Push-Out Bond Strenght of four different bioceramic sealers tested with three different obturating systems: an In Vitro study

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ABSTRACT

Aim The purpose of the current study was to evaluate the bond strength to root canal walls of four different bioceramic sealers used in combination with three different obturation techniques by push-out test.

Materials and Methods 120 monoradicular roots were selected and used for this study. After being endodontically instrumented, the roots were randomly divided in 12 groups of 10 samples each and then obturated with 4 different bioceramic sealers (Ceraseal, Meta Biomed; AH Plus, Dentsply Sirona; BIO-C Sealer Ion+, Angelus; and BioRoot RCS, Septodont) in combination with three obturation techniques ("Continuous Wave of Condensation" technique, "Domino system" carrier-based technique and "Single-Cone" obturation technique). Then the wide majority of roots were cut in slides and each of them was tested under a push out device. Loading was performed at a speed of 0,5mm/min in an apical-coronal direction, and the obtained values were analyzed statistically. Few roots were cut along their long axis to observe the bio ceramic sealers' penetration into the tubules by an optical microscope.

Results The "Continuous Wave of Condensation" technique showed a media among the four sealers used of 3,36 MPa, "Domino" technique 3,10 MPa and "Single-Cone" 3,28 MPa. However, Kruskal-Wallis one-way analysis of variance revealed the absence of statistically significant differences between sealers in all obturation techniques ($p = 0.174$, $p = 0.667$, $p = 0.148$ for 'Continuous Wave of Condensation', ' Domino' and 'Single-Cone ' respectively). The bond strenght recorded for Ceraseal was 3,15 MPa, AH Plus showed 3,11 MPa, Bio-C Ion+ 3,35 MPa and Bioroot 3,38 MPa. However, Kruskal-Wallis one-way analysis of variance revealed the absence of statistically significant differences between the obturation techniques for all materials ($p = 0.714$, $p = 0.63$, $p = 0.114$, $p = 0.655$ for 'Ceraseal', 'AH Plus', 'Bio-C Ion +' and 'BioRoot' respectively). Microscopic analysis reveals that Ceraseal, AH Plus, BIO-C Ion+ and BioRoot RCS are able to perform a three-dimensional seal of the root canal and they are able to penetrate the dentinal tubules.

Conclusions It can be concluded that if the endodontic procedure is properly performed and follows protocols based on scientific evidence, clinical success can be achieved regardless of the different materials used and the different techniques.

INTRODUCTION

Root canal filling is performed through the use of a root canal sealer in combination with the core root canal filling material, mostly gutta-percha.
Because of the poor adhesiveness of gutta-percha, it has been used in conjunction with root canal sealers to accomplish this goal (1).
While the core material fills most of the root canal, the primary role of the sealer is to obliterate the irregularities between the root canal wall and the core material.
Where the core material fails to penetrate, endodontic sealers are able to fill left voids, lateral canals and accessory canals.
Most of today's root canal filling techniques use cement to enhance the seal of the root canal obturation.
Traditional obturation methods do not provide an effective seal and this lack could be due to the traditional sealers that are used.
They shrink on the setting, have little or no adhesion to dentin, and they are not dimensionally stable when they come in contact with moisture, leading to dissolution and leakage over time.
Therefore, new materials have been developed in order to overcome some of these shortcomings: bioceramic sealers (2).
Bioceramic sealers have some advantages such as improved biocompatibility, sealing ability, anti-bacterial, ease of application and an increase in strength of root following obturation (3).
Some of these characteristics can be due to the hydrophilicity of the sealers. Bioceramic sealers are dimensionally stable. During the setting reaction, there is a creation of chemical bonding to the canal wall by hydroxyapatite and others between the ceramic particle in the sealer and the ones on the sealer-coated cones (4).
Additionally, bioceramic sealers will not result in a signif-

icant inflammatory response if an overfill occurs during the obturation process or in a root repair (5).
The purpose of the current study is to compare the bond strength to root canal walls of four different bioceramic sealers (Ceraseal, Meta Biomed; AH Plus, Dentsply Sirona; BIO-C Sealer Ion+, Angelus; and BioRoot RCS, Septodont) used with three different obturation techniques ("Continuous Wave of Condensation" technique, "Domino system" carrier-based technique and "Single-Cone" obturation technique) through push-out test.

METHODS

Specimen selection

120 single-rooted human teeth devoid of fractures, previous root canal treatments and root defects were selected for this study. Teeth have been chosen between incisors, canines and mandibular and maxillary premolars, extracted for orthodontic, prosthetic or periodontal causes. Pre-operative intraoral radiographs were taken in order to examine the endodontic anatomy of each sample.
After extraction, teeth were maintained for one hour in hydrogen peroxide, then in a saline solution to avoid dehydration and to guarantee good preservation of the samples.
Selected teeth were randomly divided into twelve study groups based on filling technique and bioceramic sealer.

Group	Technique	Sealer	
1	Continuous wave of condensation	Ceraseal	n=10
2		AH Plus	n=10
3		BIO-C ION+	n=10
4		BioRoot	n=10
5	Carrier based (Domino System)	Ceraseal	n=10
6		AH Plus	n=10
7		BIO-C ION+	n=10
8		BioRoot	n=10
9	Single-Cone	Ceraseal	n=10
10		AH Plus	n=10
11		BIO-C ION+	n=10
12		BioRoot	n=10

Root canal treatment

Samples were prepared for following shaping and cleaning procedures by removing residues of plaque, calculus and human tissue using ultrasonic instruments.
Using diamond burs mounted on a high-speed handpiece equipped with a water cooling system, standardized cavity access was made for each tooth. A round diamond bur was used to access the pulp chamber and, subsequently, a non-end cutting diamond bur oriented perpendicular to the occlusal plane was used to make the finishing phase.
Once the access cavity was completed, pre-curved stainless steel manual K-file #10 (Sweden & Martina; Due Carrare, Italy) was inserted into each canal with a watch winding movement up to the apical level, defining the working length.
All the chemo-mechanical preparation procedures of the samples were performed by two operators to reduce the operator-dependent bias.
Ni-Ti Mtwo File (Sweden & Martina) instruments were used for the root canal shaping.
Instruments were used with continuous rotation movement through an endodontic motor (X-SMART TM Plus; Dentsply Maillefer, Ballaigues - Suisse) at 250 rpm.
Following the sequence indicated by the manufacturer, the shaping was carried out in the same way for all twelve groups.
2.5 ml of 5% sodium hypochlorite (Niclor 5 dental, Ogna Lab srl, MB, Italy) for 30 minutes was used between each instrument by syringe-needle irrigation. Sodium hypochlorite used for all shaping and cleansing phases was preheated to 50 ° C by immersing the syringes containing it in 100 ° C water. Apical patency was maintained by using a # 10 K-type file after each larger file.
The final irrigation phase was carried out with 2 ml of 17% EDTA (Ogna Lab srl) for 2 minutes, followed by the last washing of 5 ml of 5% NaOCl for 5 minutes, to optimize the removal of inorganic and organic components.
Once the root canal instrumentation was completed, apical gauging was performed.
Canals were dried with endodontic paper cones.
The teeth, divided into twelve groups, were filled with different techniques and materials:
Group 1: teeth of this group were filled with the continuous wave of condensation technique using CeraSeal Bioceramic root canal sealer (Meta Biomed; Osong-eup, Republic of Korea).
Group 2: teeth of this group were filled with the continuous wave of condensation technique using AH Plus Bioceramic sealer (Dentsply Sirona; Charlotte, NC, USA).
Group 3: teeth of this group were filled with the continuous wave of condensation technique using BIO-C Sealer Ion+ (Angelus; Londrina, Brasil).
Group 4: teeth of this group were filled with the continuous wave of condensation technique using BioRoot RCS Bio Active mineral root canal sealer (Septodont; Saint-Maur-des-Fossés, France).
Group 5: teeth of this group were filled with the carrier-based technique (Domino System) using CeraSeal Bioceramic root canal sealer (Meta Biomed; Osong-eup, Republic of Korea).
Group 6: teeth of this group were filled with the carrier-based technique (Domino System) using AH Plus Bioceramic sealer (Dentsply Sirona; Charlotte, NC, USA).
Group 7: teeth of this group were filled with the carrier-based technique (Domino System) using BIO-C Sealer Ion+ (Angelus; Londrina, Brasil).
Group 8: teeth of this group were filled with the carri-

er-based technique (Domino System) using BioRoot RCS Bio Active mineral root canal sealer (Septodont; Saint-Maur-des-Fossés, France).

Group 9: teeth of this group were filled with the Single-Cone technique using CeraSeal Bioceramic root canal sealer (Meta Biomed; Osong-eup, Republic of Korea).

Group 10: teeth of this group were filled with the Single-Cone technique using AH Plus Bioceramic sealer (Dentsply Sirona; Charlotte, NC, USA).

Group 11: teeth of this group were filled with the Single-Cone technique using BIO-C Sealer Ion+ (Angelus; Londrina, Brasil).

Group 12: teeth of this group were filled with the Single-Cone technique using BioRoot RCS Bio Active mineral root canal sealer (Septodont; Saint-Maur-des-Fossés, France).

Before and at the end of the root canal treatment, all 120 teeth were x-rayed (Fig. 1A-1B).

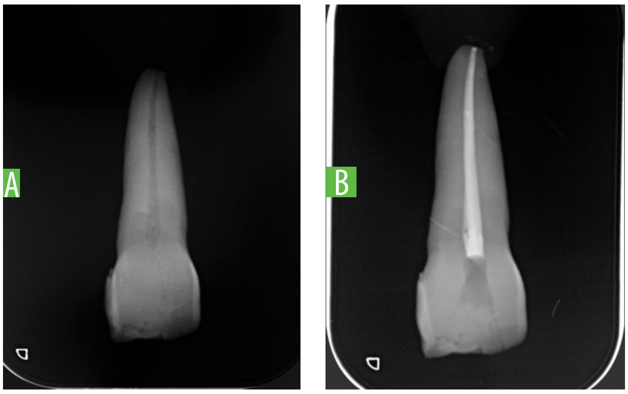

FIG 1A-1B

Preparation of the samples for the Push-Out Bond Strenght Test:

28 days after the obturation phase, four 1-mm-thick slices were obtained by sectioning the tooth perpendicular to the long axis of the dental element, under water-cooling (Isomet, Buehler, Lake Bluff, IF, USA).

The machine worked at a constant rotation speed of 150rpm.

Between 36 and 40 samples were thus obtained for each of the twelve groups (n = 36-40 / group).

Each specimen was marked on its coronal surface with a marker, and the precise thickness of each slice was measured using a digital calliper with 0,02mm accuracy (Mitutoyo, Tokyo, Japan).

Push-Out Test

The dislodgement resistance of the materials was measured using a universal testing machine (TRIAX 50 Controls). The root slices were mounted on an acrylic block of 2 × 2 cm in dimension.

In order to provide the most extended coverage over the filling material, the material was loaded with cylindrical stainless steel plungers of different diameters: 0,5mm for the apical third, 0,8mm for the middle third, and 1mm for the coronal third.

Loading was performed at a speed of 0,5mm/min in an apical-coronal direction, in order to avoid any interferences because of the root canal taper.

The maximum load applied to the filling material before debonding was recorded in Newtons. To express the bond strength in MegaPascals, the load recorded in Newtons was divided by the area of the bonded interface (mm2).

Interfacial Area was calculated by the following formula: "$A = 2\pi r \times h$", where "π" is the constant 3.14, "r" is the root canal radius, and "h" is the thickness of the slice in millimetres.

Stereomicroscope Evaluation:

Apical thirds of each tooth were sectioned parallel to the long axis of the dental element, under water-cooling (Isomet, Buehler, Lake Bluff, IF, USA), at a constant rotation speed of 150rpm.

Slices were mounted on stubs and examined under Stereomicroscope (Nikon H550L).

Photomicrographs were taken from the slices in order to make observations about the possible penetration into root canal tubules of the four bioceramic sealers.

Data presentation and analysis

Kruskal–Wallis one-way analysis of variance was used to evaluate the push-out bond strength of the root filling materials and the different obturation techniques in MPa via group-by-group comparisons.

Significance was set at $P < 0.05$.

RESULTS

The average values of bond strength of all tested groups is reported in Table 1. The values were between 2,72 and 3,69 MPa.

Group	Technique	Sealer	MPa Average
1	Continuous wave of condansation	Ceraseal	3,68
2		AH Plus	2,72
3		BIO-C ION+	3,31
4		BioRoot	3,76
5	Carrier based	Ceraseal	3,04
6		AH Plus	3,52
7		BIO-C ION+	3,06
8		BioRoot	2,81
9	Single Cone	Ceraseal	2,75
10		AH Plus	3,11
11		BIO-C ION+	3,69
12		BioRoot	3,58

TABLE 1 Average of the values of bond strength expressed in MegaPascals (MPa) of the different study groups, before statistical analysis

Tables 2-4 report the descriptive statistics of the push-out bond strength values measured with the different sealers in each obturation technique.
The "Continuous Wave of Condensation" technique showed a media among the four sealers used of 3,36 MPa, "Domino" technique 3,10 MPa and "Single-Cone" 3,28 MPa.
However, Kruskal-Wallis one-way analysis of variance revealed the absence of statistically significant differences between sealers in all obturation techniques (p = 0.174, p = 0.667, p = 0.148 for 'Continuous Wave of Condensation', ' Domino' and 'Single-Cone ' respectively).

Sealer	N	Median (in MPa)	25%	75%
Ceraseal	36	3,68	0,930	4,864
AH Plus	39	2,72	1,056	4,055
Bio-C Ion+	37	3,31	1,881	5,053
BioRoot	37	3,76	1,143	3,799

TABLE 2 Descriptive statistics of the push-out bond strength values recorded for the different sealers in the "Continuous Wave of Condensation" technique

Sealer	N	Median (in MPa)	25%	75%
Ceraseal	37	3,04	0,915	4,137
AH Plus	37	3,52	0,976	4,788
Bio-C Ion+	38	3,06	0,822	3,659
BioRoot	38	2,81	1,507	3,154

TABLE 3 Descriptive statistics of the push-out bond strength values recorded for the different sealers in the "Domino" technique

Sealer	N	Median (in MPa)	25%	75%
Ceraseal	36	2,75	1,390	2,979
AH Plus	37	3,11	0,864	3,220
Bio-C Ion+	40	3,69	1,522	5,302
BioRoot	39	3,58	1,343	3,412

TABLE 4 Descriptive statistics of the push-out bond strength values recorded for the different sealers in the "Single-Cone" technique

Tables 5-8 report the descriptive statistics of the push-out bond strength values measured in samples filled with the different techniques for each material.
The bond strenght recorded for Ceraseal was 3,15 MPa, AH Plus showed 3,11 MPa, Bio-C Ion+ 3,35 MPa and Bio-root 3,38 MPa.
However, Kruskal-Wallis one-way analysis of variance revealed the absence of statistically significant differences between the obturation techniques for all materials (p = 0.714, p = 0.63, p = 0.114, p = 0.655 for 'Ceraseal', 'AH Plus', 'Bio-C Ion +' and 'BioRoot' respectively).

Technique	N	Median	25%	75%
Continuous wave	36	3,68	0,930	4,864
Domino	37	3,04	0,915	4,137
Single Cone	36	2,75	1,390	2,979

TABLE 5. Descriptive statistics of the push-out bond strength values recorded for the different techniques in samples filled with "Ceraseal"

Technique	N	Median	25%	75%
Continuous wave	39	2,72	1,056	4,055
Domino	37	3,52	0,976	4,788
Single Cone	37	3,11	0,864	3,220

TABLE 6. Descriptive statistics of the push-out bond strength values recorded for the different techniques in samples filled with "AH Plus"

Technique	N	Median	25%	75%
Continuous wave	37	3,31	1,881	5,053
Domino	38	3,06	0,822	3,659
Single Cone	40	3,69	1,522	5,302

TABLE 7. Descriptive statistics of the push-out bond strenght values recorded for the different techniques in samples filled with "Bio-C Ion+"

Technique	N	Median	25%	75%
Continuous wave	37	3,76	1,143	3,799
Domino	38	2,81	1,507	3,154
Single Cone	39	3,58	1,343	3,412

TABLE 8. Descriptive statistics of the push-out bond strenght values recorded for the different techniques in samples filled with "BioRoot RCS"

Although they were not any statistical significant difference among the groups, the obturation technique with highest bond strength was the "Continuous Wave Condensation" and the bio ceramic sealer was Bioroot.

Stereo microscope observations

Microscopic analysis revealed two observations:

- all four bioceramic sealers that were tested have the ability to penetrate into the first part of dentinal tubules (figs. 2-16);
- the three tested obturation techniques are able to uniformly fill the root canal without leaving the presence of gaps (voids between sealer and root dentin's interface) or bubbles (voids within the core material component) (fig. 2-16).

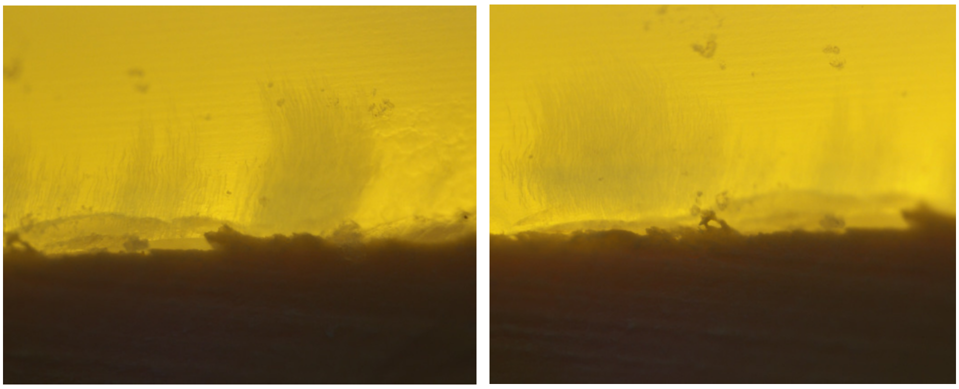

FIG. 2 Photomicrographs of tooth sample filled with “AH Plus” sealer using the Single Cone technique. The penetration of the “AH Plus” sealer inside the dentinal tubules can be highlighted.

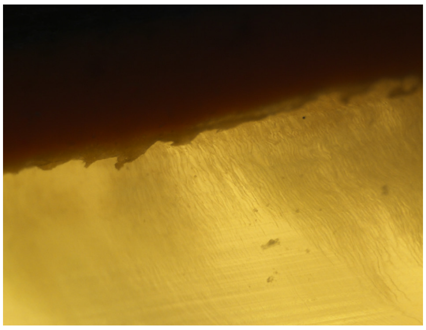

FIG. 3 Photomicrograph of a sample of the tooth filled with “Ceraseal” sealer using the carrier-based technique with the Domino system. The penetration of “Ceraseal” sealer inside the dentinal tubules can be highlighted

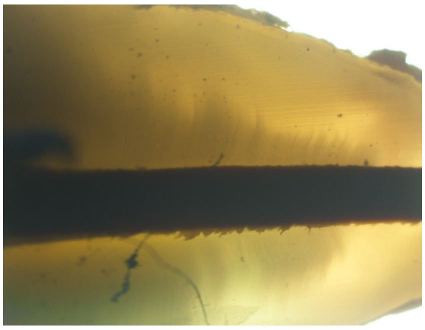

FIG. 4 Photomicrograph of tooth samples filled with “Ceraseal” sealer using the Continuous Wave of Condensation technique. The penetration of “Ceraseal” sealer inside the first tract of the dentinal tubules can be highlighted

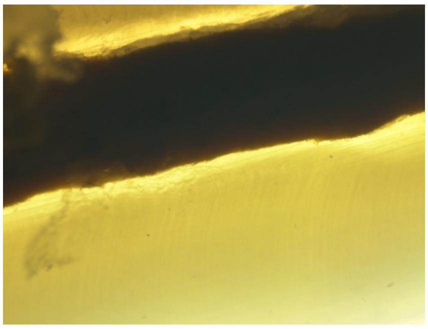

FIG. 5 Photomicrograph of samples of the tooth filled with “AH Plus” bioceramic sealer using the Continuous Wave of Condensation technique. The penetration of the “AH Plus” sealer inside the dentinal tubules can be highlighted.

DISCUSSION

The success of endodontic treatment depends on different factors such as chemomechanical preparation, filling and post-endodontic restoration. The main objective of the treatment is to eliminate the microbial entity and prevent future onset of reinfection by trying to obtain a hermetic seal. The root canal filling is performed through the use of a main material (core) and an endodontic sealer. Gutta-percha is a biocompatible material for filling most of the root space, while the sealer is essential to create a close association with the filling material.

Endodontic sealers play an important role finalized to achieve a hermetic seal of the root canal: they help to maintain a compact mass without voids inside the root canal, create a single unit configuration and to allow this

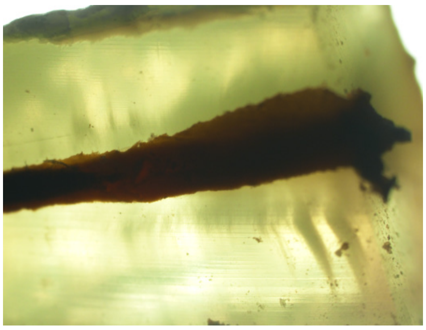

FIG. 6 Photomicrograph of tooth samples filled with “Bio-C Angelus” sealer using the carrier-based technique with the Domino system. The penetration of the “Bio-C Angelus” bioceramic inside the dentinal tubules can be highlighted.

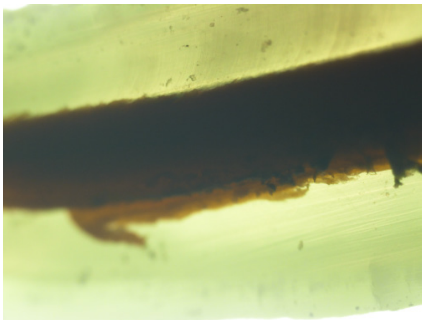

FIG. 7 Photomicrograph of tooth samples filled with “BioRoot” sealer using the Continuous Wave of Condensation technique. The penetration of the “BioRoot” sealer in the first tract of the dentinal tubules can be highlighted.

FIG. 8 Photomicrograph of a sample of a tooth filled with “Ceraseal” bioceramic sealer using the Single Cone technique. Gutta-percha has lifted from the canal during preparation. It is possible to highlight at the bottom of the root canal residual “Ceraseal” bioceramic and dentinal tubules infiltrated by the material itself.

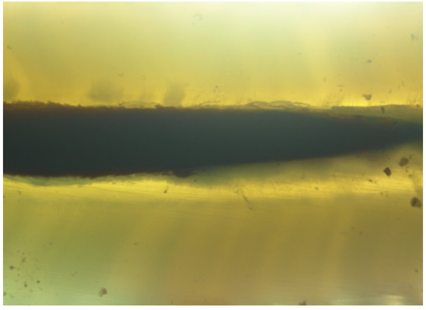

FIG. 9 Microscopic observation of a sample filled with Single Cone + AH Plus: filling of the canal

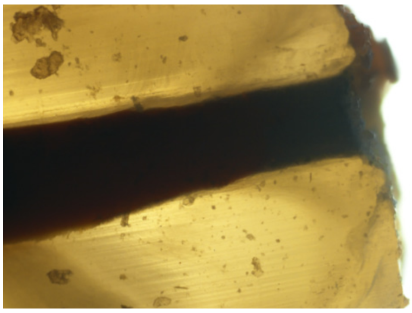

FIG. 10 Microscopic observation of a sample filled with Domino System + Ceraseal: adaptation of the material to the canal walls and correct apical closure can be highlighted

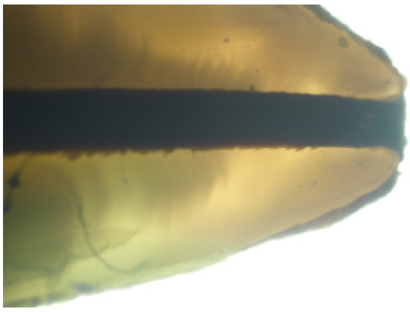

FIG 11 Microscopic observation of a sample filled with Continuous Condensation Wave technique + Ceraseal: excellent adaptation to the canal walls along the entire canal path

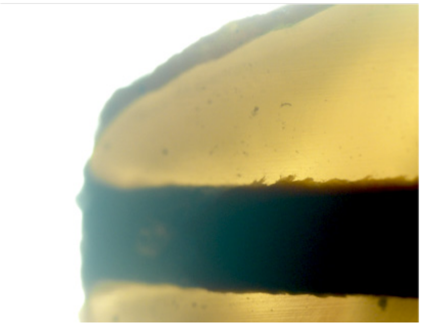

FIG. 12 Apical seal under microscopic observation of a sample filled with Continuous Condensation Wave + Ceraseal

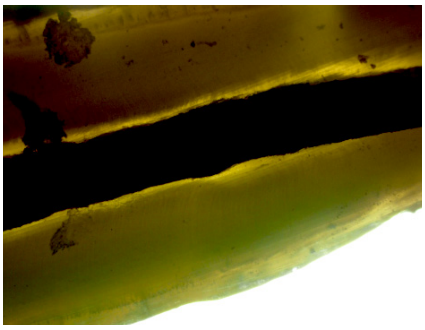

FIG. 13 Microscopic observation of a sample filled with Continuous Condensation Wave technique + AH Plus: an obturation without voids can be highlighted

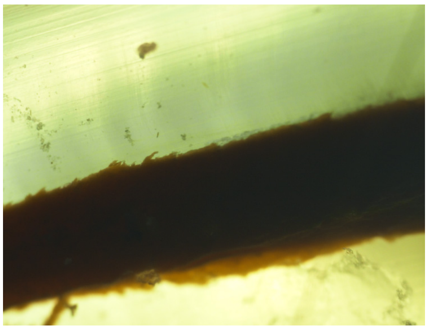

FIG. 14 Microscopic observation of a sample performed with the Domino System + Bio-C Ion sealer: absence of gaps and bubbles

mass to adhere to the canal walls (6).

Sealer's detachment from the root canal walls can happen due to micromechanical clutches or retention, by the physiological function of chewing, or by post-space preparation. Lower bond strength of the sealer to the dentinal surface can therefore have an important impact on the clinical outcome of the endodontic treatment (7). A good sealer's bond strength value to the root dentin is important to maintain the apical seal.

Sealer and core material should have the ability to improve tooth fracture resistance.

Sealer's bond strength value can be detected through Push-Out Test. This value can vary and it may depend on the type of sealer and filling technique (8).

The Push-Out Test method was used in this study. This method is preferred because it is sensitive to small variations in stress distribution during load application (9).

Even though this test does not fully replicate the performance of root canal sealers in clinical situations, the Push-Out Test still provides valuable information for the comparison of different endodontic sealers or filling techniques.

Results analysis reveals that there were no statistically significant differences between the use of the different bioceramic sealers (Table 1, Table 2, Table 3) and the use of the different filling techniques (Table 4, Table 5, Table 6, Table 7) in relation to the bond strength measured in MPa after Push-Out test.

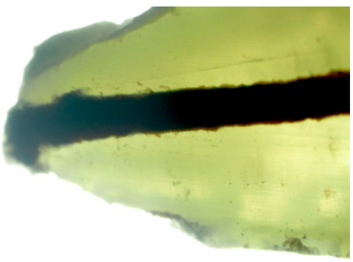

FIG. 15 Microscopic observation of a sample performed with SingleCone technique + Ceraseal: adaptation of the material to the root canal walls

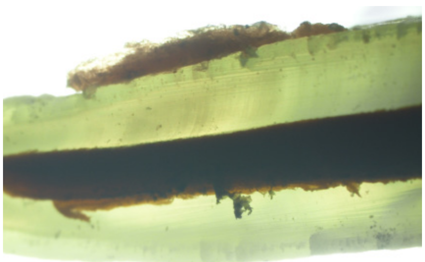

FIG. 16 Microscopic observation of a sample filled with Continuous Condensation Wave technique + BioRoot: correct root canal filling

Results suggest there were no statistically significant differences between heat-based obturation techniques and non-heat-based obturation techniques.
The strength values of adhesion to radicular dentine and performances that were recorded in this study occur in a range similar to those recorded in other scientific publications (10-13).
Solely from the point of view of the numerical results but without statistically significant differences, in combination with the "Continuous wave of condensation" technique, the best results were obtained with BioRoot RCS and the worst results with AH Plus. Regarding the "Carrier-Based" technique, AH Plus obtained the best results while BioRoot RCS was the worst. As regards the "Single-Cone" obturation technique, BIO-C sealer gave the best results while Ceraseal obtained the worst.
Sealers' mixing characteristics did not affect their bond strength: the pre-mixed sealers (Ceraseal, AH Plus, BIO-C ION+) showed the same results in terms of bond strength compared to BioRoot, the only one that required extemporaneous mixing for use in the root canal.
Bioceramic penetration into the tubules involves a better seal of the three-dimensional endodontic system in relation to the root canal filling techniques used. All four bioceramic sealers examined are able to give satisfactory results not only from the point of view of the bond strength but also from the microscopic analysis. It can support the hypothesis of creating a micromechanical and chemical bond between bioceramic biosealer and root canal dentin.
The Single-Cone obturation technique, considered the gold standard if associated with bioceramic sealers, has obtained comparable results to the other two techniques ("Domino System" and "Continuous wave of condensation") in terms of bond strength to the root canal walls.
Microscopic analysis reveals that Ceraseal, AH Plus, BIO-C Ion+ and BioRoot RCS are able to perform a three-dimensional seal of the root canal and they are able to penetrate the dentinal tubules.
The microscopic analysis also suggests that the three tested obturation techniques are able to uniformly fill the root canal without leaving the presence of gaps or bubbles.
It can be concluded that if the endodontic procedure is properly performed and follows protocols based on scientific evidence, clinical success can be achieved regardless of the different materials used and the different techniques.

CONCLUSIONS

Based on the results of this study, any of the four bioceramic sealers used in this protocol (Ceraseal, AH Plus, BIO-C Sealer Ion+, BioRoot RCS) can be used in combination with any of one of obturation techniques tested.

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