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Effect of different agitation techniques on the dentinal tubule penetration of root canal irrigant and sealer

Agitation 방법에 따른 근관세척제 및 실러의
상아세관 침투효과

2016 년 8 월

서울대학교 대학원

치의과학과 치과보존학 전공

구 유

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이 논문을 치의학 박사학위논문으로 제출함

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Abstract

Effect of different agitation techniques on the dentinal tubule penetration of root canal irrigant and sealer

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Objective: Intracanal agitation techniques can promote chemo-mechanical debridement and the sealing of root canals during endodontic treatment. The aim of this study was to compare the effectiveness of five intracanal agitation techniques on the dentinal tubule penetration of root canal irrigant and sealer.

Methods: Human maxillary premolars with single straight canals (N = 60) were prepared by using X-smart Plus motor (Dentsply Maillefer) with

ProTaper Next NiTi rotary files (Dentsply Maillefer) up to X4 (40/.06). Five milliliter Rhodamine B-mixed sodium hypochlorite was used for final irrigation together with either the conventional syringe, sonic (Endomaster, ENC system), ultrasonic (PerioScan, Sirona Dental System GmbH), Nd:YAP laser (Lokki), or V-Clean^{TM} endodontic agitator (SS White). All canals were obturated with gutta-percha and fluorescein isothiocyanate mixed AH Plus sealer (Dentsply DeTrey) using the continuous wave of condensation technique. Transverse sections were obtained at 2, 5, and 8 mm from the apex, and observed under confocal laser scanning microscopy. Maximum penetration depth and penetration percentage of both root canal irrigant and sealer were recorded. The Kruskal-Wallis and Mann-Whitney tests were performed for multiple comparisons. The Spearman coefficient (r) was calculated to confirm correlations between root canal irrigant and sealer penetration into dentinal tubules.

Results: Laser agitation technique attained more penetration depth at 8 mm level and penetration percentage at 2 mm level of root canal irrigant than other agitation techniques (P<.05). Regarding sealer penetration, the laser agitation showed more sealer penetration depth at 8 mm level than other syring and ultrasonic techniques. The four tested agitation techniques exhibited significant better effect than syringe irrigation at 2 mm level in terms of sealer penetration percentage. Laser agitation attained highest sealer penetration percentage at 8 mm level. Maximum penetration depth and percentage of both root canal irrigant and sealer penetration correlated significantly for all agitation techniques ($r > 0.7$).

Conclusions: The Nd:YAP laser agitation technique showed superiority over other agitation techniques at one or more sectioned levels from root apex in terms of dentinal tubule penetration of root canal irrigant and sealer. The use of intracanal agitation would enhance the penetration of root canal irrigant and sealer into dentinal tubules and thereby improve the sealing quality of obturation.

Keywords: Agitation; confocal laser scanning microscopy; dentinal tubule penetration; Nd:YAP laser; root canal irrigant; root canal sealer.

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Contents

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1. Introduction

The main goals of root canal treatment are to eliminate or critically reduce the microbial load from the whole canal system and to prevent its reinfection.[1-3] Microbiological studies have clearly demonstrated that once pulp necrosis occurs, bacteria are found in the main root canal space, lateral canals, and dentinal tubules.[4] Infected dentinal tubules can then act as an important reservoir of microorganisms for root canal reinfection.[5] Mechanical instrumentation alone can result in a 100- to 1000- fold reduction in bacteria, although their complete eradication does not appear feasible.[6] Therefore, root canal disinfection with the aid of intracanal irrigant agitation methods can be particularly beneficial.

There is an increasing evidence that irrigant agitation within well shaped canals plays a critical role in cleaning and disinfecting the root canal system including the dentinal tubules.[7] Traditional syringe delivers irrigant solution only 1 mm deeper than the needle tip and a vapor lock at the apical third limits irrigant delivery at the apical area.[7] The efficacy of intracanl irrigation has been enhanced beyond the conventional syringe by the development of various agitation devices or techniques.[7-13] A CanalBrush (Coltene/Whaledent GmbH+Co. KG, Germany), which is a rotary engine driven instrument, with chelating agent increased debridement and smear layer removal.[9]. Passive ultrasonic irrigation (PUI) was shown to provide better root canal debridement at the apical 3 mm level compared to a conventional syringe, due to generated acoustic microstream.[10] Also, intracanal agitation by neodymium-doped:yttrium-aluminum-garnet (Nd:YAG) or erbium (Er):YAG laser energy has been reported to be effective at smear layer removal or sealer penetration into dentinal tubules.[11-13] When lasers are activated in water, elliptical vapor bubbles form and expand, which causes high pressure and they exhibit cleaning effects. However, the Er:YAG laser requires a water spray to avoid rapid over-heating, which makes it challenging to maintain irrigant concentration. The Nd:yttrium-aluminum-perovskite (YAP) laser with 1341 nm wavelength that was introduced by Blum & Abadie,[14] is believed to be well absorbed in water,[15] although little is known about its irrigant agitation effects. The V-Clean™ endodontic agitator (SS White, Lakewood, NJ, USA), which is recently introduced in market, is a newly launched endodontic microbrush that is constructed of medical-grade polymer. This highly flexible instrument is used manually in a rotary motion to enhance canal debridement. The EndoMaster (ENC System, Seongnam, Korea), which uses a hand file to create sonic vibrations, is supposed to enhance root canal disinfection. However, their intracanal agitation effect has not been yet reported in the literature.

The antibacterial effect achieved by endodontic treatment is more likely affected by deep infiltration of irrigant to scavenge bacteria residing inside dentinal tubules, and by sealer infiltration to entomb bacteria within the tubules.[16] Therefore, the aim of this study was to investigate the effect of five agitation methods on root canal irrigant and sealer penetration into human dentinal tubules. The null hypothesis was that there are no significant differences in the penetration of root canal irrigant and sealer into dentinal tubules with the intracanal agitation techniques.

2. Materials and methods

2.1. Tooth selection and preparation

Approval was obtained from the Institutional Review Board (IRB) of Seoul National University Dental Hospital, Seoul, Korea (CRI15011). Figure 1 shows the flowchart of the present study. In detail, human single-rooted maxillary premolars were selected (n=60), which were free of caries and prior root canal treatment. They were cleaned of extraneous tissue with an ultrasonic scaler and stored in 0.5% sodium azide solution. Each tooth was examined radiographically to confirm that their canals were not calcified, and that their curvatures were less than 20° according to the Schneider technique.[17] The teeth were then decoronated with a diamond disc to produce a standardized root length of 12 mm to facilitate instrumentation. After access cavity preparation, a 21-mm, #10 K–file (Dentsply Maillefer, Zurich, Switzerland) was inserted into each canal until they were just visible at the apical foramen, and working lengths established at 1 mm short of these lengths. The canals were then sequentially instrumented by using X-smart Plus motor (Dentsply Maillefer) and ProTaper Next NiTi rotary files (Dentsply Maillefer) up to an X4 (apical size 40/0.06) at working length. Between successive files, the canals were irrigated with 1 mL of 5.25% sodium hypochlorite (NaOCl) and 17% ethylenediaminetetraacetic acid (EDTA), which were delivered through 30 G irrigation needles (Vista-Probe; Vista Dental, Racine, WI, USA) with an up-and-down motion to within 1 mm short of working length.

2.2. Final irrigation with different agitation protocols

After the completion of chemo-mechanical preparation, the teeth were randomly divided into 5 experimental groups of 12 each, for the different intracanal agitation protocols. The final irrigant was 5.25% NaOCl, which was mixed with fluorescent Rhodamine B isothiocyanate (Sigma-Aldrich, St Louis, MO, USA) at approximately 0.1wt%, to enable its subsequent visualization within dentinal tubules by confocal laser scanning microscopy (CLSM). The experimental groups were as follows:

Group 1 (n=12): Conventional syringe; 5 mL of 5.25% NaOCl was delivered over 30 seconds through a 30 G irrigation needle (Vista-Probe) at 1 mm short of working length, with slight up-and-down motion.

Group 2 (n=12): Sonic agitation; 5 mL of 5.25% NaOCl was deposited during 30 seconds, and agitated with a #15 K-file, which was mounted in the

EndoMaster (ENC System) and advanced to the working length, in the “H” mode setting.

Group 3 (n=12): Ultrasonic agitation; 5 mL of 5.25% NaOCl was agitated by ultrasound for 30 seconds with an ISO #15 stainless steel ultrasonic file (Sirona Dental System GmbH, Bensheim, Germany), which was mounted in the ultrasonic device (PerioScan, Sirona Dental System GmbH) and placed at 1 mm short of working length in the “PERIO 3” setting.

Group 4 (n=12): V-Clean^{TM} endodontic agitator; 5 mL of 5.25% NaOCl was agitated with a V-Clean^{TM} endodontic agitator (#25/.04 taper, SS White). The agitator was placed at working length, and a slight up-and-down motion was exerted during 30 seconds.

Group 5 (n=12): Laser agitation; 5 mL of 5.25% NaOCl was activated by a 1341 nm Nd:YAP laser (Lokki dt, Vienne, France) at 280 mJ in 10 Hz pulse repetition rate as recommended by the manufacturer, with a flexible laser fiber (200 μm). The teeth were held upright by an operator and the fiber placed 3 mm from the apex and activated 4 times for 5 seconds each in an apical-to-coronal motion along the long axes of the canals, with 10 second intervals in between. Additional irrigant was deposited only if the coronal reservoir was depleted. The power density was 5.73 W/cm^2, and the energy density was 892 J/cm^2.

2.3. Root canal obturation

All canals were dried with ProTaper Next® paper points and obturated with ProTaper Next® gutta-percha X4 (Dentsply Maillefer) and AH plus sealer (Dentsply DeTrey, Konstanz, Germany) by using the continuous wave of condensation technique. Prior to use, the sealer was mixed with fluorescein isothiocyanate (FITC, Sigma-Aldrich) at approximately 0.1 wt%, to display a green fluorescence under CLSM. The FITC-mixed sealer was thoroughly dispersed into the canal by using a pre-fitted gutta-percha cone. The coronal gutta-percha was then removed with a heated plugger (SuperEndo-α^2; B&L Biotech, Ansan, South Korea), and the remaining apical third compacted with a stainless steel plugger for approximately 10 seconds. Then, the middle and coronal portions of the canal were backfilled with warm injectable gutta-percha device (SuperEndo-β; B&L Biotech), and vertically compacted at the canal orifice. The roots were sealed with Caviton (GC Corporation, Tokyo, Japan), and then stored in an incubator at 37^{o}C and 100% humidity for 24 hours to allow complete setting of the sealer.

2.4. Confocal laser scanning microscopy

Each root was embedded in an acrylic resin block. Transverse sections were made with a slow-speed, water-cooled diamond saw (Isomet Low Speed Saw; Buehler, Lake Bluff, IL, USA) at 2 mm (apical), 5 mm (middle), and 8 mm (coronal) level from the root apex. The apical and coronal surfaces of the sections were then standardized to 500 μm in thickness by polishing with 1200, 2400 and 4000 grit silicon carbide abrasive papers (Struers, Westlake, OH, USA). These sections were mounted on glass slides and examined by a confocal laser scanning microscope (Zeiss LSM-Pascal; Carl Zeiss, Göttingen, Germany) with a He/Ne G laser (543 nm and 632 nm). Magnified images (×50 and ×70) were captured in the fluorescent mode and analyzed with Zeiss LSM Image Examiner software (Carl Zeiss).

The maximum depth of irrigant and sealer penetration into dentinal tubules (×70 images), and the percentage of penetration into dentinal tubules (×50 images) were calculated by using a method previously described (Fig. 2).[18, 19] In brief, each image was imported into the Zeiss LSM Image Examiner, and the circumference of the root canal wall outlined and measured. The length along the canal circumference where Rhodamine B mixed-NaOCl (red fluorescence) and FITC mixed-sealer (green fluorescence) had penetrated into the dentinal tubules, were measured. The percentage of dentinal tubules penetrated (%) was calculated from the ratio of the arc of the canal wall where irrigant had penetrated, to that of the entire canal wall circumference. The maximum root canal irrigant and sealer penetration depth (μm) was measured as the distance from the tubule orifice at the canal wall, to the deepest point of penetration along the dentinal tubule. These measurements were made by an investigator who was blinded to the agitation protocols, and they were repeated three times to ensure consistency and reproducibility.

2.5. Statistical analysis

Kruskal-Wallis analyses were performed for overall comparisons of penetration, followed by Mann-Whitneytests for multiple comparisons ($P = .05$). The Friedman test was used to compare the differences at the apical, middle, and coronal levels, and the Bonferroni correction applied for pair-wise comparisons between levels ($P = .05$). The Spearman correlation coefficient (r) was calculated at each level to determine correlations between irrigant and sealer penetration according to the categorization of Dancey and Reidy.[20] The IBM SPSS Statistics for Windows Version 22.0. (IBM Corp, Armonk, NY, USA) was used for statistical analysis.

3. Results

For root canal irrigant, maximum penetration depth and penetration percentage are shown in Figures 3a and 3b, respectively. At 2 mm level from the apex, there were no significant differences in maximum penetration depth between groups ($P > .05$). At 5 level, there was significantly more penetration depth in the laser group than the syringe, ultrasonic, and V-clean agitation groups ($P < .05$). At 8 mm level, the laser group attained the highest penetration depth among all groups ($P < .05$). For all groups, penetration depths at 2 mm level were significantly less than those at 5 mm and 8 mm ($P < .05$).

At 2 mm level, the sonic and ultrasonic groups showed significantly higher penetration percentage than the syringe group and the laser group significantly attained the highest penetration percentage than the other agitation techniques ($P < .05$). At 5 mm level, the laser group obtained the highest penetration percentage than the other agitation techniques except V-Clean ($P > .05$). Additionally, there were no significant differences at 8 mm level for all agitated groups ($P > .05$).

For root canal sealer, maximum penetration depth and penetration percentage are shown in Figures 4a and 4b, respectively. There were no significant differences among the five groups at 2 and 5 mm levels in terms of maximum penetration depth ($P > .05$). However, at 8 mm level, laser agitation obtained higher penetration depth than traditional syringe and ultrasonic agitation ($P < .05$). For all groups the penetration depth of sealer at 2 mm level was the least ($P < .05$).

Regarding the penetration percentage of root canal sealer, the 4 tested agitation techniques showed significant differences at 2 mm level than the traditional syringe group ($P < .05$), but no differences were found at the 5 mm level among all 5 groups ($P > .05$). In addition, at 8 mm level, the laser agitation showed superiority over the other agitation techniques ($P < .05$).

A Spearman's correlation analysis indicated that there were significant correlations between the maximum penetration depth and percentage of root canal irrigant and sealer at each level (Spearman correlation coefficient: $r > 0.7$, Table 1). Representative CLSM images of root canal irrigant and sealer penetration into dentinal tubules for the five experimental groups at each level are presented in figures 5 to 9.

4. Discussion

This study investigated the efficacy of different agitating techniques, in terms of dentinal tubule penetration of root canal irrigant and sealer to achieve improved disinfection and sealing of root canal system.[21] The effect of each agitation technique was assessed as percentage and maximum depth of dentinal tubule penetration that were concurrently measured for both root canal irrigant and sealer. As a result, The Nd:YAP laser agitation technique showed superiority over other agitation techniques at one or more sectioned levels from root apex in terms of dentinal tubule penetration of root canal irrigant and sealer. Several factors can influence the penetration of root canal irrigant and sealer into dentinal tubules. Zou *et al.* showed that temperature, contact time, and concentration influenced the penetration of NaOCl into tubules.[22] Anatomical features may also limit root canal irrigant penetration into dentinal tubules. The tubules are larger and more densely packed within the coronal and middle thirds of the roots, and tubular sclerosis begins within the apical area.[23] This may partly account for the lower penetration of root canal irrigant and sealer at the apical 2 mm level, which was shown in the present study. Furthermore, since canal curvatures can also limit the penetration of root canal irrigant ans sealer, this study was restricted to relatively straight canals (curvatures $< 20^{o}$). Similar findings were reported for different sealer systems and obturation techniques.[2,24]

Previous studies have compared various intracanal agitation techniques with the conventional syringe for penetration of root canal irrigant into dentinal tubules.[25, 26] However, the present study used two distinct fluorescent dyes to distinguish and quantify root canal irrigant and sealer penetration of dentinal tubules concurrently under CLSM, by using the method introduced by Gharib *et al*.[27] Based on this methodology, the Nd-YAP laser clearly attained higher penetration depth for root canal irrigant (5 mm and 8 mm levels) and sealer (8 mm level) into dentinal tubules, when compared to syringe irrigation. Similarly, Kundabala *et al*. showed that an 810 nm diode laser significantly improved irrigant penetration depth when compared to the conventional syringe.[28] A previous study also reported that Nd:YAG laser with 1320 nm wavelength was better than either NaOCl or EDTA alone, for sealer penetration.[11] Other studies showed that an Er:YAG laser was effective at dentin debridement and smear layer removal.[12,13] However, the Er:YAG laser requires a water spray to avoid rapid over-heating, which makes it challenging to maintain irrigant concentration. The present study used "ENDO–mode" as an irrigation setting of Nd:YAP laser, which is 280 mJ in 10 Hz repetition and the results showed superiority over other agitation techniques at one or more sectioned levels from root apex in terms of dentinal tubule penetration of root canal irrigant and sealer. Other researchers who studied the same equipment at 260 mJ and 5 Hz, also confirmed the cleansing effect of Nd:YAP laser during canal irrigation.[15] This could be attributed to fluid dynamics and imploding vapor bubbles generated at their fiber tips, and shock wave effects of the laser.[24] Furthermore, the cleaning efficacy of laser is speculated to be further enhanced by secondary cavitation bubbles, because of the excitation by the bubble collapse of the consecutive laser pulse.[13] Further research would be interesting to examine the cleansing efficacy of Nd:YAP laser agitation in terms of entire root canal system including hard-to-reach areas such as isthmus, fins, loops, ramifications, and C-shaped canals.

When a clinician considers the use of Nd:YAP laser for the purpose of intracanal agitation in infected root canal, thermal damage to surrounding periodontal tissue by exploding and imploding can be possible. This is because apical portion of the instrumented root become thinner or perforated when the root end was resorbed by a large pathologic lesion. In this situation, when the laser fiber approaches closer to the root apex, this area can be more susceptible to thermal damage.[29] Another concern caused by the use of intracanl laser agitation is the possibility of pain by irrigant or debris extrusion. Therefore, in the present study, the laser fiber placed 3 mm from the apex and activated 4 times for 5 seconds each in an apical-to-coronal motion along the long axes of the canals with lower power setting as a previous study suggested.[11]

Sonic and ultrasonic devices have been proposed for maximizing irrigant hydrodynamics and distribution within the root canal system, and a prior study found that they improved irrigation of lateral canals.[30] Interestingly, in the present study there was no significant differences in promoting penetration of root canal irrigant and sealer into dentinal tubules between sonic and ultrasonic agitation. This underperformance of the ultrasonic device may have been due to the shorter time for agitation, and inadvertent contact between the ultrasonic file and canal walls, which may have dampened its effectiveness.[31, 32]

The more recently introduced V-Clean™ endodontic agitator is uniquely designed to provide a dual-action scrubbing/scraping process that removes the smear layer, dislodges and removes debris from the canal, and concurrently agitates irrigating solutions. The V-Clean™ has a similar design to the CanalBrush (Coltene/Whaledent GmbH+Co) and is a rotary engine driven instrument. Kamel *et al*. showed that a CanalBrush with chelating agent increased canal debridement and smear layer removal.[9] However, the present results revealed that the V-Clean™ endodontic agitator did not show any significant improvement over the conventional syringe for irrigant penetration of dentinal tubules at three levels. This is in accordance with study of Garip *et* *al*. who found that the CanalBrush did not show any significant improvement in smear layer removal from the canal walls, when compared to conventional irrigation.[33] It is speculated that the manual activation of V-Clean™ generates limited vortex of irrigant compared to other machine-assisted devices, and complex anatomical variations of the root canal system may impede its contact with the canal wall. Furthermore, the manual scrubbing or scratching motion could cram debris into dentinal tubules, which may also explain the underperformance of V-Clean™ agitator in this study.

The influence of the smear layer on irrigant and sealer penetration into dentinal tubules is an ongoing debate that is still unravelling. Paqué et al reported that irrigant penetration was largely dependent on the presence of tubular sclerosis in the dentine, rather than the absence of a smear layer.[23] Therefore, the present study did not directly investigate the effect of the intracanal agitation methods on the removal of smear layer. Instead, concurrent analysis of root canal irrigant and sealer penetration into dentinal tubules using CLSM was performed to investigate the potential role of irrigant penetration, as an indirect indicator, for evaluating the degree of smear layer removal. The ions dissociated from NaOCl are smaller than AH 26 Plus sealer particles and have better flowability, thus, correlations of maximum penetration depth or percentage of root canal irrigant and sealer were not anticipated. Nonetheless, the Spearman correlation coefficient revealed that there were significant correlations in the tubular penetration of root canal irrigant and sealer. This finding indirectly indicates that smear layer cleansing from the dentinal surface by intracanal agitation might cause similar penetration pattern of both root canal irrigant and sealer into dentinal tubules. Additional studies that employ a smear layer model are needed to confirm this finding.

5. Conclusions

This *in vitro* study has increased our understanding of the intracanal irrigant agitation effects of an Nd:YAP laser. The Nd:YAP laser agitation technique showed more effects over other agitation techniques at certain levels from root apex in terms of dentinal tubule penetration of root canal irrigant and sealer. The use of intracanal agitation could enhance the penetration of root canal irrigant and sealer into dentinal tubules and might improve the sealing quality of obturation.

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Figures

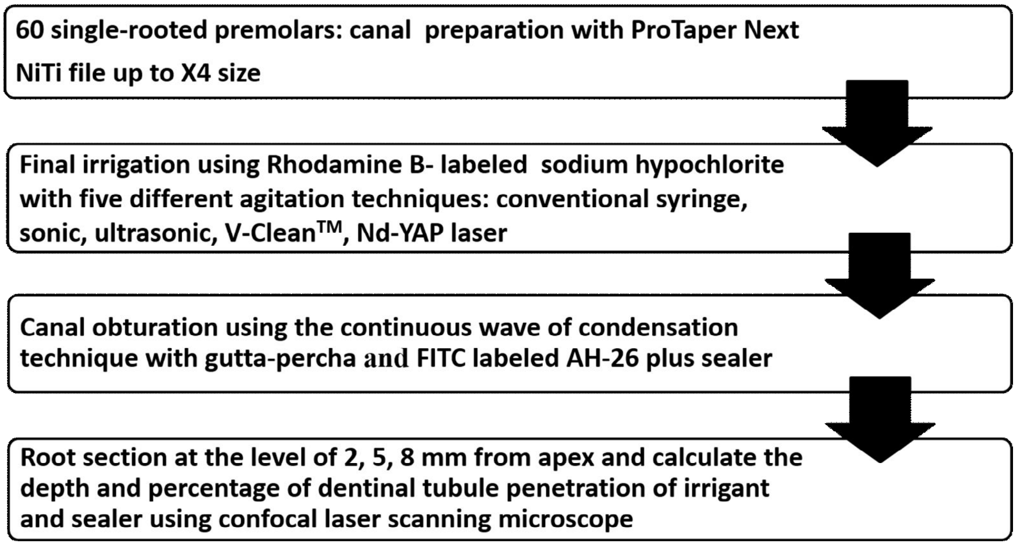


Figure 1. Experimental flowchart of the present study.

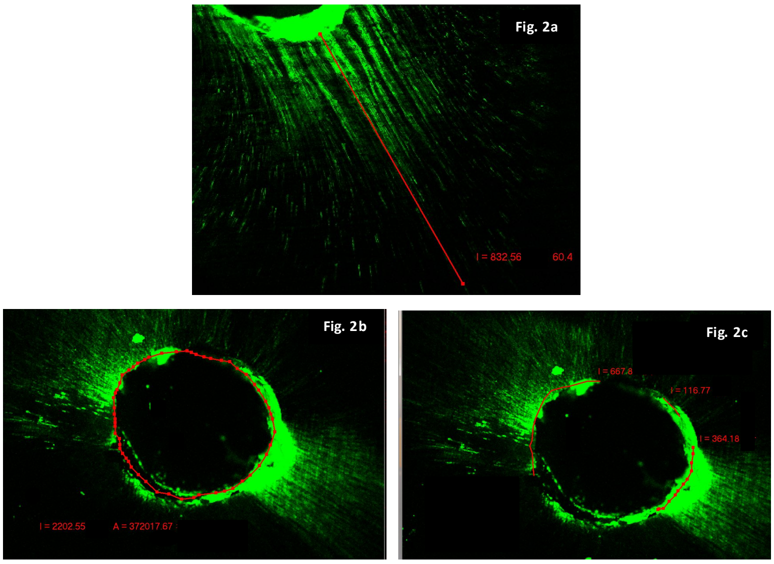


Figure 2. Schema of the measurement of maximum penetration depth (Fig. 2a) and outline of the circumference (Fig. 2b) and penetrated length along the circumference (Fig. 2c). Penetration percentage = Sum of the penetrated length (Fig. 2c) / Circumference (Fig. 2b).

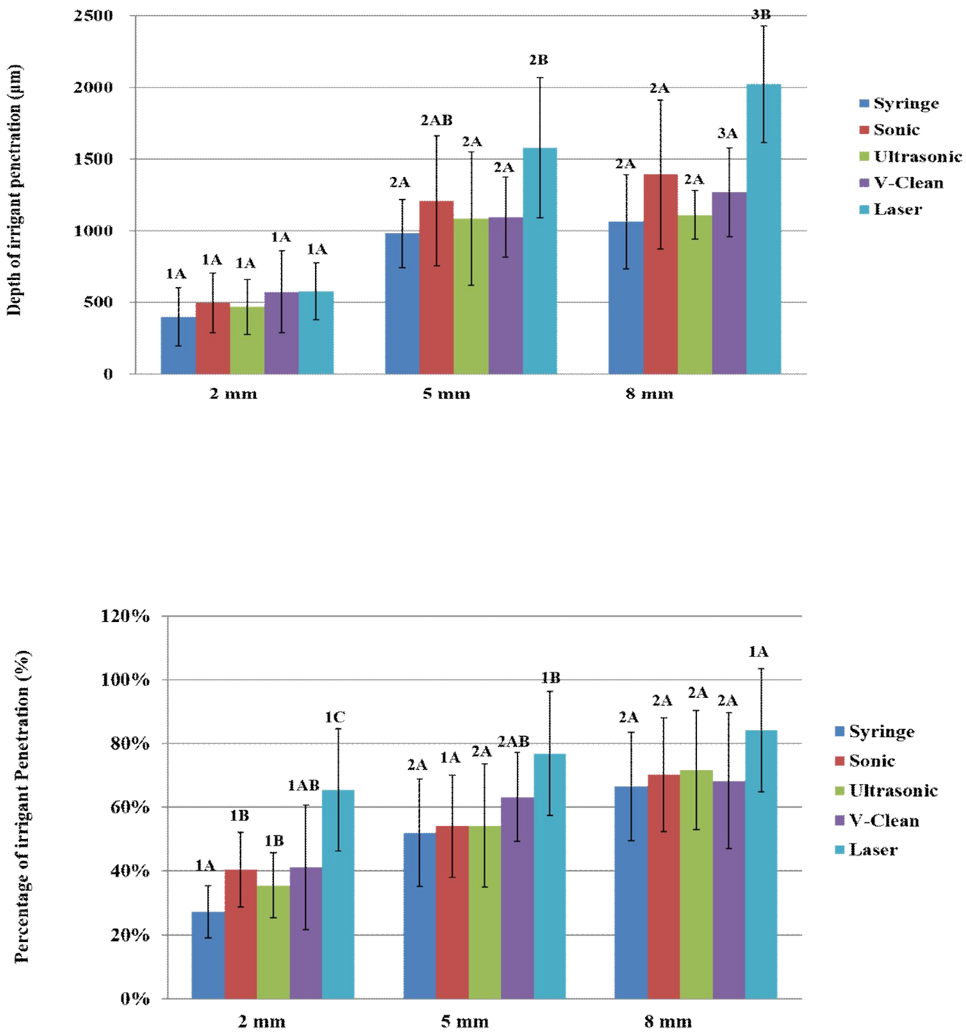
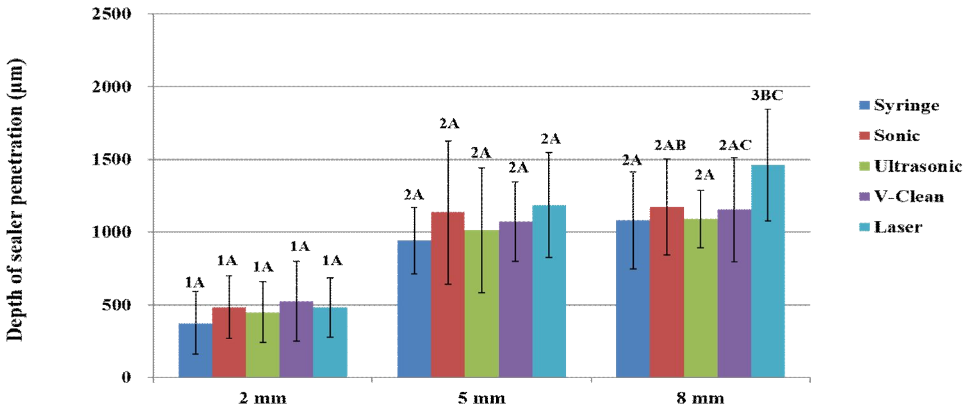


Figure. 3. Maximum penetration depth (µm, a) and percentage (%, b) of irrigant at each level from apex of each experimental group. Groups with same letters within same level are not significantly different from each other ($P > .05$).

Different numbers within the same group indicate significant differences at 2 mm, 5 mm, and 8 mm levels ($P < .05$).



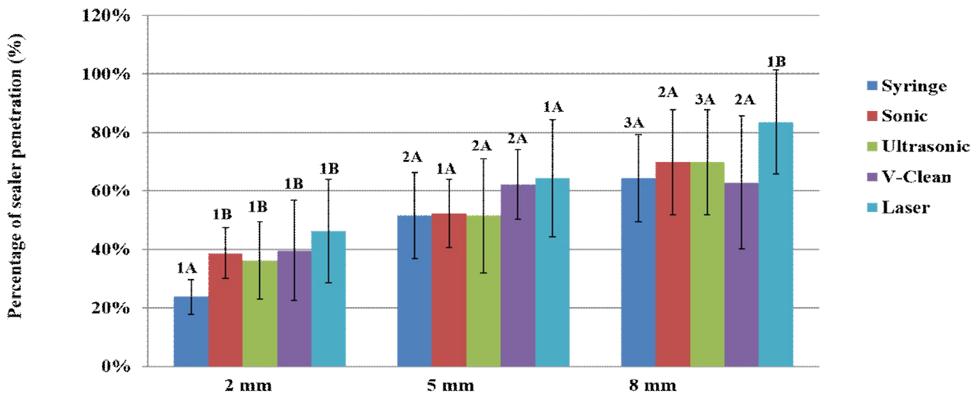


Figure. 4. Maximum penetration depth (µm, a) and percentage (%, b) of sealer at each level from apex after application of five agitation methods. Groups with same letters within same level are not significantly different from each other (*P*

> .05). Different numbers within the same group indicate significant differences at 2 mm, 5 mm, and 8 mm levels ($P < .05$).

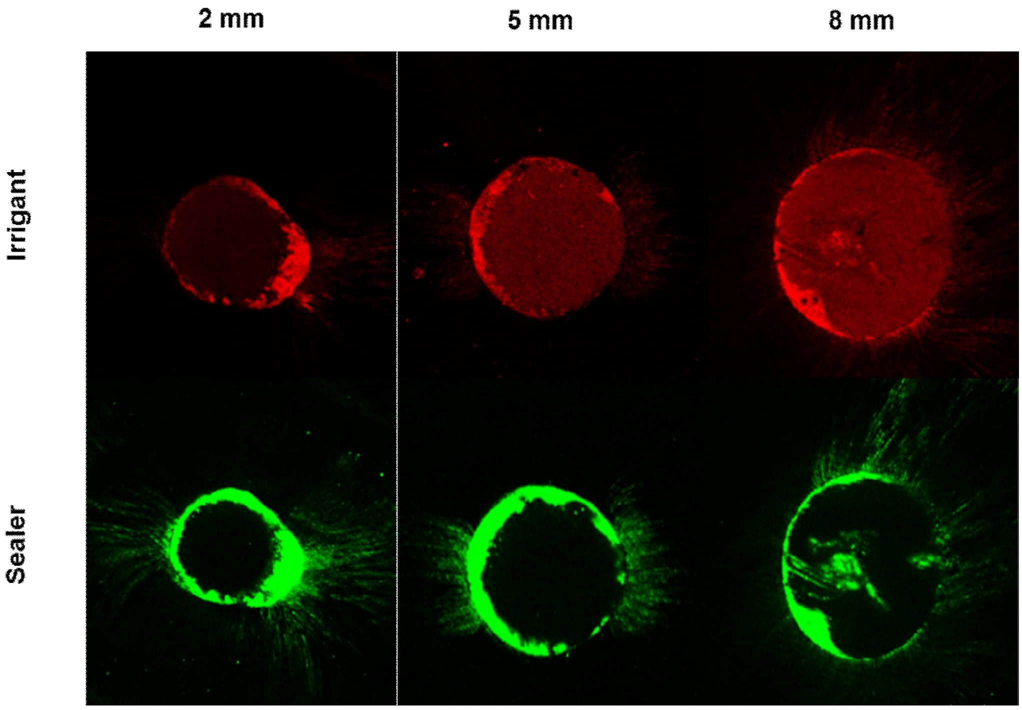


Figure. 5. Representative CLSM images of both irrigant and sealer from conventional syringe group (original magnification, ×50) at 2 mm, 5 mm, and 8 mm levels. The upper images (red) represent Rhodamine B-mixed NaOCl while the lower images (green) represent FITC-mixed root canal sealer.

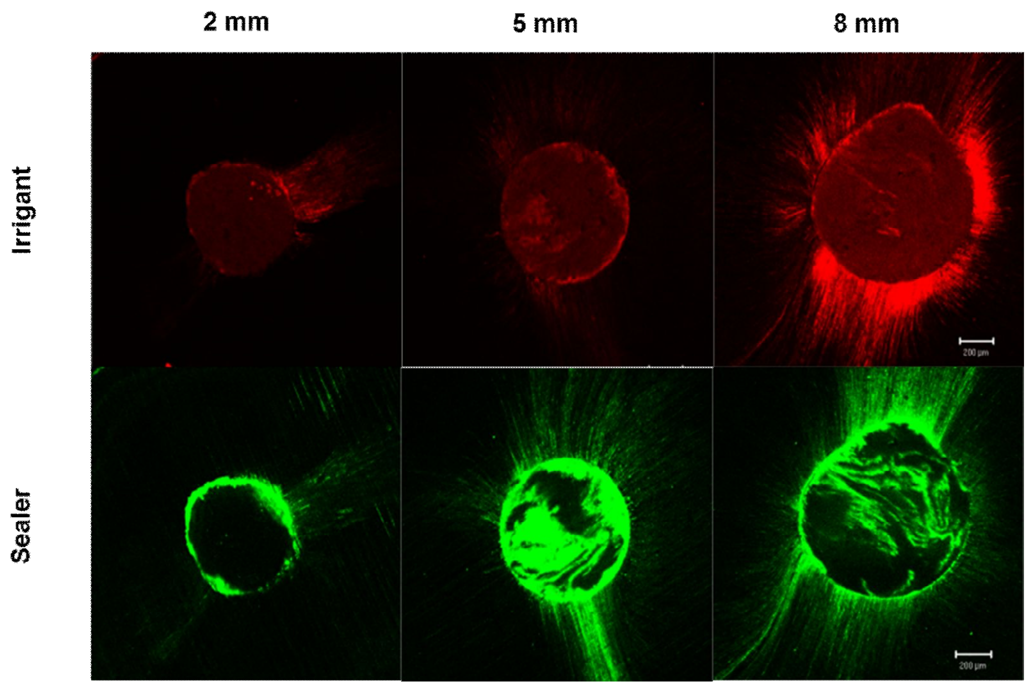


Figure. 6. Representative CLSM images of both irrigant and sealer from sonic group (original magnification, ×50) at 2 mm, 5 mm, and 8 mm levels. The upper images (red) represent Rhodamine B-mixed NaOCl while the lower images (green) represent FITC-mixed root canal sealer.

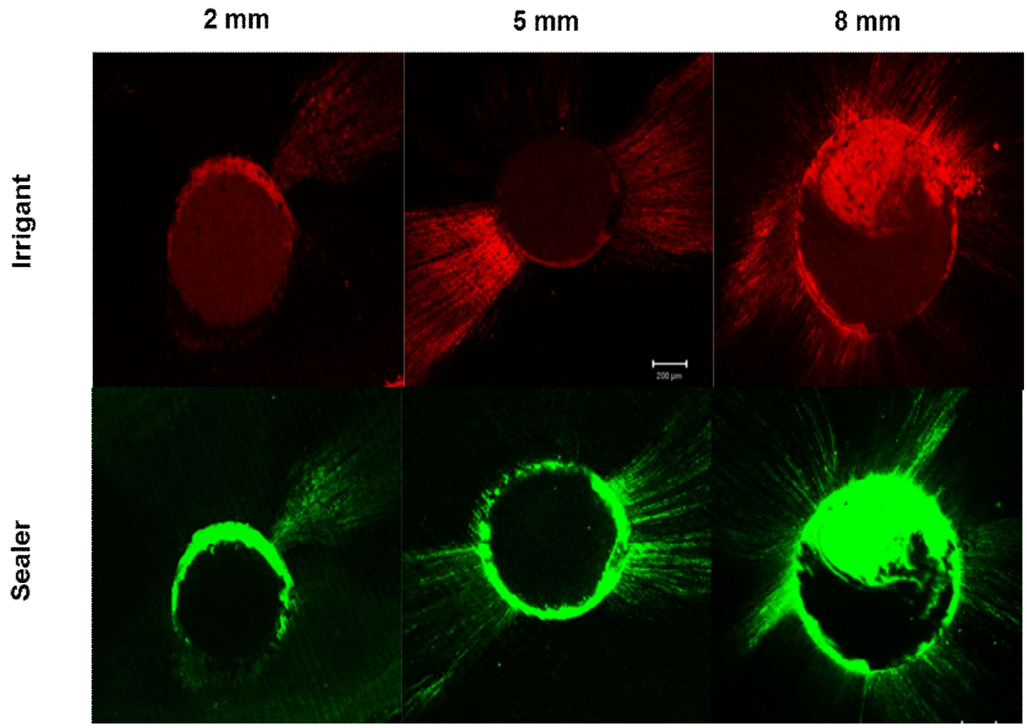


Figure. 7. Representative CLSM images of both irrigant and sealer from ultrasonic group (original magnification, ×50) at 2 mm, 5 mm, and 8 mm levels. The upper images (red) represent Rhodamine B-mixed NaOCl while the lower images (green) represent FITC-mixed root canal sealer.

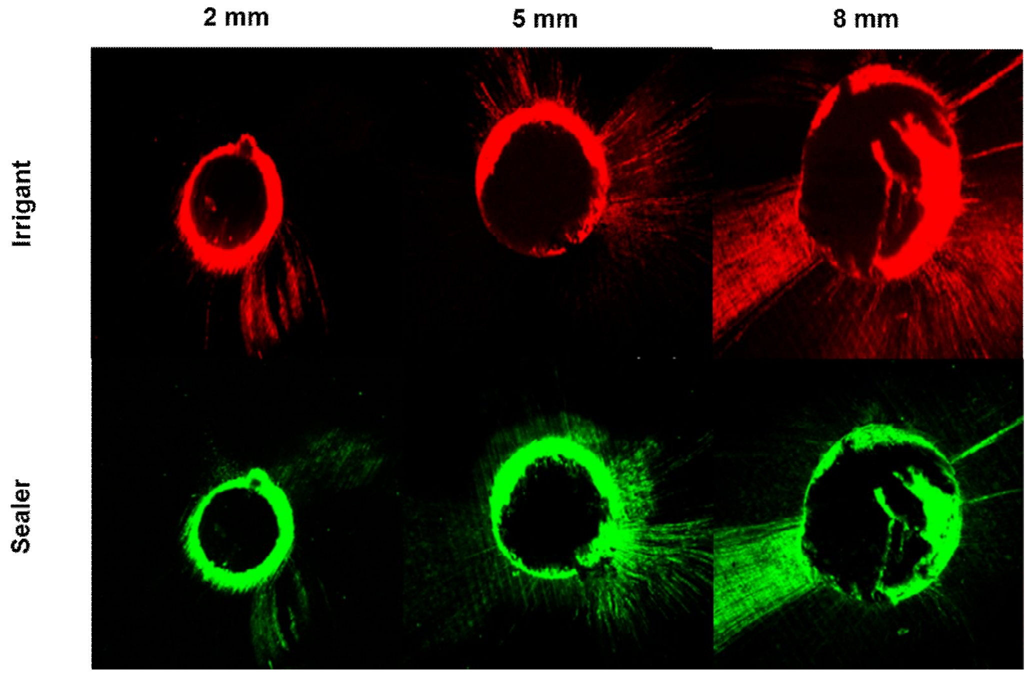


Figure. 8. Representative CLSM images of both irrigant and sealer from V-Clean agitator group (original magnification, ×50) at 2 mm, 5 mm, and 8 mm levels. The upper images (red) represent Rhodamine B-mixed NaOCl while the lower images (green) represent FITC-mixed root canal sealer.

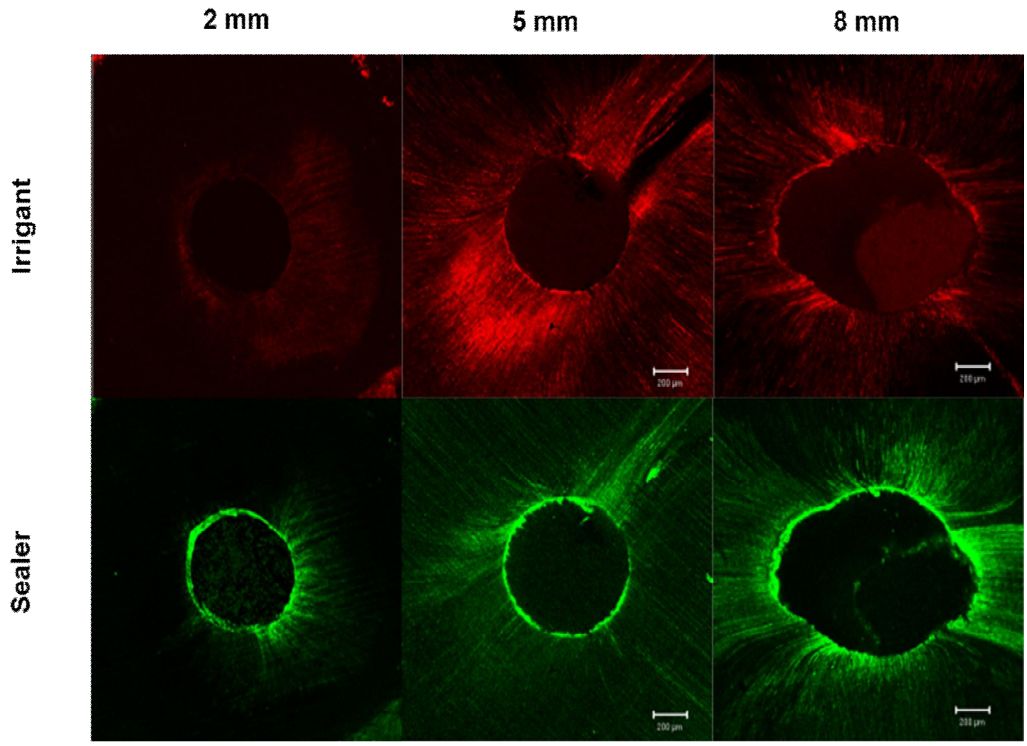


Figure. 9. Representative CLSM images of both irrigant and sealer from Nd-YAP group (original magnification, ×50) at 2 mm, 5 mm, and 8 mm levels. The upper images (red) represent Rhodamine B-mixed NaOCl while the lower images (green) represent FITC-mixed root canal sealer.

Table 1. Depth (μm) and percentage (%) of root canal irrigant into dentinal tubules

	Group	n	2 mm level		5 mm level		8 mm level	
			Mean ± SD	Median	Mean ± SD	Median	Mean ± SD	Median
Maximum depth (μm)	Syringe	12	399.55 ± 202.59[a]	407.33	981.26 ± 237.56[a]	1024.36	1063.61 ± 329.03[a]	1009.76
	Sonic	12	495.82 ± 208.38[a]	464.54	1211.92±452.48[ab]	1148.57	1393.8 ± 520.19[a]	1218.83
	Ultrasonic	12	469.33 ± 192.88[a]	477.09	1083.95 ± 464.46[a]	1106.90	1109.86 ± 169.81[a]	1121.76
	V-Clean	12	574.36 ± 286.19[a]	526.54	1094.00± 279.47[a]	1111.21	1268.35 ± 309.93[a]	1272.10
	Laser	12	579.27 ± 200.73[a]	548.13	1577.79 ± 488.69[b]	1597.50	2021.04 ± 405.10[b]	2175.52
p-value			0.27		0.023		0.001	

	Group	n	2 mm level		5 mm level		8 mm level	
			Mean ± SD	Median	Mean ± SD	Median	Mean ± SD	Median
Percentage (%)	Syringe	12	27.28 ± 8.13[a]	26.95	51.91 ± 16.81[a]	47.95	66.49 ± 16.98[a]	72.65
	Sonic	12	40.39 ± 11.72[b]	39.00	54.04 ± 16.03[a]	51.25	70.16 ± 17.8[a]	68.50
	Ulteasonic	12	35.43 ± 10.14[b]	33.80	54.19 ± 19.24[a]	52.65	71.73 ± 18.77[a]	70.80
	V-Clean	12	41.14 ± 19.60[ab]	41.00	63.15 ± 13.94[ab]	66.70	68.23 ± 21.29[a]	74.65
	Laser	12	65.38 ± 19.22[c]	69.55	76.81 ± 19.47[b]	75.60	84.18 ± 19.37[a]	94.10
p-value			0.001		0.012		0.262	

Equal letters in the same column indicate no significance; SD means standard deviation.

Table 2. Depth (µm) and percentage (%) of root canal sealer into dentinal tubules

	Group	n	2 mm level		5 mm level		8 mm level	
			Mean ± SD	Median	Mean ± SD	Median	Mean ± SD	Median
Maximum depth (µm)	Syringe	12	375.10±217.67[a]	330.74	940.97 ± 228.81[a]	865.28	1080.06 ± 334.91[a]	1014.41
	Sonic	12	481.95 ± 211.91[a]	443.55	1133.61±493.29[a]	1024.15	1173.26 ± 330.79[ab]	1156.52
	Ultrasonic	12	447.88 ± 209.06[a]	425.76	1012.22±428.59[a]	1080.37	1090.04 ± 196.34[a]	1079.43
	V-Clean	12	523.86 ± 275.76[a]	524.97	1072.29±271.62[a]	1105.78	1156.10 ± 358.56[ab]	1226.65
	Laser	12	480.40 ± 203.81[a]	432.72	1187.09±360.64[a]	1167.68	1463.07 ± 385.77[b]	1527.02
p-value			0.573		0.504		0.066	
	Group	n	2 mm level		5 mm level		8 mm level	
			Mean ± SD	Median	Mean ± SD	Median	Mean ± SD	Median
Percentage (%)	Syringe	12	23.79 ± 5.90[a]	22.00	51.53 ± 14.68[a]	51.40	64.64 ± 14.95[a]	64.30
	Sonic	12	38.64 ± 8.66[b]	38.95	52.28 ± 11.58[a]	48.50	69.83 ± 18.08[a]	66.15
	Ultrasonic	12	36.24 ± 13.21[b]	31.85	51.47 ± 19.43[a]	55.50	69.77 ± 18.00[a]	67.95
	V-Clean	12	39.73 ± 17.17[b]	39.00	62.29 ± 11.93[a]	63.20	62.97 ± 22.62[a]	65.10
	Laser	12	46.16 ± 17.69[b]	39.25	64.40 ± 20.00[a]	66.30	83.60 ± 17.86[b]	92.70
p-value			0.001		0.132		0.048	

Equal letters in the same column indicate no significance; SD means standard deviation

Table 3. Spearman's correlation coefficient analysis between irrigant and sealer penetration patterns

	Maximum penetration depth			Penetration percentage		
	Apical	Middle	Coronal	Apical	Middle	Coronal
r	0.900	0.900	0.822	0.777	0.781	0.749
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

"*r*" represents the Spearman correlation coefficient; 0.70 - 0.99 indicates a strong correlation (Dancey and Reidy's categorization, 2004)

국문초록

Agitation 방법에 따른 근관세척제 및 실러의 상아세관 침투효과

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1. 목적

본 연구의 목적은 다양한 agitation 방법을 사용하여 근관세척제와 **실러의** 상아세관 침투 효과를 비교하는 것이다.

2. 재료 및 방법

직선의 단근관을 가지는 사람의 상악소구치 (n=60)를 준비하여 ProTaper Next NiTi 전동파일 (Dentsply Maillefer)을 이용하여 X4 까지 근관형성 하였고, 근관형성 중 5.25% 차아염소산나트륨 용액과 17% EDTA 용액을 각각 1ml 씩 사용하여 근관세척 하였다.

Agitation 방법을 다음과 같이 5개의 그룹으로 나누고 (전통적인 syringe

사용, sonic (Endomaster), ultrasonic (PerioScan), V-Clean™ endodontic agitator (SS White), 및 Nd:YAP laser (Lokki), 각 그룹 당 12개의 치아를 분배하였다. 근관충전 전에 즉시 Rhodamine B를 섞은 차아염소산나트륨 용액을 모든 근관내에 동일한 양 (5ml)을 넣고 각 agitation 방법을 적용하였다. 모든 근관은 거타퍼차와 fluorescein isothiocyanate로 처리한 AH Plus sealer(Dentsply DeTrey)를 이용하여 열연화 가압충전법으로 충전하였고, 치근단에서 2, 5, 8 mm 상단의 횡단면을 잘라 공초점 현미경을 이용해 관찰하였다. 근관세척제와 실러의 최대 침투영역을 깊이(길이)와 비율로 기록하였다. 결과 값에 대해서 Kruskal-Wallis와 Mann-Whitney 통계법을 사용하여 다중비교를 하였고, Spearman coefficient를 이용하여 근관세척제와 sealer의 상관관계를 분석하였다.

3. 결과

레이저를 이용한 agitation technique이 다른 agitation technique보다 근관세척제의 침투깊이(5mm, 8mm level)와 침투율(2mm, 5mm level)이 가장 높았다 ($P < .05$). 실러 침투에서도 레이저를 이용한 agitation system이 8mm level에서 실러 침투깊이와 침투율이 다른 agitation technique보다 유의성있게 높았다 ($P < .05$). Sonic과 ultrasonic agitation technique은 치근단 2mm 상단 지점에서 대조군에 비해 근관세척제와 실러 침투 비율이 높았다(P< .05). V-Clean™ endodontic agitator 은 치근단 2mm 상단 지점에서 실러 침투 비율이 대조군에 비해 높았다 (P< .05). 모든 agitation techniques에서 근관세척제와 실러의 상아세관내 침투 깊이와 침투율은 서로 상관관계를 보였다 ($r > 0.7$).

4. 결론

Nd:YAP 레이저 agitation technique은 다른 agitation technique보다 1개 이상의 치근단 절단면 level에서 근관세척제와 실러의 상아세관 침투에서 우수한 효과를 보여주었다. 근관내 agitation 의 사용은 근관세척제나 실러의 상아세관내 침투를 증가시켜 근관충전의 폐쇄능을 증가시킬 것으로 사료된다.

주요어: Agitation; 공초점 현미경; 상아세관 침투; Nd:YAP 레이저; 근관세척제; 실러

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