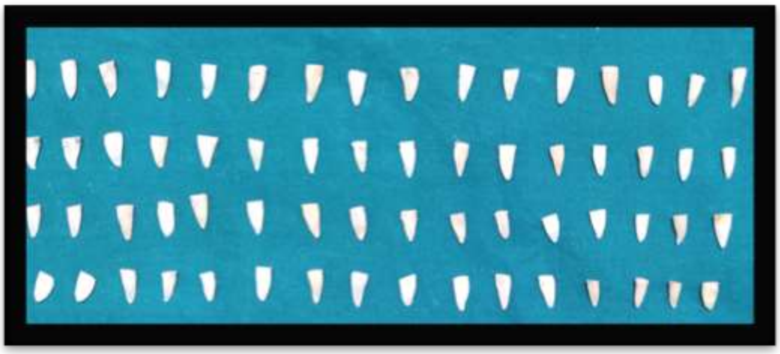


Fig 1: decoronated tooth sample

Fig 2: Post Space preparation

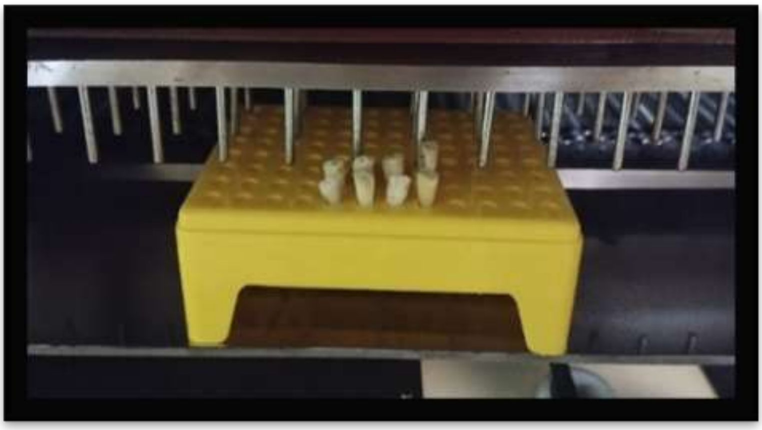


Fig 3: NTAP exposure to the samples

Fig 4: Cold Plasma Machine along with samples ready to be exposed.

Fig 5: fiber post luted with Multilink

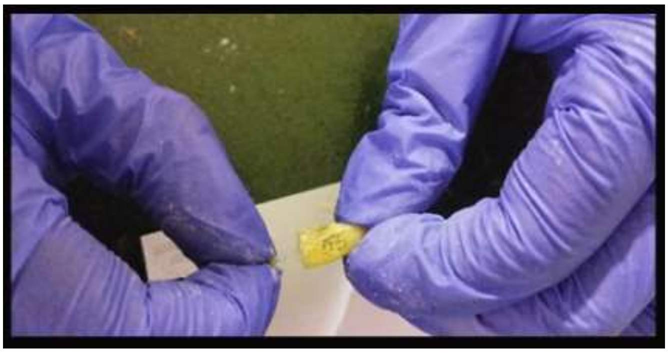


Fig 6: fiber post luted with GIC

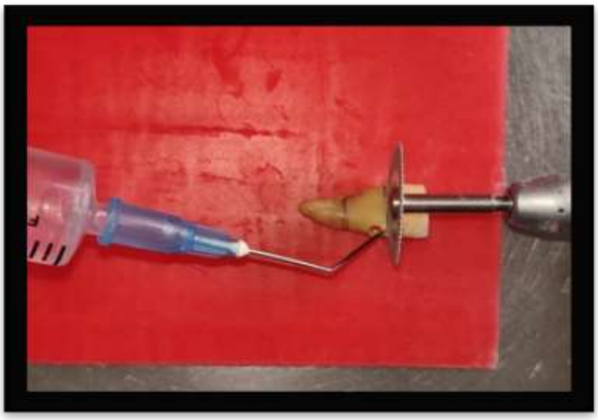


Fig 7: Samples being sectioned under water coolant to obtain coronal and middle third parts.

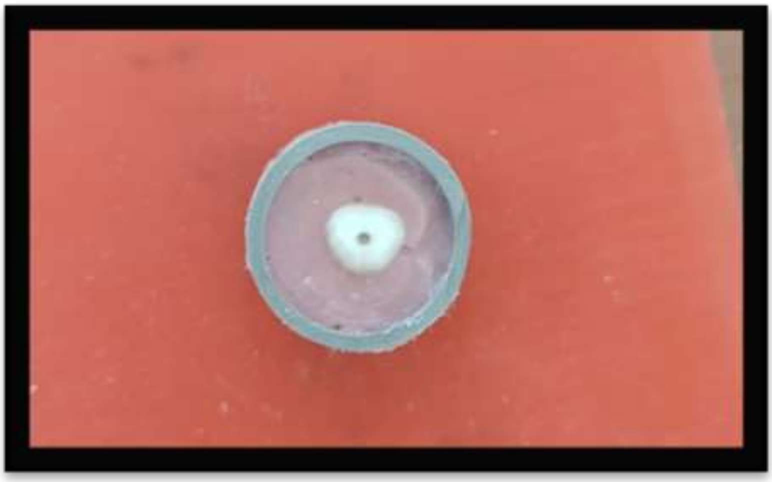


Fig 8: JIG

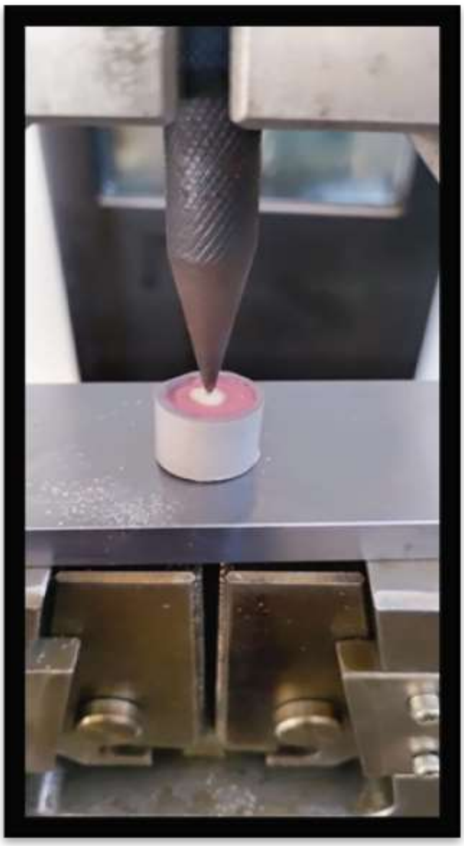


Fig 9 : Universal testing machine with samples to be tested for push out bond strength.

- All the extracted teeth samples were cleaned with an ultrasonic tip (WOODPECKER) to remove any debris and soft tissues remnants. The specimens were then disinfected by immersion in 0.5% chloramine-T solution for one week, stored in distilled water until the time of use (maximum of 3 months).
- Decoronation was done at 1 mm above the cementoenamel junction using a diamond disc under copious water irrigation.
- Access was refined with an airotor (NSK) hand piece.

- A 10 K hand file (Mani, Japan) was inserted into the canal to check the patency. The file was progressively inserted in the canal, until it was seen coming out of the apical foramen.
- Working length was determined by decreasing the length by 1 mm short of the apex. The root canals were then instrumented with hand files by conventional technique to a size of 60K file. Irrigation protocol followed for the study was the use of 5 ml of saline followed by 5 mL of 5.25% sodium hypochlorite (Cerkamed, Poland) and a final rinse of 5 ml of saline.
- The canals were dried with paper points and were obturated with 60 ISO size gutta percha as master cone and using 25 size gutta-percha for LATERAL COMPACTION making use of size 25 finger spreader.
- The sealer used was AH Plus sealer - resin based sealer.
- Now all the teeth were stored for 24 hours for the sealer to set.
- In order to prepare the post space, first a heated hand instrument (50 K file) was used to remove Guttapercha leaving 5 mm in all the canals. This was followed by the use of GG Drills (Mani, Japan) and Peezo-reamers (Mani, japan). All the canals were enlarged up till the size of GG Drill number 3 and piezo reamer number 3.
- In the present study the fiber post used is by the company SUPER ENDO and the size selected was the black band fiber post for all the samples to maintain standardization.
- The samples were now divided into four groups in order to segregate them into categories of NTAP exposure and absence of NTAP exposure.
- The duration of exposure of root dentin surface to NTAP was kept at 30 seconds at a voltage of 22Kv.

A) GROUP I : Root dentin surface treatment with NTAP and fiber post luted with dual cure resin cement (MULTILINK). (n=16)
B) GROUP II : Root dentin surface treatment with NTAP and fiber post luted with Glass Ionomer cement (GC Gold Label). (n=16)
C) GROUP III : No surface treatment of root dentin with NTAP and fiber post luted with dual cure resin cement (MULTILINK). (n=16)
D) GROUP IV: No surface treatment of root dentin with NTAP and fiber post luted with Glass Ionomer Cement (GC Gold Label). (n=16)

- The samples were now divided into three parts and the push out Bond Strength was measured for at the coronal and middle third part.
- The apical part of the teeth having gutta percha was discarded.
- Testing of push out bond strength was performed on cut specimens of tooth mounted on acrylic jigs.
- The acrylic jig was prepared using a diamond disc under water coolant to obtain 2mm-thick sections from the coronal and middle thirds of the roots. The thickness of slices was checked using a digital caliper (Mitutoyo, Japan) with 0.01 mm accuracy. The coronal side of each slice was marked by a waterproof marker which is subjected to testing.
- Cylindrical plastic tubes were cut of dimension 2cm X 2 cm.
- Now on a glass slab a wax sheet was spread and the 2mm thick sections of the tooth sample were embedded on the wax sheet keeping the coronal surface of the tooth towards the wax sheet.
- The cylindrical plastic tubes were then placed over the sectioned teeth and monomer and polymer were added to it and were kept untouched until they set. The wax sheet

was removed to reveal the tooth surface. The samples were now ready to be tested under the universal testing machine for the micro pushout bond strength.

- A plunger with 0.8 mm diameter applied load to the center of the posts at a crosshead speed of 2 mm/min. The maximum load tolerated by the posts was recorded in Newton (N).
- The PBS was calculated in megapascals (MPa) by dividing the force (N) by surface area of the testing material where,

N/2p x r x h

1. **p is the constant 3.14**
2. **r is the root canal radius** and
3. **h is the thickness of the root canal slice in millimetre**.

- All the data were analysed using the version of SPSS for windows V25 software.

Statistical analysis.

The groups were compared using:

1. Independent Student's t test.
2. One factor analysis of variance (ANOVA).
3. The significance of mean difference between (inter) groups was done by Tukey's HSD (honestly significant difference) post hoc test after ascertaining normality by Shapiro-Wilk's test and homogeneity of variance between groups by Levene's test.

$P < 0.05$ was considered statistically significant.

Analyses were performed on SPSS software (Windows version 22.0).

Results

1. According to Table 01 and figure 10 it was observed the the push out bond strength was highest in the groups were surface treatment with NTAP and multilink was used as the luting agent for post cementation in all the coronal samples.

Table 01: Summary and comparison of push out bond strength (MPa) among four groups at coronal one third by ANOVA.

Group	Mean ± SD (n=16)	F value	P value
NTAP exposure with multilink bonding	22.07 ± 1.14	623.00	< 0.001
No NTAP exposure with multilink bonding	12.39 ± 1.17		
NTAP exposure with GIC bonding	20.62 ± 0.87		
No NTAP exposure with GIC bonding	8.64 ± 0.93		

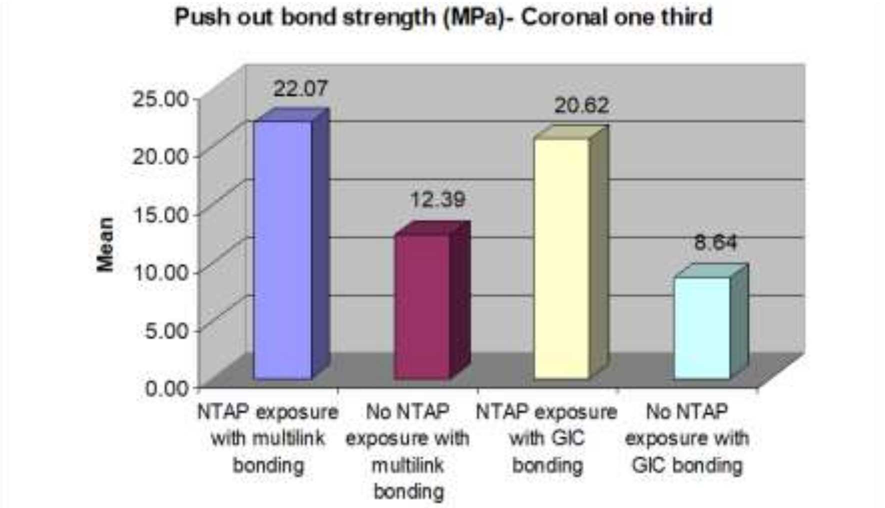


Fig. 10. Mean push out bond strength of four groups at coronal one third.

2. Similar results were observed in all the samples in the middle one third of root surface.

Table 2: Summary and comparison of push out bond strength (MPa) among four groups at middle one third by ANOVA.

Group	Mean ± SD (n=16)	F value	P value
NTAP exposure with multilink bonding	17.43 ± 1.22	321.90	< 0.001
No NTAP exposure with multilink bonding	9.19 ± 0.86		
NTAP exposure with GIC bonding	15.86 ± 1.17		
No NTAP exposure with GIC bonding	6.55 ± 1.34		

Push out bond strength of four groups at middle one third were summarized in Mean ± SD and compared by ANOVA (F value).

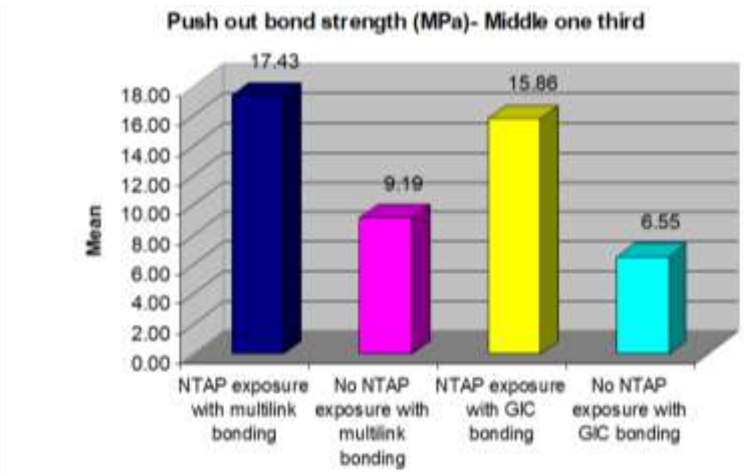


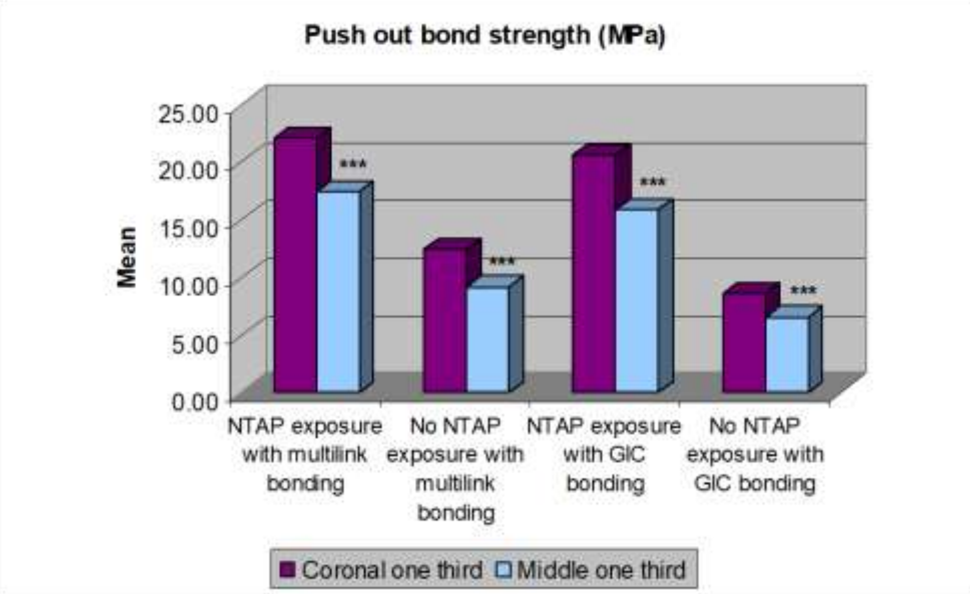
Fig. 11. Mean push out bond strength of four groups at middle one third.

3. Lastly all the samples in the coronal one third were compared with all the samples in the middle one third and it was observed that the push out bond strength of all the samples in the coronal one third was significantly higher than the samples in the middle one third.

Table 3: For each group, comparisons of difference in mean push out bond strength (MPa) between two parts by Student's t test.

Group	Coronal one third	Middle one third	Mean diff.	t value	P value
NTAP exposure with multilink bonding	22.07 ± 1.14	17.43 ± 1.22	4.65	11.13	< 0.001
No NTAP exposure with multilink bonding	12.39 ± 1.17	9.19 ± 0.86	3.20	8.81	< 0.001
NTAP exposure with GIC bonding	20.62 ± 0.87	15.86 ± 1.17	4.76	13.07	< 0.001
No NTAP exposure with GIC bonding	8.64 ± 0.93	6.55 ± 1.34	2.08	5.09	< 0.001

Push out bond strength of two tooth parts were summarized in Mean ± SD and compared by Student's t test (t value).



***P < 0.001- as compared to Coronal one third

Fig. 12. Comparisons of difference in mean push out bond strength between two tooth parts.

Discussion

The core principle of adhesion relies on bringing the bonding solution and substrate into close proximity to facilitate molecular connection, allowing for either chemical absorption or surface micromechanical entanglement. Successful dentin bonding hinges on the adhesive system's ability to wet the dentinal surface effectively, coupled with the surface's capability to support and improve wettability.(11–14)

However, challenges like thicker smear layers, inadequate moisture control, low acidity, and neutralization of acidic monomers in self-etch primers within root dentin raise concerns about the efficacy of self-etch adhesives in penetrating root dentin. Recent efforts have focused on developing dentin surface modification techniques either chemical/electrical methods to enhance the penetration and absorption of bonding agents, which aims to address the limitations of adhesives in the root canal system.(15–17)

In this study Non-thermal atmospheric plasma is a novel technique that can be used as a surface treatment agent that improves the bond strength and also improves dentin surface characteristics. Plasma treatment acts by enlarging dentinal tubule openings and reduces smear layer thickness. It enhances the bond strength to both enamel and dentin by elevating its surface energy. This facilitates favourable interactions between the adhesive and substrate without causing an increase in surface temperature.(18)

Non-thermal atmospheric plasmas consist of charged species, radicals, and energetic photons that can induce targeted surface modifications. Through plasma treatment surfaces can experience increased surface energy and acquire hydrophilic characteristics by eliminating hydrocarbons and introducing hydroxyl groups.(11)

In the present study, argon was used because previous studies have shown that argon creates a hydrophilic surface more effectively than helium. (16,18,19)

A 30 seconds of plasma treatment decreases the water contact angle of dentine surface from 65º to 4º, which is close to a value of super hydrophilic surfaces. This feature of non-thermal atmospheric plasmas plays a significant role in the observed better penetration of the model adhesive.(11)

Various studies have shown when NTAP is applied to the dentin surface the penetration of the adhesives especially those containing HEMA that are hydrophilic, increases due to increased surface hydrophilicity.(18)

There is an increase in bond strength of Bis-GMA compound after the application of NTAP as it removes excess water from the collagen network without collapsing the collagen matrix. This increases the penetration of Bis-GMA content in the hybrid layer leading to fully formed resin tags, increasing the bond strength. The above reactions are due to the availability of charged and reactive particles in the plasma inducing polymerization and interaction between the dentin surface and infiltration of the adhesive.(18)

Collagen fibers are natural polymers that have functional groups embedded in their structure, which prevents interaction with dental adhesives. This prevents the collagen fibers from forming covalent bonds with the functional monomers of adhesives. The application of plasma on the collagen surface allows collagen functional groups to temporarily lose their covers to interact with the functional groups of adhesives.(18)

According to **Mahounak et al** CAAP can induce chemical bonding between HEMA and dentin collagen. The reactive oxygen species in the plasma can be used in the form of carbonyl groups in type I collagen molecules thro which surface interactions play a role in increasing the hydrogen bonds between the collagen fibrils and adhesive. Strong chemical and physical bonds formed by plasma treatment subsequently promote the migration of HEMA into demineralized dentin.(15)

Another reason for enhancing the adhesive–dentin bonding strength is that plasma treatment could introduce activated sites, such as free radicals or peroxides to the dentin surface which would initiate polymerization of adhesive monomers and graft resin onto the collagen fibrils through covalent chemical bonding.(20)

With respect to the second observation of the study that multilink showed superior bond strength than GIC it can be said that the setting reaction of multilink takes place due to extensive cross-linking of monomers and creates high molecular weight polymers. Water released during the process contributes to the initial hydrophilicity of cement that provides improved adaptation to the tooth structure.(19,21–23)

GICs showed the lower mean push-out bond strength as compared to other groups, because adhesion mechanism of GIC is purely chemical in nature leading to the formation of an “ion-exchange” layer consisting of reciprocal diffusion of ions from GIC and dentin. A chemical bond is formed between carboxyl groups of polyakenoic acid and the calcium component of hydroxyapatite. The failure occurring are cohesive in nature within the cement rather than at the

chemical interface between glass ionomer and dentin. However, GICs require 4–6 weeks to attain the maximum strength and the voids due to air entrapment reduces the bond strength of GICs.(21)
Lastly the fact that coronal one third of root presents a higher bond strength that middle one third of the root surface because of the fact that dentinal tubules are cleaner, larger, denser, and more vertically oriented in the coronal region and provide a higher bond strength to the fiber post in this region.
The coronal dentin often has a higher mineral content and different collagen orientation compared to the middle one third of dentin. Polymerization of adhesive materials might be more effective in the coronal portion due to better penetration of light or other polymerization methods, resulting in stronger bonds. Also, the middle one-third of the root is more prone to flexure and deformation under functional loads compared to the coronal one-third. This increased flexure can potentially compromise the bond strength of fiber posts in this region.(15)

Conclusion
Within the limitations of this study it can be concluded that the exposure with Non Thermal Atmospheric plasma helps to increase the push out bond strength of fiber post when luted in root canal system. Multilink is a better adhesive than GIC and the push out bond strength in the coronal one third is superior than the middle one third.

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