Original Article

The Effect of Nonthermal Plasma on the Push-Out Bond Strength of Two Different Root Canal Sealers

KY Yeter, B Güneş, A Terlemez[1], E Şeker[2]

Departments of Endodontics and [2]Prosthodontics, Eskişehir Osmangazi University, Faculty of Dentistry, Eskişehir, [1]Department of Endodontics, Necmettin Erbakan University, Faculty of Dentistry, Konya, Turkey

Received: 22-Oct-2019; **Revision:** 02-Dec-2019; **Accepted:** 03-Feb-2020; **Published:** 11-Jun-2020

ABSTRACT

Background: An optimum bonding between the sealer and dentin is important for impermeable root canal filling and many procedures were applied to improve root canal dentin and in turn the bond strength between the sealer and dentine. There is lack of sufficient data on the effect of nonthermal plasma application on the bond strength of sealers to the root canal dentin. **Aim:** The purpose of this study was to evaluate the effect of NAP on the push-out bond strength (PBS) of a bioceramic and resin-based root canal sealer (RCS) to root canal dentin. **Materials and Methods:** Forty single-rooted mandibular premolars were decoronated. After preparation and final irrigation, the specimens were divided into four groups (n = 10). Group AH: Root canals were filled with gutta-percha (GP) and AH Plus RCS, Group P-AH: Root canals were filled with GP and AH Plus RCS following the NAP application, Group BC: Root canals were filled with GP and Endosequence BC RCS, and Group P-BC: Root canals were filled with GP and Endosequence BC RCS following the NAP application. Then roots were sectioned horizontally to obtain ~1 mm thick dentin disks. PBS test was performed to the second (coronal) and fourth (middle) slices. Data were analyzed with the Kruskal–Wallis and *t*-test. **Results:** There was a statistically significant difference among the groups for both coronal and middle regions ($P < 0.05$). P-BC group showed higher PBS than AH and P-AH groups in the coronal region. P-BC group showed higher PBS than the other groups in the middle region. **Conclusions:** The use of NAP did not influence the push-out bond strength of AH-Plus sealer to the root canal dentin. The Endosequence-BC sealer showed a better bond strength than the AH-Plus sealer after NAP application.

Keywords: *Bioceramic sealer, epoxy resin sealer, non-thermal atmospheric pressure plasma, push-out bond strength*

Introduction

A complete debridement, elimination of microorganisms, and a fluid-tight seal filling of the root canal system is necessary to provide a successful root canal treatment.[1] This prevents recontamination of root canal syWstem with microorganisms and their by-products which are the main factors of pulpal and periapical pathosis.[2] Using gutta-percha (GP) with root canal sealers (RCSs) is the common procedure to fill the canals.[3] Bonding between the dentin and RCSs through micromechanical retention or frictional resistance is favorable in sustaining the unity of sealer–dentin interface.[4,5]

Many types of RCSs are available in the market. Recently, bioceramic-based RCSs like mineral trioxide aggregate (MTA) are favored because of their biocompatibility and bioactivity.[6,7]

Endosequence BC (Brasseler USA, Savannah, GA), a bioceramic-based RCS, is composed of tri- and di-calcium silicate, calcium hydroxide,

Access this article online

Quick Response Code:

Website: www.njcponline.com

DOI: 10.4103/njcp.njcp_578_19

Address for correspondence: Dr. KY Yeter, Department of Endodontics, Eskisehir Osmangazi University, Faculty of Dentistry, 26480 Eskisehir, Turkey. E-mail: kubrayesildal@gmail.com

How to cite this article: Yeter KY, Güneş B, Terlemez A, Şeker E. The effect of nonthermal plasma on the push-out bond strength of two different root canal sealers. Niger J Clin Pract 2020;23:811-6.

calcium phosphates, and colloidal silica as inorganic components.[8] It can be used as a premixed paste as it contains water-free thickening vehicles. Zirconium oxide was added to the sealer as the radiopacifier.[9] It is a hydrophilic and insoluble material that uses the moisture in the dentinal tubules to accomplish the setting procedure.[10]

AH Plus (Dentsply, Konstanz, Germany), an epoxy resin-based RCS, is defined as the "gold standard" in literature. In addition, it is the most commonly used RCS[11,12] which contains Bisphenol-A and Bisphenol-F epoxy resins, zirconium oxide, calcium tungstate, silica, aerosol, and iron oxide pigments in Paste A; N-Dibenziyl-5-oxanonane, silica, aminoadamantane, TCD-diamine, calcium tungstate, tricylodecane-diamine, silicone oil aerosol and zirconium oxide in Paste B. AH Plus has some advantages such as biocompatibility, low solubility, and adhesion to dentine.[12]

There are many applications that could change the surface properties of root canal dentine to improve the bond strength between the sealer and dentin. These procedures change the physical conditions of dentine by removing the smear layer, thereby opening the dentinal tubules and increasing the wettability of root canal dentin.[13-15]

Plasma that contains highly reactive particles such as electrons, ions, electronically excited neutrals, and free radicals is the fourth state of the matter. Nonthermal atmospheric plasmas (NAP) are partially ionized gases at room temperature.[16,17] The highly energetic particles are carried to the plasma-treated surfaces after plasma application.[18] NAP treatment causes changes on the surface energy of the materials and increases the bonding ability of the plasma-treated surface.[19] In recent years, NAP has several applications in dentistry such as root canal disinfection,[20] tooth bleaching,[21,22] changing dentinal conditions to improve adhesion.[23] NAP improves the adhesive properties between the enamel, dentinE and composites and also increases the wettability of enamel and dentin.[17] The dentin tubules were found to develop hydrophilic property upon NAP treatment and thus increase the penetration depth of the adhesive materials.[19,24] Many studies[23,25,26] showed that NAP improved the bonding strength between dentin and adhesive materials. To our knowledge, no study has compared the effect of NAP application on the push-out bond strength (PBS) of Endosequence BC sealer.

The purpose of this *ex-vivo* study was to investigate the effect of NAP application on the PBS of a bioceramic- and a resin-based RCS to dentine. The null hypothesis was that nonthermal plasma has no effect on the PBS of sealers.

Materials and Methods

Specimen selection

The protocol of this study was approved by the Ethics Committee of the Eskisehir Osmangazi University (80558721/G-56). Freshly extracted 40 human mandibular premolars were used. Inclusion criteria were: teeth with a single and straight root canal; a straight, nonresorbed, noncarious, and at least 15 mm length root without any cracks. Teeth were stored in distilled water and decoronated 15 mm from the apex with a high-speed handpiece under water cooling.

Root canal preparation

A #10 K file was inserted into the root canal until it was visible from the apical foramen to measure the working length. After working length determination, the root canals were prepared with a single file system (Reciproc R50, VDW, Munich, Germany). 5% NaOCl was used for irrigation during the preparation procedure. Final irrigation was performed with 5 mL of 17% EDTA, 5 mL of 5% NaOCl, and 5 mL of distilled water, respectively. The root canals were dried with paper points before the filling procedure.

Splitting the specimens

Specimens were divided into four experimental groups: (n = 10)

Group AH: Root canals were filled with AH Plus sealer and GP,

Group P-AH: Root canals were filled with AH Plus sealer and GP following the NAP application,

Group BC: Root canals were filled with Endosequence BC sealer and GP,

Group P-BC: Root canals were filled with Endosequence BC sealer and GP following the NAP application.

NAP application

For plasma application, a plasma jet equipment with Argon gas (Kinpen 11, Neoplas, Germany) was used with a flow rate fixed as 5 L/min. [Figure 1]. The pressure of argon gas was stabilized at 2.5 bars and the length between the root canal orifice and the nozzle of plasma was fixed and standardized as 5 mm throughout the whole plasma application process. Plasma application was performed to each root canal for 30 sec with a 15-mm-length plasma stream.

All root canals were filled with the cold lateral compaction technique. After the procedure, the orifices of the root canals were sealed with a temporary filling material (CavitG, 3M ESPE, Germany).

Preparation of specimens for push-out test

Specimens were incubated at 37°C and 100%

humidity for 1 week to allow setting of the RCSs. Then the specimens were buried perpendicularly in autopolymerized acrylic resin (Meliodent, Bayer Dental, Leverkuser, Germany) and the roots were sectioned horizontally with a low speed, water-cooled diamond saw (Buehler, IL, USA) to obtain ~1 mm thick slices. The first two slices from the corona were termed as coronal and the third and fourth were termed as middle. [Figure 2]

PBS test

PBS test was performed on the second and fourth slices. A metallic plunger with the speed of 0.5 mm/min was used in the apical–coronal direction [Figure 2] until the root filling material was displaced from the root canal with a universal testing machine (Instron). The maximum load was quantified in Newtons (N). The N value was converted to megapascals (MPa) for each segment by dividing the N value into the total bonding area. The total bonding area was calculated with this equation for each dentin disk: $\pi(r_1 + r_2)$ h, where h is the thickness of disk, r_1 apical radii of the root canal, r_2 is the coronal radii of the root canal, and π =3.14.

Statistical analysis

Data were statistically analyzed with the statistical package program SPSS 18.0 (SPPS Inc, Chicago, IL, USA). The significance threshold was determined as 5%. According to the Kolmogrov–Smirnov test, the data was not normally distributed. So, the Kruskal–Wallis test and *t*-test were performed for the statistical analysis of the obtained data.

Results

The mean and standard deviation values of each experimental group are shown in Table 1. There was a statistically significant difference between the groups with regard to both coronal and middle regions ($P < 0.05$). In the coronal region, while the P-BC group showed higher PBS than the AH and P-AH groups, no statistically significant difference was found between the P-BC and BC groups. In middle region, the P-BC group showed higher PBS than all the other groups. Upon comparison of the bond strength values of the coronal and middle regions, a significant difference was found only in the P-AH group ($P < 0.05$). The coronal region showed higher PBS than the middle region in the P-AH group. However, there was no significant difference with respect to the different root regions in the AH, BC and P-BC groups. ($P > 0.05$)

The failure modes were determined under stereomicroscope as adhesive, cohesive, and mixed failures. Adhesive failure is the failure at the sealer–dentin interface; cohesive failure is the failure within the filling material, and mixed failure is the occurrence of both adhesive and cohesive failures in a specimen. Representative SEM images were obtained for each failure mode. The examples of failure modes are shown in Figure 3. The distribution of the percentage of failure modes are shown in Table 2. In the AH group, the most dominant failure mode was mixed for both coronal and middle regions. In the P-AH group, the most

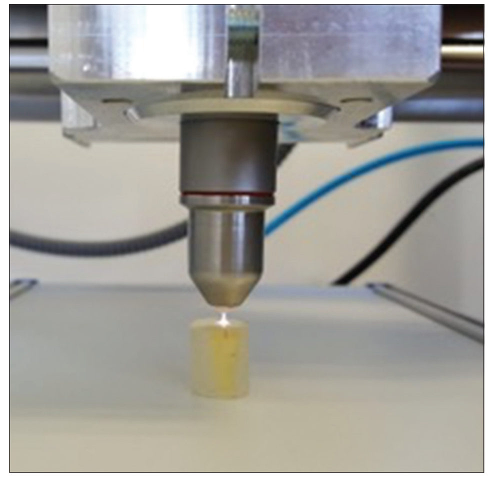

Figure 1: Application of NAP into the root canal

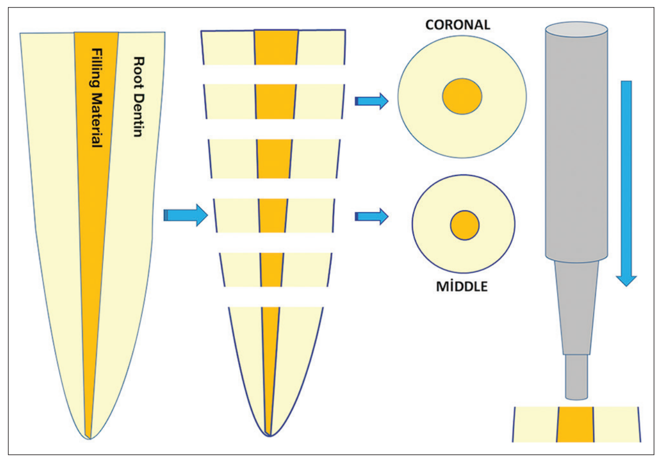

Figure 2: Schematization of the preparation of the dentin disks for the push-out test and implementation of push-out test

Table 1: Mean bond strength values of coronal and middle thirds in MPa

	Coronal		Middle	
	Mean	Std. deviation	Mean	Std. deviation
AH	3,262^{aA}	1,409	2,455^{aA}	1,575
PAH	5,018^{aA}	1,816	3,322^{aB}	0,870
BC	5,33^{abA}	5,83	5,34^{aA}	5,39
PBC	11,14^{bA}	11,44	12,73^{bA}	10,89

Different lowercase letters in same columns indicate statistical significant difference between experimental groups. Different uppercase letters in same rows indicate statistical significant difference between root regions of each group

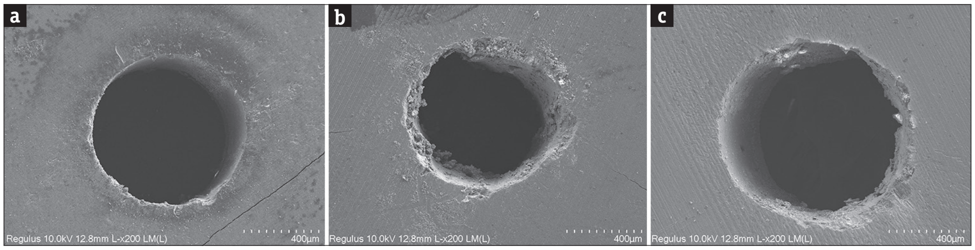

Figure 3: SEM images for each failure mode. (a) Adhesive failure mode, (b) cohesive failure mode, (c) Mixed failure mode

Table 2: Distribution of failure modes in percentages (%)

		Adhesive	Cohesive	Mixed
AH	Coronal	-	10	90
	Middle	20	-	80
PAH	Coronal	-	10	90
	Middle	50	-	50
BC	Coronal	-	30	70
	Middle	-	40	60
PBC	Coronal	-	80	20
	Middle	-	50	50

common failure mode was mixed for coronal region but mixed and adhesive failure modes occurred evenly in the middle region. In the BC group, mixed failure mode was the dominant mode for both coronal and middle regions. In the P-BC group, cohesive failure mode was the most common mode for coronal region and the percentage of cohesive and mixed failure modes were equal.

Discussion

NAP application is a contemporary subject in endodontics. Excited atomic, molecular, ionic, and free-radical species are included in NAP which is a partially ionized gas.[26] These species can enhance the surface energy of the applied area, making it perform better molecular interactions.[27] This characteristic of cold plasma could improve the adhesion of dentin surface/adhesive material.[26] In this study, the effect of 30 s NAP application on the PBS of AH Plus and Endosequence BC sealers was evaluated.

In this study, for testing the bond strength of resin cement to the root dentin, the push-out test was used. The PBS test provides uniform stress distribution throughout the resin–dentin interface of the dentin disk and lessens the occurrence of premature failures. Also, it allows to examine the bond strength of different root canal regions. The thickness of the dentin disk is also important for push-out testing. The optimum thickness for the disks was reported to be 1 mm because with decreased thickness of dentin disks, the risk of friction and stress distribution decreased.[28] Diameter of the plunger is another factor that can affect the results of PBS test. The ratio of the diameter of the plunger and GP must be more than 60%.[29] All of these factors that may affect the results of PBS test were considered throughout the study and the thickness of the dentin disks were determined as 1 mm. The tip of the plungers was determined as 0.8 mm for coronal region and 0.6 mm for middle region in accordance with the apical diameter of the coronal and middle sections.

Ritts *et al*. (2010) found that NAP application for 30 s increased the bonding of the dental composite to dentin while prolonged application of plasma adversely affected the bond strength.[23] Also, Abreu *et al*. evaluated the effect of 15 s, 30 s and 45 s NAP application on the microtensile bond strength of adhesives and the results showed that 30 s NAP application improved the microtensile bond strength.[30] A study by Chen *et al*. stated there was no significant difference between 30 s and 45 s plasma application on the wettability of dentin surface[31] and after 30 s NAP treatment, the water contact angle values decreased to <5°, which was close to a value of super hydrophilic surfaces. So, in this study, the application time was determined as 30 s.

According to the results of this study, plasma application has significant effects on the PBS of calcium silicate-based Endosequence BC sealer in such a way that in the coronal region AH and P-AH groups showed lower PBS value than the P-BC group. Although the P-BC group showed higher PBS values than the BC group in the coronal region, the difference was not statistically significant. The P-BC group showed higher PBS than all the other groups in the middle region. So, the null hypothesis was rejected. Endosequence BC sealer is a tricalcium silicate-based and hydrophilic RCS. During the setting process, the sealer creates a chemical bond with root canal dentine by producing hydroxyapatite. In addition, it can easily spread over the dentinal walls due to its low contact angle.[32] Changes on the root canal dentin surface after NAP application such as wettability, chemical interactions, and grafting hydrophilic groups on to the surface could increase the dentinal tubule penetration of BC sealer. After 30s plasma application, the contact angle values decrease and the low contact angle values define the hydrophilic surface properties.[16] However, carbonyl groups of dentin surface increase after argon plasma application. These carbonyl groups enhance the hydrophilic property of dentin surface.[25] This might be an advantageous factor for BC sealer besides chemical bonding to dentin. The reason of the higher bond strength values of Endosequence BC sealer after NAP treatment might be this surface modification.

It has been previously reported that plasma application caused lower bond strength value of MTA-Fillapex group and plasma application did not affected the bond strength value of AH Plus.[33] The finding of our study partly in agreement with this study. According to our result there is no difference on PBS of AH-Plus RCS with or without NAP application. However, our conflicting results about MTA Fillapex and Endosequence BC sealer could be arising from different ingredients, different physical properties such as fluidity of the sealers and different application methods of nonthermal plasma.

Failure mode results indicate that P-BC group has a higher percentage of cohesive failures than the other groups which means better bond strength to root canal dentin. This failure mode result is compatible with push-out bond strength test results of the present study.

Future studies are needed to say accurate information about effects of plasma application to root canal dentin for improving the bond strength of RCSs.

Conclusion

Under the limitations of the present *ex-vivo* study, NAP application had no effect on the PBS of AH Plus to the root canal dentin for both coronal and middle regions. NAP application positively affects the PBS of Endosequence BC sealer in middle region but it was not effective in coronal region.

Acknowledgements

This study was presented as an oral presentation at CED-IADR/NOF Oral Health Congress in Vienna, Austria, 2017. The authors would like to thank to Dr. Yasin ALTAY from Eskisehir Osmangazi University, Faculty of Agriculture for statistical analysis.

Clinical relevance

The application of nonthermal plasma into the root canal walls provides a better bond strength while using bioceramic-based root canal sealers for obturation procedure.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Oliveira DS, Cardoso ML, Queiroz TF, Silva EJ, Souza EM. Suboptimal push-out bond strengths of calcium silicate-based sealers. Int Endod J 2016;49:796-801.
2. Zhang H, Shen Y, Ruse ND, Haapasalo M. Antibacterial activity of endodontic sealers by modified direct contact test against Enterococcus faecalis. J Endod 2009;35:1051-5.
3. Shokouhinejad N, Gorjestani H, Nasseh AA, Hoseini A, Mohammadi M, Shamshiri AR. Push-out bond strength of gutta-percha with a new bioceramic sealer in the presence or absence of smear layer. Aust Endod J 2013;39:102-6.
4. Huffman BP, Mai S, Pinna L, Weller RN, Primus CM, Gutmann JL, *et al*. Dislocation resistance of ProRoot endo sealer, a calcium silicate-based root canal sealer, from radicular dentine. Int Endod J 2009;42:34-46.
5. Saleh IM, Ruyter IE, Haapasalo MP, Orstavik D. Adhesion of endodontic sealers: Scanning electron microscopy and energy dispersive spectroscopy. J Endod 2003;29:595-601.
6. Camilleri J, Sorrentino F, Damidot D. Investigation of the hydration and bioactivity of radiopacified tricalcium silicate cement, biodentine and MTA angelus. Dent Mater 2013;29:580-93.
7. Han L, Okiji T. Bioactivity evaluation of three calcium silicate-based endodontic materials. Int Endod J 2013;46:808-14.
8. DeLong C, He J, Woodmansey KF. The effect of obturation technique on the push-out bond strength of calcium silicate sealers. J Endod 2015;41:385-8.
9. Zhang W, Li Z, Peng B. *Ex vivo* cytotoxicity of a new calcium silicate-based canal filling material. Int Endod J 2010;43:769-74.
10. McMichael GE, Primus CM, Opperman LA. Dentinal tubule penetration of tricalcium silicate sealers. J Endod 2016;42:632-6.
11. Roggendorf M. Wurzelkanalfüllmaterialien up-to-date. Bavarian Dent J 2004;4:32-4.
12. Tyagi S, Mishra P, Tyagi P. Evolution of root canal sealers: An insight story. Eur J Gen Dent 2013;2:199-218.
13. Ozkocak I, Sonat B. Evaluation of effects on the adhesion of various root canal sealers after Er: YAG laser and irrigants are used on the dentin surface. J Endod 2015;41:1331-6.
14. Topcuoglu HS, Tuncay O, Demirbuga S, Dincer AN, Arslan H. The effect of different final irrigant activation techniques on the bond strength of an epoxy resin-based endodontic sealer: A preliminary study. J Endod 2014;40:862-6.
15. Martins CV, Leoni GB, Oliveira HF, Arid J, Queiroz AM, Silva LA, *et al*. Influence of therapeutic cancer radiation on the bond strength of an epoxy- or an MTA-based sealer to root dentine. Int Endod J 2016;49:1065-72.
16. Chen M, Zhang Y, Sky Driver M, Caruso AN, Yu Q, Wang Y. Surface modification of several dental substrates by non-thermal, atmospheric plasma brush. Dent Mater 2013;29:871-80.
17. Prado M, Menezes MSO, Gomes B, Barbosa CAM, Athias L, Simao RA. Surface modification of gutta-percha cones by non-thermal plasma. Mater Sci Eng C Mater Biol Appl 2016;68:343-9.
18. Yavirach P, Chaijareenont P, Boonyawan D, Pattamapun K, Tunma S, Takahashi H, *et al*. Effects of plasma treatment on the shear bond strength between fiber-reinforced composite posts and resin composite for core build-up. Dent Mater J 2009;28:686-92.
19. Zhang Y, Yu Q, Wang Y. Non-thermal atmospheric plasmas in dental restoration: Improved resin adhesive penetration. J Dent 2014;42:1033-42.
20. Pan J, Sun K, Liang Y, Sun P, Yang X, Wang J, *et al*. Cold plasma therapy of a tooth root canal infected with enterococcus faecalis biofilms *in vitro*. J Endod 2013;39:105-10.

21. Pan J, Sun P, Tian Y, Zhou HX, Wu HY, Bai N, *et al*. A novel method of tooth whitening using cold plasma microjet driven by direct current in atmospheric-pressure Air. Ieee T Plasma Sci 2010;38:3143-51.
22. Sun P, Pan J, Tian Y, Bai N, Wu HY, Wang LX, *et al*. Tooth whitening with hydrogen peroxide assisted by a direct-current cold atmospheric-pressure air plasma microjet. Ieee T Plasma Sci 2010;38:1892-6.
23. Ritts AC, Li H, Yu Q, Xu C, Yao X, Hong L, *et al*. Dentin surface treatment using a non-thermal argon plasma brush for interfacial bonding improvement in composite restoration. Eur J Oral Sci 2010;118:510-6.
24. Han GJ, Kim JH, Chung SN, Chun BH, Kim CK, Seo DG, *et al*. Effects of non-thermal atmospheric pressure pulsed plasma on the adhesion and durability of resin composite to dentin. Eur J Oral Sci 2014;122:417-23.
25. Dong X, Ritts AC, Staller C, Yu Q, Chen M, Wang Y. Evaluation of plasma treatment effects on improving adhesive-dentin bonding by using the same tooth controls and varying cross-sectional surface areas. Eur J Oral Sci 2013;121:355-62.
26. Chen M, Zhang Y, Dusevich V, Liu Y, Yu Q, Wang Y. Non-thermal atmospheric plasma brush induces HEMA grafting onto dentin collagen. Dent Mater 2014;30:1369-77.
27. Kim JH, Han GJ, Kim CK, Oh KH, Chung SN, Chun BH, *et al*. Promotion of adhesive penetration and resin bond strength to dentin using non-thermal atmospheric pressure plasma. Eur J Oral Sci 2016;124:89-95.
28. Goracci C, Tavares AU, Fabianelli A, Monticelli F, Raffaelli O, Cardoso PC, *et al*.T The adhesion between fiber posts and root canal walls: Comparison between microtensile and push-out bond strength measurements. Eur J Oral Sci 2004;112:353-61.
29. Pane ES, Palamera JE, Messer HH. Critical evaluation of the push-out test for root canal filling materials. J Endod 2013;39:669-73.
30. Abreu JL, Prado M, Simao RA, Silva EM, Dias KR. Effect of non-thermal argon plasma on bond strength of a self-etch adhesive system to NaOCl-treated dentin. Braz Dent J 2016;27:446-51.
31. Chen M, Zhang Y, Driver MS, Caruso NA, Yu Q, Wang Y. Surface modification of several dental substrates by non-thermal, athmospheric plasma brush. Dent Mater 2013;29:871-80.
32. Gade VJ, Belsare LD, Patil S, Bhede R, Gade JR. Evaluation of push-out bond strength of endosequence BC sealer with lateral condensation and thermoplasticized technique: An *in vitro* study. J Conserv Dent 2015;18:124-7.
33. Menezes M, Prado M, Gomes B, Gusman H, Simão R. Effect of photodynamic therapy and non-thermal plasma on root canal filling: Analysis of adhesion and sealer penetration. J Appl Oral Sci 2017;25:396-403.