Original Article

Laser-assisted Root Canal Filling Removal of Lower Incisors – A Micro-CT Study

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ABSTRACT

Aim: To compare the efficiency of root canal filling removal from oval-shaped root canals with high-energy Er:YAG laser and additional instrumentation with a rotary Ni-Ti XP-Endo Finisher R system. **Materials and Methods:** The *in vitro* study was accomplished on 12 freshly extracted single-rooted mandibular incisors with one straight oval-shaped root canal, shaped with XP-Endo Shaper 30/.04 and obturated by using the warm vertical condensation technique subjected to further endodontic orthograde retreatment. Group 1: the first retreatment was carried out using a high-energy Er:YAG laser (n = 12). Group 2: the additional retreatment of the same specimens was performed with the XP-Endo Finisher-R system (n = 12). The effectiveness of the retreatment techniques was evaluated by a threefold micro-CT examination. The amount of the remaining root canal filling material was analyzed by Mann–Whitney U test and Friedman tests. **Results:** A significant decrease in the quantity of the root canal filling was found following the first and after the second retreatment, compared to the initial values in all examined sections ($P < 0.001$). Within groups, additional application of the Ni-Ti system resulted in no significant removal of the filling materials ($P > 0.05$). **Conclusions:** None of the systems resulted in complete root canal filling removal. Despite the improved results after the application of the supplementary retreatment protocol, none of the root canal walls were completely clean in the apical area. The high-energy Er:YAG laser and XP-Endo Finisher R rotary system can be successfully used in endodontic orthograde retreatment under relevant operating parameters.

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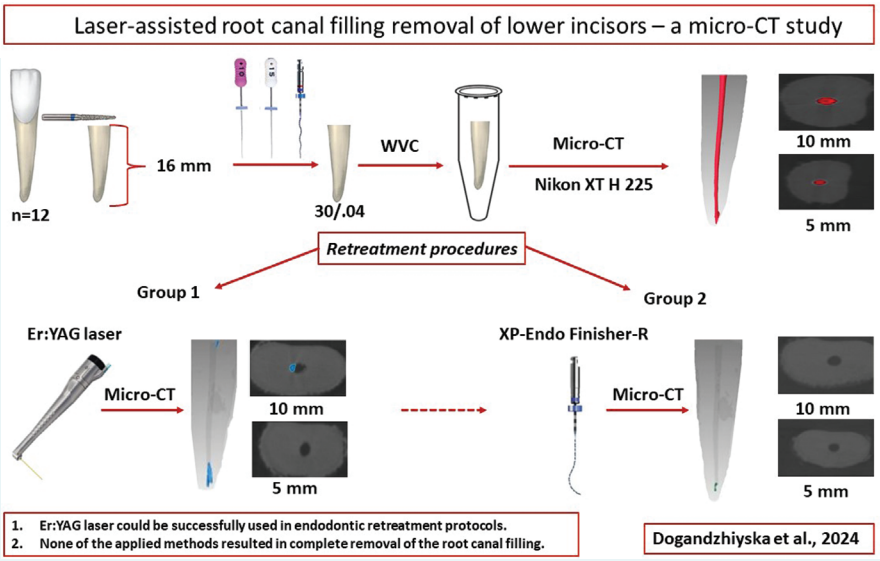

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Introduction

Root canal therapy failure may occur due to numerous causes. Some of them, such as insufficient obturation of the root canal space and coronal microleakage, may be subject to repeated endodontic treatments. It is a difficult and time-consuming procedure, but it is undoubtedly the first choice for the treatment of endodontic mishaps when root canal access is possible.[1,2] Thorough removal of the root canal substance and regaining patency to the apical foramen are a requisite for appropriate cleaning, followed by new obturation. Three methods are usually applied to remove obturation materials: mechanical, ultrasonic, and chemical (various solvents).[3-6]

Recent literature proposes the use of lasers in the retreatment process.[7,8] Laser energy improves the cleanliness of the root canal space, removes tissue remnants and smear layer, and has a proven antibacterial effect.[9-11] With the aid of lasers, clinicians could soften materials prior to their removal; thus, the stress on the canal wall and the risk of cracking induced by rotary instrumentation are reduced. Moreover, the utilization of lasers decreases the risk of intracanal instrument breakage and avoids overheating of the tooth, which is very dangerous for the periodontal ligament and bone. One of the major advantages of the application of laser light is its possibility to operate without solvents that can be toxic. Despite the reduced tactile sensation, the use of tips with increased flexibility and radiating irradiation reduces methodological flaws such as ledge formation, perforations, and transportation in curved canals. Various high-energy laser systems such as diode, Nd:YAG/YAP, and Er:YAG lasers can be used for the removal of the root canal material. The use of Nd:YAG and Nd:YAP lasers in the retreatment process was described and evaluated in the late 1990s.[12]

Progress in the endodontic field resulted in the implementation of NiTi rotary instruments which are not only effective in primary root canal shaping, but are also efficient and less tedious in gutta-percha/sealant removal during endodontic retreatment compared to hand files.[13] Ni-Ti rotary files which are specifically manufactured for the retreatment process are proven to be safe enough.[14] With the improvement in the metallurgical and manufacturing process, new systems have emerged on the market, enabling thorough removal of the root canal filling, especially in oval-shaped root canals. The XP-endo Finisher and XP-endo Finisher R (*FKG Dentaire, La Chaux-de-Fonds, Switzerland*) are such novel instruments made of ultra-flexible Martensite-Austenite Electropolish FleX NiTi alloy.[15,16] They can be successfully used for additional cleaning of the root canal walls, preserving the initial anatomy of the canal and its irregularities.

Nowadays, there is still lack of data concerning the effectiveness of laser energy in the endodontic

retreatment of canals with oval shape, used alone or in combination with NiTi files.

The purpose of the current *in vitro* investigation was to analyze the efficacy of the high-energy Er:YAG laser used alone or in combination with XP-Endo Finisher R files in removal of the root canal obturation material from oval-shaped canals.

Materials and Methods

Sample collection

The experiment was carried out on 12 freshly extracted single-rooted mandibular incisors with one straight oval-shaped root canal (approval protocol no. 907/22.03.22). Teeth with any abnormalities were discarded. The specimens were kept in saline solution.

Sample preparation

The external surfaces of all samples were debrided from any tissue plaque with an ultrasonic scaler (Wellsamed GmbH, Leipzig, Germany). They were further polished with Sof-Lex discs (3M ESPE Dental), a polishing brush (Wellsamed GmbH, Leipzig, Germany), and polishing paste Cleanic (Kerr Dental, Orange, CA, USA). The length of all samples after decoronation was found to be 16 mm. The final working length was measured by a hand stainless steel K-file (10/.02).

A glide path was prepared manually with hand K-files 10/.02 and 15/.02. The instrumentation was performed with XP-Endo Shaper 30/.04 in the presence of Endo-prep gel (Cerkamed, Stalowa Wola, Poland) and 2% Chloraxid (Cerkamed, Stalowa Wola, Poland). The shaping process was finished with a final rinse with ENDO-SOLution (Cerkamed, Stalowa Wola, Poland) and saline. Each rotary file was used for three canals only. The root canals of all specimens were filled by using the warm vertical compaction technique and an epoxy resin sealer.[17] The quality of the filling material was evaluated by micro-CT examination. Any samples exhibiting insufficient or root canal filling with gaps were discarded and replaced by new ones.

Retreatment procedures

Group 1. The first retreatment was carried out using a high-energy Er:YAG laser (AT Fidelis, Fotona) and R14 hand piece (n = 12). Endodontic quartz tips PRECISO 300/20 with cylindrical shape, flat top, diameter 0.3 mm, and length 20 mm were used. All tips were adjusted to 1 mm less than the specified working length. Removal of the filling material was accomplished by a crown-down technique with continuous movement of the tip under air–water cooling.

Laser irradiation parameters

λ=2940 nm

Mode – pulsed

Output energy – 60 mJ

Frequency – 10 Hz

Power – 1 W

The effectiveness of the laser energy was evaluated by a second micro-CT examination of the same samples.

Group 2. The already treated samples were further instrumented with XP-Endo Finisher-R, following manufacturer's instructions.

A third micro-CT assessment of file efficiency was performed.

Micro-CT examination

The three-stage scanning of the samples and their reconstruction was accomplished by Nikon XT H 225 (Nikon Metrology, Tring, UK) and CT Pro 3D version XT 3.1.3, (Nikon Metrology, Hertfordshire, UK), as described previously.[17] Afterward, the amount of the residual filling was volumetrically analyzed individually for each root canal. With the aid of the aforementioned software, the samples from the initial scans were separated to enable individual manipulation and inspection. The available root canal filling material was registered in two parallel to the axial wall of the tooth planes—apically and coronally (5 mm and 10 mm away from the root end, respectively).[17] The initial and residual root canal filling in each section was three-dimensionally segmented by the method of region growing. The quantitative measurement of the volume (mm^3) was performed after the utilization of a color code for the root canal filling material. All the procedures regarding the micro-CT examination were executed by a single experienced operator, who was unaware of the stages, the instruments, and the technique of the endodontic retreatment.

Statistical analysis

IMB SPSS Statistics Version 25.0 software was used for statistical analysis of the data. All results were tabulated. Mann–Whitney U test and Friedman test were used for the comparison of two independent samples and for comparing differences between groups when the dependent variable being measured is ordinal, respectively. The Kruskal–Wallis test was run to compare several independent samples. The confidence level was set at 95% (α = 0.05).

Results

None of the two experimental techniques could ensure complete cleanliness of the root canal walls. During the course of the study, we did not witness any file or laser tip deformation or separation. Furthermore, no procedural mishaps occurred. The amount of root canal filling material was recorded in percentage and volume along the entire canal (16 mm), at 5-mm and 10-mm levels from the root terminus [Figure 1].

The analysis of the data (Friedman test) showed that the successive use of Er:YAG laser and XP-Endo Finisher R during an endodontic orthograde retreatment significantly decreased the volume of the root canal filling in all samples compared to the baseline values of the same parameter at all observational levels ($\chi^2(2) = 24.000$, $P < 0.001$) [Table 1].

The largest amount of root canal filling material was removed along the entire root canal after both retreatment techniques [Table 2]. Nonetheless, this result remained statistically insignificant in comparison with the remaining observational levels of the root canal. The Kruskal–Wallis H test showed that there was a statistically insignificant difference in the amount of the removed root canal filling material (%) at the different observational levels after the use of Er:YAG laser, $\chi^2(2) = 0.464$, $P = 0.793$, with a mean rank of the proportion of the obturation material of 20.17 along the entire canal, 17.42 for the 10-mm level, and 17.92 for the 5-mm section. The same test was run to assess the effect of the XP-Endo Finisher R files at the three tested levels. Additional shaping with the Ni-Ti system led to a nonsignificant decrease in the bulk of the obturation material ($\chi^2(2) = 0.146$, $P = 0.930$) with a mean rank of the percentage of root canal filling material of 19.42, 18.25, and 17.83 for the entire canal, at 10- and 5-mm level, respectively. Filling residues after the retreatment procedures were registered mainly in the middle portion of the canal (at 10-mm level).

Despite the positive impact of the supplementary shaping with XP-Endo Finisher R, the rotary system was unable to ensure that the root canal walls were totally free of the obturation material. The intergroup comparison indicated no significant reduction in the remaining material after the rotary instrumentation (Kruskal–Wallis H test, $\chi^2(2) = 0.041$, $P = 0.980$) [Table 3]. The XP-Endo Finisher R was more effective apically.

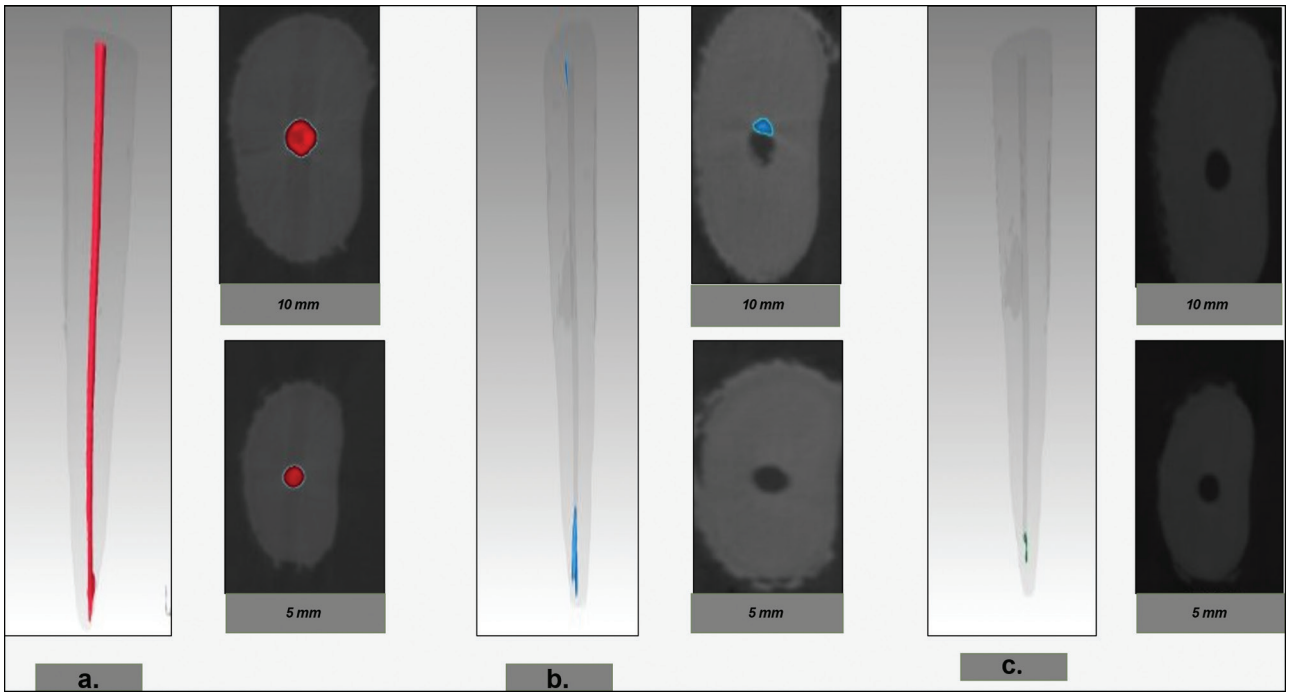

Figure 1: Micro-CT scanning of a sample – sagittal and cross-section images. a) First scan – after root canal filling (colored in red). b) Second scan – after Er:YAG laser retreatment (root canal residue is colored in blue). c) Third scan – after supplementary shaping with XP-Endo Shaper R (root canal residue is colored in green)

Table 1: Amount of the removed root canal filling (mm^3) registered by micro-CT scanning

Root level	Micro-CT scanning number	N	Mean±Std.Dev	Median	Min	Max	*P* value
Full length	I	12	12.63 ± 5.51	11.55	5.36	22.95	
	II	12	8.03 ± 5.75	7.71	0.75	19.77	<0.001*
	III	12	6.76 ± 5.99	5.84	0.54	19.54	
10 mm	I	12	3.62 ± 1.31	3.95	1.14	5.78	
	II	12	2.75 ± 1.21	2.69	0.52	4.53	<0.001*
	III	12	2.17 ± 1.28	2.01	0.44	4.23	
5 mm	I	12	1.13 ± 0.35	1.12	0.65	1.92	
	II	12	0.85 ± 0.38	0.82	0.10	1.48	<0.001*
	III	12	0.65 ± 0.29	0.74	0.06	1.07	

Table 2: Amount of removed root canal filling (%) at different canal levels using Er:YAG laser and XP-Endo Finisher R

Retreatment technique	Root level	N	Mean ± Std.Dev (%)	Median (%)	Min (%)	Max (%)	*P* value
Er:YAG laser*	Full length	12	34.84 ± 29.68	37.01	0.89	96.73	
	10 mm	12	25.87 ± 19.85	21.29	3.64	63.45	0.793
	5 mm	12	27.88 ± 22.22	28.45	0.07	85.32	
XP-Endo Finisher R*	Full length	12	48.22 ± 29.11	49.16	2.02	97.63	
	10 mm	12	43.10 ± 21.61	39.02	16.24	80.36	0.930
	5 mm	12	43.95 ± 21.03	42.29	18.64	90.26	

* The amount of filling removed after using both retreatment techniques is compared with the initial values after filling the root canal

Table 3: Amount of removed root canal filling (%) at different canal levels using XP-Endo Finisher R after initial retreatment with Er:YAG laser

Retreatment technique	Root level	N	Mean ± Std.Dev (%)	Median (%)	Min (%)	Max (%)	*P* value
XP-Endo Finisher R	Full length	12	23.22 ± 15.26	25.53	1.14	51.19	
	10 mm	12	24.27 ± 17.77	16.03	6.56	58.97	0.980
	5 mm	12	23.52 ± 13.25	30.54	1.62	35.49	

Discussion

The main objective of the present study was to compare the efficiency of root canal filling removal from oval-shaped root canals with the sole use of a high-energy Er:YAG laser and additional treatment of the samples with XP-Endo Finisher R files. These type of canals pose a significant challenge during endodontic orthograde retreatment. Machine-driven instruments do not tend to properly follow the anatomical shape of the root canal, thus leaving unprepared areas, compacted with bacteria, debris, and filling material.[11,18-20] The amount of unremoved canal filling is greater in oval-shaped root canals compared to round ones, which can compromise the healing process. The standardization of the samples and the application of an accurate and sample-preserving method for a realistic quantitative measurement of the remaining obturation material is a prerequisite for obtaining reliable results in our experiment.[20-23]

The aim of the retreatment procedures is to perform a second endodontic treatment, to negotiate, clean, shape, and seal the complex endodontic space.[24,25] The high-energy Er:YAG laser may represent an alternative to apical surgery.[26] The optical fiber with a dimension of 300 μm allows beam progression into root canals previously prepared to a # 30 K-file. The specific Er:YAG laser wavelength (λ = 2940 nm) is very well-absorbed by the water and provides a minimal thermal effect on the adjacent tissues. The laser works with water–air cooling and pulse mode of radiation at different powers.[27,28] Applying a higher frequency and power reduces the operating time but increases the risk of undesirable side effects. There is scientific evidence for residual canal contents, mainly in the apical root canal third, and areas of carbonization and dentin damage with increasing laser power.[28] These conclusions corroborate with those of other experiments, demonstrating the potential of laser irradiation to effectively remove the gutta-percha and AH plus sealer.[26,28,29] Currently, the basic problem for using lasers in endodontics is to establish the proper settings for the given operation since the literature does not contain all the pertinent information.

The incomplete removal of the root canal filling in our investigation can be explained by the thermal and photoablation mechanisms of laser radiation. Since gutta-percha is a dense material that does not contain or absorb water, the "micro-explosions" are mainly encountered due to the water introduced for cooling during the operation with the laser fiber. Thermal ablation of the canal filler leads to its heating and transition to the more plastic and sticky α form, which might jeopardize its thorough removal. Additionally, the incomplete removal of the root canal filling can be associated with the discrepancy between the cylindrical shape of the laser tip and that of the root canal.

The combined instrumentation with Er:YAG laser and XP-Endo Finisher R resulted in an incomplete elimination of root canal filling, although a significant change from its original quantity was recorded. The specific features of the file used for the additional instrumentation[30] led to a more efficient cleaning of material remnants. Our results coincide with those of previous investigations in which the utilization of XP-Endo Finisher R improved the outcomes achieved during the endodontic orthograde retreatment.[31-33]

The greater efficiency of XP-Endo Finisher R in the apical portion of the teeth might be ascribed to the round form of the canals at that level[34] and the tip size matching the file used for the initial endodontic retreatment (size 30). Despite the improved results after the application of the supplementary retreatment protocol, none of the root canal walls were completely clean in the apical area.

Research on the use of solvents during endodontic orthograde retreatment is conflicting. Despite the manufacturer's recommendations to combine XP-Endo Finisher R with the solvents, they were not implemented in the current protocol. Our decision was based on the risk of a creation of a thin layer of softened gutta-percha, which might remain attached to the root canal walls and thus hamper its subsequent removal in terms of efforts and time.[32] Although several methods have been recommended for endodontic orthograde retreatment recently, further scientific investigations are necessary to evaluate the efficacy of these techniques and to find the most efficient method for each case.[35]

Conclusion

Based on our results, we can conclude that the high-energy Er:YAG laser could be successfully used in endodontic retreatment protocols following appropriate operating parameters. Additional shaping with the XP-Endo Finisher-R files improved the cleanliness of the root canals, although insignificantly. None of the applied methods resulted in an absolute removal of the root canal filling. Future studies are needed to determine the optimal endodontic retreatment strategies for lower incisors.

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Conflicts of interest

The authors report no conflict of interest.

Authors contributions

Conception and study design: EK, VD, and IC-I. Acquisition and collation of data: MR, EK, and VD. Analysis and interpretation of data-VD, EK, and IC-I. Writing the manuscript- VD. Critical revision of the paper- EK and IC-I. All authors read and approved the final manuscript.

Ethical policy and institutional review board statement

Ethical approval was obtained by the Commission on Scientific Research Ethics at Medical University, Sofia, Bulgaria.

Patient declaration of consent

Not applicable.

Data availability statement

Data set available on request.

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