ABSTRACT

Objective: BioRoot®, which contains pure calcium silicate, is used in cold lateral compaction. However, hydroxyl ions are still released when BioRoot® is used in warm vertical compaction. This study compared the effects of cold and warm vertical compaction on the push-out bond strength of BioRoot®.

Methods: Specimens from 16 root canals instrumented with ProTaper Next X5 50/06 were divided into two groups (n=16 specimens per group). Group 1 was obturated using cold lateral compaction, whereas Group 2 was obturated using warm vertical compaction. All samples were incubated for 48 h (37°C, 100% humidity) and embedded into an acrylic block. Starting at 7 mm from the apex, two 2-mm-thick slices of each sample were cut. Dislodgement resistance was measured using a universal testing machine, and the push-out bond strength was calculated.

Results: There was a significant difference in the push-out bond strength value between cold (4.5–41.1 MPa) and warm (4.12–24.25 MPa) compaction obturation (p<0.05).

Conclusion: Cold lateral compaction provides better adhesion capability than warm vertical compaction in root canal obturation.

Methods

Specimens

In this study, we used 16 recently extracted human single-rooted mandibular premolars. The teeth were thoroughly cleaned and stored in saline solution at room temperature. Their crowns were cut transversally using a double-faced diamond disc to obtain a 16 mm standardized root length, and working lengths were established by inserting a #10 K-file (Dentsply, Tulsa, OK, USA) into the root canal terminus until it became visible through the apical foramen and then retracting it by 1 mm. Root canals with an initial apical #15 K-file were selected to standardize the root canal diameter.

ProTaper Next X5 50/06 (Dentsply) was used for root canal instrumentation. All teeth were irrigated with 3 ml of 2.5% NaOCl (Onemed Medicom, Sunabay, Indonesia) using a 30-gauge side-vented needle (Ultradent, Jordan, MN, USA) throughout instrumentation. Sonic activation (Dentsply) and 17% ethylenediaminetetraacetic acid (EDTA; Meta Biomed, South Korea) were used for final irrigation.

The teeth were randomly divided into two groups: Group 1 teeth were obturated using cold lateral compaction with the single-cone technique, while Group 2 teeth were obturated using warm vertical compaction with the continuous-wave technique (SybronEndo, Orange, CA, USA). The
root canals were dried using tapered paper points and then filled with gutta-percha (Dentsply) X5 50/06 and BioRoot™ (Septodont, Saint-Maur-des-Fosses, France) according to the manufacturer's instructions. The teeth were restored using Cavit G (3M, USA) and kept at 37°C in 100% relative humidity for 48 h to ensure complete setting of the sealer.

Each root was embedded in a custom-made resin mold in a vertical position. After the resin set, two 2-mm-thick horizontal sections were cut 7–11.75 mm from the apex using a circular diamond disc, resulting in 16 specimens per group. The middle third of the root was used as the specimen to obtain a rounded root canal cross-section and to ensure that the sealer is evenly distributed. If a section revealed a root canal with isthmuses, an oval root canal, or voids in the obturation, the specimen was discarded and replaced by a new set; this occurred in only two teeth.

**Push-out bond strength test**

For each specimen, the dislodgement resistance was measured and the mode of failure evaluated. The specimens were subjected to a compressive load using a universal testing machine (Shimadzu, Kyoto, Japan) at a crosshead speed of 1 mm/min and a cylindrical plunger with a 0.6-mm-diameter to apply the vertical load onto the gutta-percha core; the tip's diameter was dimensioned according to the gutta-percha point to ensure equal distribution of the load on 60–80% of the gutta-percha cone diameter without touching the sealer and specimen. That is, the plunger tip diameter was 0.6 mm, the plunger tip contacted ~60% of the gutta-percha area, and the plunger tip – gutta-percha diameter ratio was <0.85 mm, as suggested by Chen et al. and Donnemeyer et al. A push-out force was applied apicocoronally until bond failure occurred, which was manifested by extrusion of the gutta-percha core and a sudden drop along the load deflection. A graph of the applied load was generated using software, and failure was automatically determined. The failure load was recorded in Newtons (N), and the push-out bond strength of each specimen was calculated and expressed in N/mm² (MPa).

**Mode of failure test**

The mode of failure between sealer and dentine was examined under a stereomicroscope camera at ×30 magnification. Each specimen was evaluated and classified into one of three failure modes, as described by Skidmore et al.:  
- Adhesive failure, no material left on the root canal wall  
- Cohesive failure, material present on the entire root canal wall  
- Mixed failure, material in patches on root canal wall.

**Statistical analysis**

According to the Shapiro-Wilk test, data were not distributed normally (p<0.05), so statistical analysis of the push-out bond strength was performed using the Mann-Whitney U test (p<0.05). The mode of failure was analyzed using the Chi-square test.

**RESULTS AND DISCUSSION**

All specimens showed measurable adhesion to root dentine. Group 1 had a significantly higher median push-out bond strength (20.91; p<0.05; standard deviation [SD] = 2.44) compared to Group 2 (Table 1). The high push-out bond strength was assumed to be due to the release of calcium hydroxide from the sealer. The mode of failure in Group 1 was a cohesive failure, while in Group 2 was a mixed failure with predominantly cohesive failure, as shown in Table 2 and Fig. 1.

Studies on the push-out bond strength of BioRoot™ are still limited. A sealer’s bioactivity determines the quality of root canal obturation [15]. In general, shear bond strength and microtensile bond strength tests are widely used to evaluate the effectiveness of a dental material [16]. The microtensile bond strength test is commonly used in dentistry, but it is unreliable when using the root canal as a specimen because of a high percentage of premature bond failure and variation in test results [15]. Push-out bond strength and planar interface tests are part of the shear bond strength test [16]. The push-out bond strength test is reproducible and easy to interpret, which is why we used it [16]. The universal testing machine can analyze the minimum value of the bond strength and can use root canal specimens [16].

Eliminating the smear layer can strengthen the bond and minimize microleakage between a root canal and sealer [1]. However, previous studies on push-out bond strength showed variation in test results because of different protocols used [15]. Factors that affect the push-out bond strength include the root canal diameter and taper after instrumentation, the type of obturation (cold or warm vertical compaction), the root canal area, width of the specimen, load, and speed of the test [15].

The most crucial factors in the push-out bond strength test are the diameter of the plunger tip used and the diameter of the specimen [15]. Chen et al. reported that a plunger tip diameter <0.6 mm and >0.85 mm affects the push-out bond strength and suggested that the plunger tip diameter, based on the plunger tip – gutta-percha diameter ratio, should be <0.85 mm [15]. In contrast, Pane et al. showed that a plunger tip diameter >0.85 mm does not affect the push-out bond strength [17]. Donnemeyer et al. reported that the plunger tip should contact 60%–85% of the gutta-percha area so that the load is evenly distributed [18].

According to Skidmore et al., a specimen should be ±1 mm thick to prevent uneven load distribution [19]. In this study, the 2 mm thickness of the specimen used might be why the push-out bond strength differed in Groups 1 and 2. This finding was in agreement with those of several authors who also used 2-mm-thick specimens; although the results varied, statistically, the SD was low [14,16].

Donnemeyer et al. were the first to analyze the push-out bond strength of calcium silicate-based sealers using the single-cone technique [18]. The mean push-out bond strength of BioRoot™ using the single-cone technique in previous and the present study was quite different because of different study protocols used: Specimen and instrumentation technique. The bond strength between BioRoot™ and the root canal was strong, which could be explained by the mode of failure in previous and the present study: Mixed versus cohesive failure.

### Table 1: Comparison of push-out bond strength between Groups 1 and 2 (MPa)

| Group | n  | Median | Min.-Max. | p-value |
|-------|----|--------|-----------|---------|
| Group 1 | 16 | 19.6500 | 4.5–41.1 | 0.001 |
| Group 2 | 16 | 8.7100 | 4.12–24.25 |         |

*Mann-Whitney U test (p<0.05)*

### Table 2: Mode of failure during dislodgement in Groups 1 and 2

| Failure Type (%) | Group 1 | Group 2 |
|------------------|--------|--------|
| Cohesive failure | 16 (100) | 0 |
| Mixed failure    | 0      | 5 (31.3) |

*Chi-square test (p<0.05)
Camilleri reported that heat produced during warm vertical compaction affects the physical properties of a calcium silicate-based sealer but not its chemical properties [13]. In the initial setting BioRoot™ releases calcium hydroxide in both cold and warm vertical compaction. Carmona et al. reported that the released calcium hydroxide stimulates biomineralization in the interfacial layer of the sealer and root canal and affects the push-out bond strength [6]. The low push of bond strength of warm vertical compaction might be due to the calcium hydroxide released only in the pre-induction phase, 1 min after the sealer liquid and powder are mixed. It is still unclear whether the calcium hydroxide continues to be released until the Pasca-acceleration phase, 30 h after the sealer liquid and powder are mixed. The heat produced during warm vertical compaction also accelerates the sealer’s setting time and affects the sealer’s film particles. According to ISO 6876, the film particle size should be <50 µm to obtain good flow and to positively influence sealer penetration into dentin tubules.

Obturation with a monoblock system is still under development since obturation using gutta-percha and a sealer as the gold standard still does not provide a complete dentinal seal [16]. Patil et al. reported that the push-out bond strength of AH Plus with cold lateral compaction is higher compared to Resilon/Epiphany, with a mean value of 1.49 and a SD of 0.16 [14].

The results of this study were confirmed by Gade et al., who analyzed the mode of failure of EndoSequence BC using warm vertical compaction and the single-cone technique [14]. The mode of failure of the single-cone technique was a cohesive failure, while that of warm vertical compaction was a mixed failure. The lack of adhesive failure in both studies showed that regardless of the obturation technique used, calcium silicate-based sealers have a good adhesion to the root canal.

**CONCLUSION**

The push-out bond strength of cold lateral compaction is higher compared to warm vertical compaction. Cold lateral compaction shows cohesive failure, while warm vertical compaction shows mixed failure but predominantly cohesive failure.

**REFERENCES**

1. Cohen S, Hargreaves K, editors. Pathway’s of the Pulp. 11th ed. Missouri: Elsevier; 2016.
2. Wang Y, Liu S, Dong Y. *In vitro* study of dentinal tubule penetration and filling quality of bioceramic sealer. PLoS One 2018;13:1-11.
3. Ingle JJ, Bakland LK, editors. Endodontics. 5th ed. London: BD Decker Inc.; 2002.
4. Siqueira J. Endodontic Infections. Berlin: Quintessence Publishing; 2011.
5. Tyagi S, Tyagi P, Mishra P. Evolution of root canal sealers: An insight story. Eur J Gen Dent 2013;2:199.
6. Reyes-Carmona JF, Felippe MS, Felippe WT. The biomineralization ability of mineral trioxide aggregate and portland cement on dentin enhances the push-out strength. J Endod 2010;36:286-91.
7. Mohammadi Z, Dummer PM. Properties and applications of calcium hydroxide in endodontics and dental traumatology. Int Endod J 2011;44:697-730.
8. Reyes-Carmona JF, Felippe MS, Felippe WT. Biomineralization ability and interaction of mineral trioxide aggregate and white portland cement with dentin in a phosphate-containing fluid. J Endod 2009;35:731-6.
9. Martin RL, Monticelli F, Brackett WW, Loushine RJ, Rockman RA, Ferrari M, et al. Sealing properties of mineral trioxide aggregate orthograde apical plugs and root fillings in an *in vitro* apexitification model. J Endod 2007;33:272-5.
10. Aggarwal V, Miglani S, Kohli S, Singla M. Comparative evaluation of push-out bond strength of ProRoot MTA, biodentine, and MTA plus in furcation perforation repair. J Conserv Dent 2013;16:462.
11. Mediche S, Superiore I. Analysis of single point and continuous wave of condensation root filling techniques by micro-computed tomography. Ann Ist Super Sanita 2012;48:35-41.
12. Tanomaru M, Viapiana R, Guerriero J. From MTA to new biomaterials based on calcium silicate De MTA a nuevos biomateriales basados en Silicato de Calcio. J Dent Sci 2016;18:18-22.
13. Camilleri J. Sealers and warm gutta-percha obturation techniques. J Endod 2015;41:72-8.
14. Gade V, Belsare L, Patil S, Bhide R, Gade J. Evaluation of push-out bond strength of endosquence BC sealer with lateral cement and thermoplasticized technique: An *in vitro* study. J Conserv Dent 2015;18:124-7.
15. Chen WP, Chen YY, Huang SH, Lin CP. Limitations of push-out test in bond strength measurement. J Endod 2013;39:283-7.
16. Abada HM, Farag AM, Alhadainy HA, Darrag AM. Push-out bond strength of different root canal obturation systems to root canal dentin. Tanta Dent J 2015;12:185-91.
17. Pane ES, Palamara EA, Messer HH. Critical evaluation of the push-out test for root canal filling materials. J Endod 2013;39:669-73.
18. Donnemeyer D, Dorrnseifer P, Schäfer E, Dammaschke T. The push-out bond strength of calcium silicate-based endodontic sealers. Head Face Med 2018;14:13.
19. Skidmore LJ, Berzins DW, Bahcall JK. An *in vitro* comparison of the intraradicular dentin bond strength of resilon and gutta-percha. J Endod 2006;32:963-6.