BASIC RESEARCH – TECHNOLOGY

Efficiency and Temperature Rise of File Ablation by Neodymium:Yttrium-Aluminum-Perovskite Laser *In Vitro*

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SIGNIFICANCE

The Nd:YAP laser provides a method to remove a separated file by laser ablation. When the number of pulses is <5, the temperature rise of the root surface is considered safe to the surrounding periodontium.

ABSTRACT

Introduction: Retrieving a separated file in the root canal system requires a skilled clinician. A metal file can be removed by ablation via the neodymium:yttrium-aluminum-perovskite (Nd:YAP) laser; however, the efficiency and potential hazards of the ablation procedure are still unclear. The aim of this study was 2-fold: to investigate the efficiency of file ablation using the Nd:YAP laser and to evaluate the rise in temperature of the root surface *in vitro*. **Methods:** In part 1 of this study, #10 and #15 C-files (VDW GmbH, Munich, Germany) and ProTaper Next X1 and X2 files (Dentsply Maillefer, Ballaigues, Switzerland) were selected. Under 8.5×, the Nd:YAP laser was used to ablate the files starting at the tip of the file. The length of the file was recorded after each 5-pulse ablation. In part 2 of this study, 3 files each of the #15 C-file and the ProTaper Next X2 were separated in 6 distal roots of mandibular second molars with single canals. Two-pulse and 5-pulse modes were used to ablate the separated files, and the rise in root surface temperature was recorded with an infrared camera. Another 3 unaltered distal roots served as the negative control. For scanning electron microscopic evaluation, the teeth were split with bone scissors and observed under a scanning electron microscope to evaluate the surface change of the file and the root canal wall. **Results:** The average length of the ablated files after each 5-pulse interval was 0.113–0.158 mm with no statistical difference between the different files.The temperature rise of the negative control group (mean ± standard deviation = 1.86° ± 0.11°C and 5.81° ± 0.35°C for the 2- and 5-pulse group) was significantly lower than the roots with separated files (mean ± standard deviation = 3.74° ± 0.20°C and 4.02° ± 0.11°C for 2-pulse C-file and ProTaper Next X2; 8.47° ± 0.19°C and 9.04° ± 0.20°C for 5-pulse C-file and ProTaper Next X2). The temperature rise of all groups was lower than 10°C. The 2-pulse group showed a lower temperature rise than the 5-pulse group. The diameter or the type of alloy had no effect on the temperature rise. **Conclusions:** Separated files (stainless steel or nickel-titanium alloy) can be ablated by the Nd:YAP laser. When the number of pulses is less than 5, the temperature rise of the root surface is considered safe to the surrounding periodontium. *(J Endod 2021;47:982–988.)*

KEY WORDS

File ablation; Nd:YAP laser; scanning electron microscope; temperature rise

File separation is an unfortunate complication that can happen during root canal treatment. When a file separates, it can be difficult to remove based on where it separates within the canal[1]. The decision to retrieve the separated file or bypass and incorporate the file into the final obturation is a decision the clinician must consider during the intraoperative phase of treatment. Several methods have been used to retrieve separated files including ultrasonics[2–4], the Instrument Removal System (Dentsply Tulsa Dental, Tulsa, OK)[5,6], and a small-diameter trepan burs system (Micro-Retrieve & Repair System; Superline NIC Dental, Shenzhen, China)[7]. For best results, these methods require the use of a dental operating microscope and the skill of an endodontic specialist. Attempts to retrieve separated files are not without potential consequences. Separating another file, perforation of the root canal wall, or pushing the file

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beyond the apical foramen are possible unfortunate consequences that may occur during the retrieval process. Research published by Farge et al[8] tested the ability of the neodymium:yttrium-aluminum-perovskite (Nd:YAP) laser in endodontic retreatment procedures. The authors demonstrated the ability of the Nd:YAP laser to bypass #6 and #8 stainless steel files that had been separated in the root canal.

The Nd:YAP laser has a wavelength of 1340 nm and has been used for canal disinfection[9–11], dentinal hypersensitivity[12], root canal retreatment[8], periodontal therapy[13], and surface treatment for direct or indirect restoration adhesive[14,15]. Different from other wavelength lasers, the Nd:YAP laser can be absorbed by metals like nickel-titanium (NiTi) and stainless steel by ablating the metal into gas. Ablating separated metal instruments within the root canal system using the Nd:YAP laser could possibly be used as a method to remove separated files; however, the efficiency of file ablation by the Nd:YAP laser has not been reported, and the potential hazard of the temperature rise of the root surface to the surrounding tissue is unclear.

The aim of this study was 2-fold:

(1) To evaluate the efficiency of file ablation using the Nd:YAP laser and
(2) To record the temperature rise of the root surface during the file ablation procedure. The morphology of ablated files and the root canal wall after ablation were also observed using scanning electron microscopy.

MATERIALS AND METHODS

The laser device used for testing was the Lokki (LOBEL Medical, Les Roches de Condrieu, France) (Fig. 1*a*) using yttrium-aluminum-perovskite doped with neodymium crystal as the active laser medium. The wavelength of the laser is 1340 nm, which is in the middle infrared range. The laser beam was transmitted by optical fibers of 200 μm and 320 μm. Nine different modes of pulses and energy were preset on the control panel (Fig. 1*a*). The "C+" mode (frequency = 5 Hz, average power = 1.8 W, energy = 360 mJ) and a 200-μm fiber were selected for ablating the file according to the manufacturer's recommendations. The operator wore protective eyewear (LOBEL Medical) during experimental testing as recommended by the manufacturer.

Part 1: Evaluation of File Ablation Efficiency

Three new files from each group, #10 and #15 C-files (VDW GmbH, Munich, Germany) and ProTaper Next X1 and X2 (Dentsply Maillefer, Ballaigues, Switzerland), were used for a total of 12 new files. The C-files are ISO size hand instruments with a constant taper of 2% and made of stainless steel. The tip size was 100 μm and 150 μm for the #10 and #15 files, respectively. The ProTaper Next files, which are made of NiTi alloy, have tip diameters of 170 μm and 250 μm and tapers of 5% and 6% for X1 and X2, respectively. The shank of the file was fixed on a holder, and the laser fiber was placed end to end in direct contact to the file tip (Fig. 1*b*). The following procedure was completed with the use of a dental operating microscope (OPMI Pico; Carl Zeiss Surgical GmbH, Oberkochen, Germany) under 8.5× magnification. After the tip of the laser fiber made contact with the tip of the file, the Nd:YAP laser was activated. After 5 pulses (1 second), the length of the file was measured with a caliper, and the file length that was ablated by the laser was calculated. Each file was ablated 12 times (5 pulses) for $N = 36$.

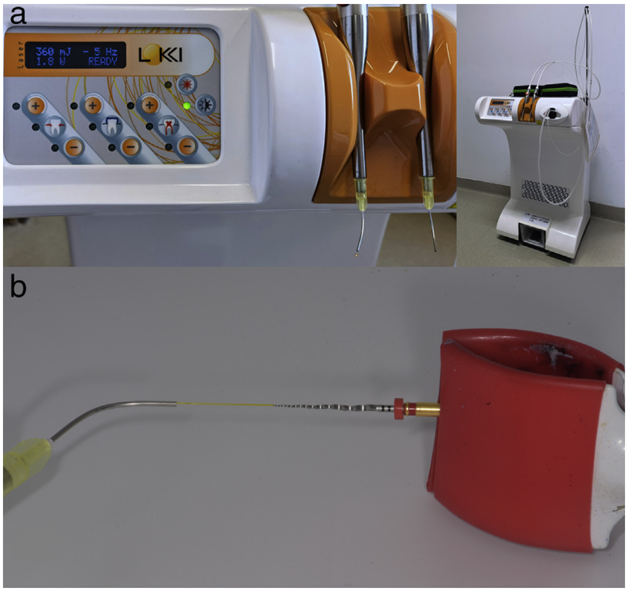

FIGURE 1 – (*a*) The Lokki laser unit panel and unit and (*b*) the laser fiber touching the ProTaper Next X2 file at D0.

Part 2: Measurement of Temperature Rise on the Root Surface

The study was approved by the Biomedical Ethics Committee of Peking University Hospital of Stomatology, Beijing, China (pkussirb-2020056079). A total of 9 mandibular second molars were extracted due to severe periodontitis and selected for this study. Teeth with open apices, resorptions, root fractures, or a curvature of root more than 10°were excluded. Preoperative radiographs using a #2 phosphor plate (SOREDEX DIGORA; KaVo, Orange, CA) were taken to measure the thickness of dentin in the middle of the distal root with a metal ruler. Nine teeth with a single canal in the distal root and a dentin thickness in the middle of the root of approximately 1.0 mm when measured from a sagittal view were included in the study.

Access to the root canal system was completed by preparing a conventional access preparation using the cavity access set (Dentsply Maillefer) to remove the coronal pulp tissue. The distal canal orifice was identified, and the canal was irrigated with distilled water without instrumentation. The teeth were stored in distilled water at 4°C before testing. Nine teeth were randomly divided into 3 groups: the negative control group (no files in the canal), the #15 C-file group, and the ProTaper Next X2 group. Three #15 C-files and 3 ProTaper Next X2 files were separated in the middle of the distal canal of the latter 2 groups (6 teeth) by purposefully weakening the file with a bur at 4.0 mm from D0. The file was inserted into the canal and rotated apically until the file separated. A digital periapical radiograph was taken to confirm the location of the files.

The tooth was fixed on a holder, and an infrared camera (226; FOTRIC, Shanghai, China) was positioned perpendicular to the distal surface of the root; the canals were kept dry during testing. AnalyzIR 4.2.0 software (FOTRIC) recorded the real-time temperature of the root surface through the infrared camera. The temperature rise of the root surface was calculated by the highest temperature recorded by the infrared camera

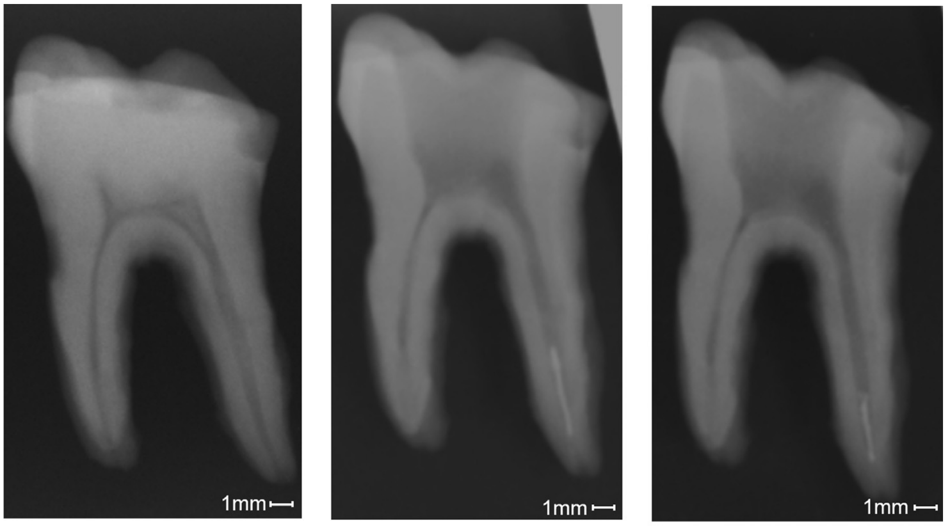

FIGURE 2 – The radiographs: preoperative, separated file (ProTaper Next X2 as sample), and postoperative radiographs.

during ablation minus the room temperature (26°C).

Under the use of the dental operating microscope at 8.5× magnification, the fiber tip of the laser made contact with the separated file. The file was ablated for 2 pulses, and the infrared camera recorded the highest temperature during the ablation. The tooth was allowed to cool to room temperature, and the procedure was repeated 6 times. After completing 6 cycles as listed previously, the number of pulses was increased to 5, and the procedure was repeated 6 more times. For teeth in the negative control group, the laser fiber was inserted into the middle third of the empty canal without touching the canal wall, the laser was activated in the same mode, and the temperature was recorded. All of the testing was completed by the same senior endodontist. The preoperative, separated file (ProTaper Next X2), and postoperative radiographs are shown in Figure 2.

Scanning Electron Microscopic Observation

The tooth was split with bone scissors (Kangqiao, Shanghai, China), and the canal wall and ablated file were observed using a scanning electron microscope (SU8010; Hitachi, Tokyo, Japan). Energy-dispersive spectroscopic analysis was used to evaluate the elements of the file and the dentin.

Statistical Analysis

Statistical analysis was completed using SPSS 22.0 (IBM Corp, Armonk, NY). The data were analyzed using 1-way analysis of variance/least significant difference and the Dunnett test.

TABLE 1 - The Average Length of File Ablated by the Neodymium:Yttrium-Aluminum-Perovskite Laser for 5 Pulses

Group	Mean ± SD (mm)
#10 C-file	0.158 ± 0.023
#15 C-file	0.122 ± 0.016
ProTaper Next X1	0.144 ± 0.018
ProTaper Next X2	0.113 ± 0.015

SD, standard deviation.

RESULTS

Part 1: Efficiency of the File Ablation

The average lengths of the ablated files by 5 pulses were as follows: #10 C-file, 0.158 mm; #15 C-file, 0.122 mm; ProTaper Next X1, 0.144 mm; and ProTaper Next X2, 0.133 mm (Table 1). There was no significant difference among groups ($P > .05$).

Part 2: Temperature Rise of Root Surface

For the 2-pulse group, the mean temperature rise of the negative control group (1.86° ± 0.11°C) was significantly lower than that of the C-file group (3.74° ± 0.20°C) and the ProTaper Next group (4.02° ± 0.11°C). For the 5-pulse group, the mean temperature rise of the negative control group (5.81° ± 0.35°C) was significantly lower than that of the C-file group (8.47° ± 0.19°C) and the ProTaper Next group (9.04° ± 0.20°C) ($P < .05$).

With the same number of pulses, there was no significant difference in temperature rise between different files ($P > .05$). The diameter or alloy of files had no effect on the temperature rise. For the same file, the temperature rise on the root surface of the 2-pulse group was significantly lower than that of the 5-pulse group ($P < .05$, Fig. 3).

Scanning Electron Microscopic Observation

The negative control group demonstrated a significant amount of dentin fusion on the canal wall (Fig. 4, *red arrow*). The canals with a separated #15 C-file (Fig. 5) and a ProTaper Next X2 file (Fig. 6) both showed both melting of the file (*black arrow*) and dentin fusion (*red arrow*).

The results of the energy-dispersive spectroscopy of the unablated dentin wall (Fig. 7*a*) and dentin fusion (Fig. 7*b*) showed similar elements consisting mainly of calcium, phosphorus, and oxygen. The results of the energy-dispersive spectroscopy are shown in Figures 8*c–e* and 9*f–h*. Compared with the unablated area of the file, the oxygen element appeared on the area of the melted file, which indicates that the metal elements were oxidized during the ablation. In the dentin fusion, <5% of metal elements (iron or titanium) were detected.

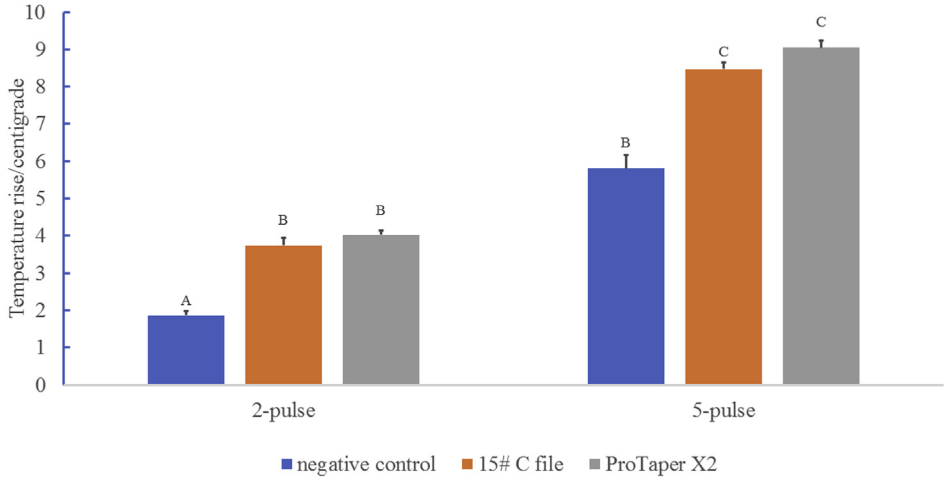

FIGURE 3 – The temperature rise on the root surface of different files and pulses. Dissimilar letters indicated significant differences from each other ($P < .05$).

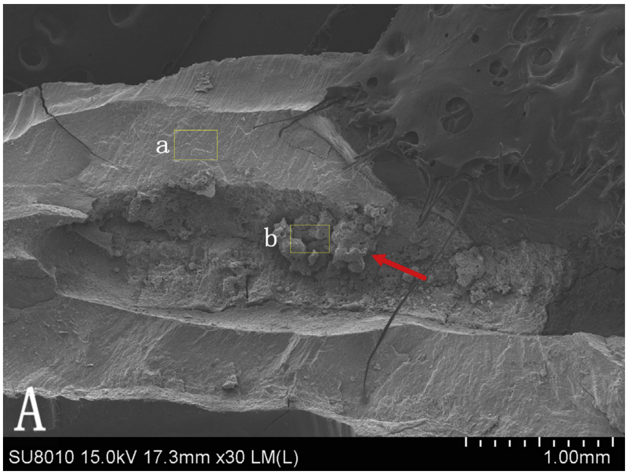

FIGURE 4 – Scanning electron microscopy of the negative control. Dentin fusion (*red arrow*). The energy-dispersive spectroscopic results of areas a and b shown in Figure 7.

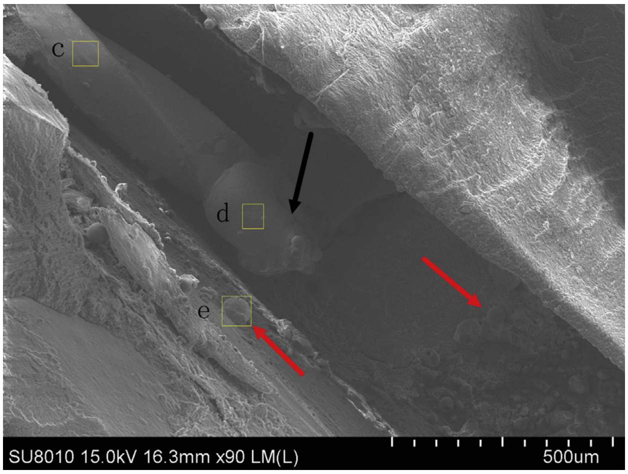

FIGURE 5 – Scanning electron microscopy of the canal with a #15 C-file after ablation. Dentin fusion (*red arrow*) and the file (*black arrow*). The energy-dispersive spectroscopic results of areas c, d, and e shown in Figure 8.

DISCUSSION

The Nd:YAG laser was originally used for welding stainless steel and NiTi alloy[16,17]. The parameters were 300–400 mJ and 10 Hz, which were similar to our study. The Nd:YAG laser can induce the fusion and resolidification of metal. In our study, both the endodontic stainless steel and NiTi files absorbed the Nd:YAP laser energy and were vaporized into gas, which allowed the practitioner the ability to instrument the canal to the apex even after file separation. Our results demonstrate that 5 pulses can ablate about 0.1 mm of the file. After 6 times of 2-pulse and 6 times of 5-pulse exposures, about 1–1.5 mm of the file can be ablated. Without cooling time, the 4.0-mm file can be completely ablated after 1–2 minutes. Clinically, one would expect greater than 15 minutes to allow for cooling, irrigation, and drying. Future studies evaluating the related laser parameters such as power, frequency, energy, and the distance between the fiber and file are required.

It is known that a temperature rise of more than 10°C will harm the pulp and periodontal tissue due to thermal effects[18,19]. In a previous study[20], when the Nd:YAP laser was used perpendicular to the dentin surface in a continuous activating mode (a 13-second duration), the temperature of 1.0 mm dentin rose to 90°C without water spray and 40°C with water spray. In another study[11], the Nd:YAP laser was used for canal disinfection, and despite the fact that the working time was 10 seconds, with the help of sodium hypochlorite solution and the spiral out motion of the laser fiber, the temperature rise on the root surface was <5°C. In our study, the canal was dry when the Nd:YAP laser was used (pulses less than 5) to ablate the separated file resulting in a

FIGURE 6 – Scanning electron microscopy of the canal with the ProTaper Next X2 file after ablation. Dentin fusion (*red arrow*) and the file (*black arrow*). The energy-dispersive spectroscopic results of area f, g, and h are shown in Figure 9.

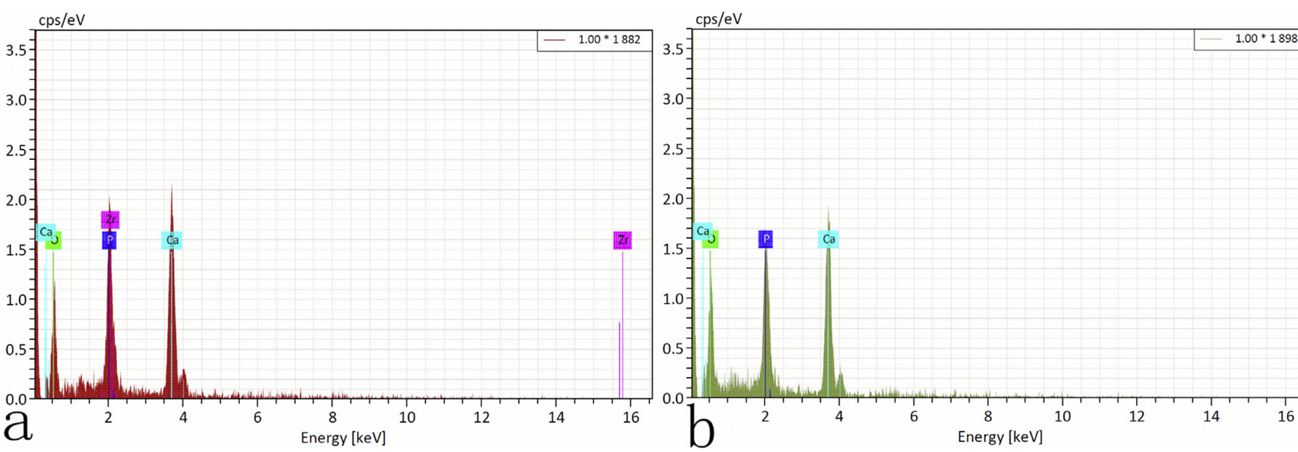

FIGURE 7 – Energy-dispersive spectroscopy of the (*a*) unablated dentin area and (*b*) dentin fusion area of the negative control.

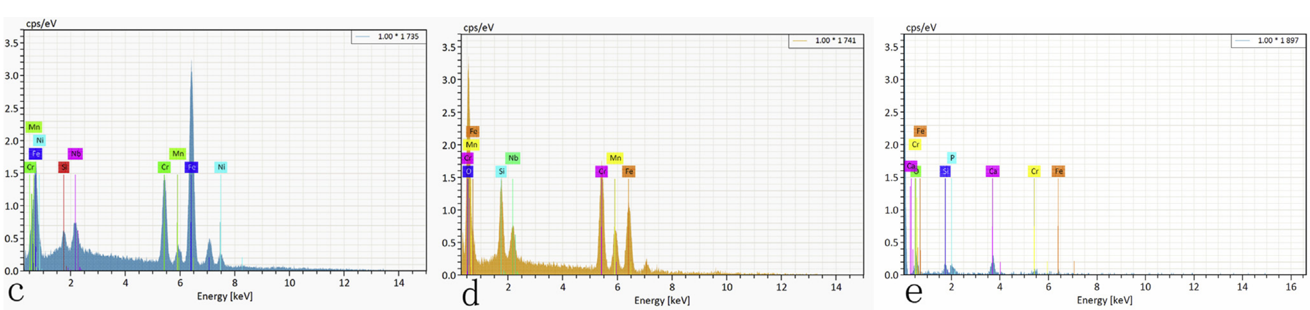

FIGURE 8 – Energy-dispersive spectroscopy of the C-file (*c*) unablated area, (*d*) ablated area, and (*e*) dentin fusion area.

temperature rise <10°C. It is important to note that in clinical practice the procedure should be completed with frequent irrigation of the canal to cool down the temperature.

In this study, dentin fusion was observed under a scanning electron microscope for all 3 samples. This may be due to the thermal effect of the laser that causes the dentin to melt and resolidify[21,22]. Although no pure metal or alloy particles were embedded on the root canal wall, there were metal elements (<5% from energy-dispersive spectroscopy) detected in the dentin fusion indicating that during the procedure the vaporized gas released during the ablation of the metal may be absorbed by dentin fusion.

Our research demonstrated that even if the laser fiber was parallel to the canal wall, there was still fusion of the dentin. According to a previous study[8], if the fiber was perpendicular to the dentin, it created craters on the dentin surface, which may result in perforation of the canal wall. To reduce the danger of perforation, the fiber tip should be as parallel to the dentin wall as possible, and the fiber should contact the separated file precisely without touching the dentin; this can only be accomplished with the use of the dental operating microscope.

The distal roots of mandibular second molars with single canals and minimal canal curvature (<10°) were selected for testing. The separated end of the files could be visualized with the use of the microscope. Because of the fact that the laser fiber cannot be precurved, if

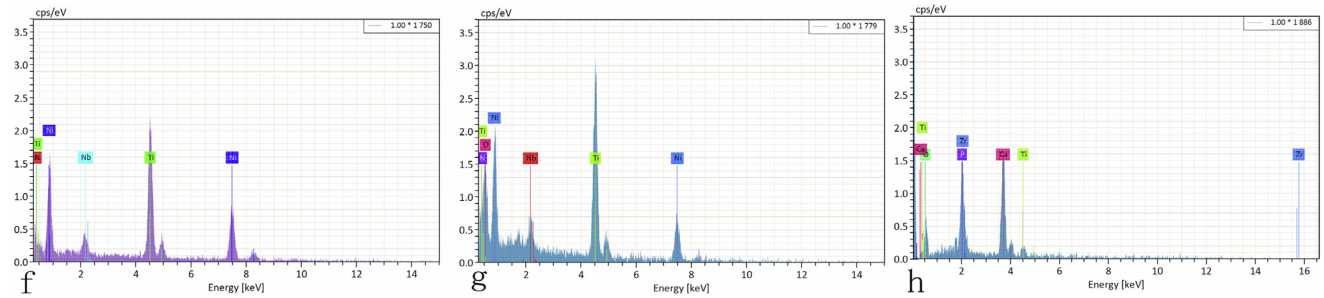

FIGURE 9 – Energy-dispersive spectroscopy of the ProTaper Next X2 file (*f*) unablated area, (*g*) ablated area, and (*h*) dentin fusion area.

the file was separated beyond the canal curvature, it would be necessary to establish straight-line access to the separated file before ablation. Failure to establish straight-line access increases the risk of damage to the dentinal wall with a greater potential for perforation.

On the basis of this research, using the Nd:YAP laser to ablate separated files from the root canal is a feasible method of treatment. However, the use of the Nd:YAP laser to safely remove files that have separated beyond the curvature of the canal requires further investigative research.

CONCLUSION

The results of this research demonstrated the ability of the Nd:YAP laser with less than 5 pulses to safely and effectively ablate separated files (stainless steel or NiTi alloy) from the root canal system.

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The authors deny any conflicts of interest related to this study.

REFERENCES

1. Souter NJ, Messer HH. Complications associated with fractured file removal using an ultrasonic technique. J Endod 2005;31:450–2.
2. Meidyawati R, Suprastiwi E, Setiati HD. Broken file retrieval in the lower right first molar using an ultrasonic instrument and endodontic micro forceps. Case Rep Dent 2019;2019:7940126.
3. Shahabinejad H, Ghassemi A, Pishbin L, Shahravan A. Success of ultrasonic technique in removing fractured rotary nickel-titanium endodontic instruments from root canals and its effect on the required force for root fracture. J Endod 2013;39:824–8.
4. Fu M, Zhang Z, Hou B. Removal of broken files from root canals by using ultrasonic techniques combined with dental microscope: a retrospective analysis of treatment outcome. J Endod 2011;37:619–22.
5. Cruz A, Mercado-Soto CG, Ceja I, et al. Removal of an instrument fractured by ultrasound and the instrument removal system under visual magnification. J Contemp Dent Pract 2015;16:238–42.
6. Alomairy KH. Evaluating two techniques on removal of fractured rotary nickel-titanium endodontic instruments from root canals: an in vitro study. J Endod 2009;35:559–62.
7. Yang Q, Shen Y, Huang D, et al. Evaluation of two trephine techniques for removal of fractured rotary nickel-titanium instruments from root canals. J Endod 2017;43:116–20.
8. Farge P, Nahas P, Bonin P. In vitro study of a Nd:YAP laser in endodontic retreatment. J Endod 1998;24:359–63.
9. Liu T, Huang Z, Ju Y, Tang X. Bactericidal efficacy of three parameters of Nd:YAP laser irradiation against Enterococcus faecalis compared with NaOCl irrigation. Lasers Med Sci 2019;34:359–66.
10. Gu Y, Perinpanayagam H, Kum DJ, et al. Effect of different agitation techniques on the penetration of irrigant and sealer into dentinal tubules. Photomed Laser Surg 2017;35:71–7.
11. Namour A, Geerts S, Zeinoun T, et al. Safety irradiation parameters of Nd:YAP laser beam for endodontic treatments: an in vitro study. Biomed Res Int 2016;2016:4741516.
12. Fornaini C, Brulat-Bouchard N, Medioni E, et al. Nd:YAP laser in the treatment of dentinal hypersensitivity: an ex vivo study. J Photochem Photobiol B 2020;203:111740.

13. Ambrosini P, Miller N, Briancon S, et al. Clinical and microbiological evaluation of the effectiveness of the Nd:Yap laser for the initial treatment of adult periodontitis. A randomized controlled study. J Clin Periodontol 2005;32:670–6.

14. Chen CC, Huang TH, Kao CT, Ding SJ. Effect of conditioners on bond durability of resin composite to Nd:YAP laser-irradiated dentin. Dent Mater J 2006;25:463–9.

15. El Gamal GA, Rocca JP, Fornaini C, et al. Microhardness evaluations of CAD/CAM ceramics irradiated with CO2 or Nd:YAP laser. Laser Ther 2017;26:13–8.

16. Vannod J, Bornert M, Bidaux JE, et al. Mechanical and microstructural integrity of nickel–titanium and stainless steel laser joined wires. Acta Mater 2011;59:6538–46.

17. Hagiwara R, Suehara M, Fujii R, et al. Laser welding method for removal of instruments debris from root canals. Bull Tokyo Dent Coll 2013;54:81–8.

18. Behnia A, McDonald NJ. In vitro infrared thermographic assessment of root surface temperatures generated by the Thermafil Plus system. J Endod 2001;27:203–5.

19. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: a vital-microscopic study in the rabbit. J Prosthet Dent 1983;50:101–7.

20. Armengol V, Jean A, Marion D. Temperature rise during Er:YAG and Nd:YAP laser ablation of dentin. J Endod 2000;26:138–41.

21. Liu J, Lu PJ, Sun YC, Wang Y. Advances in collateral damage of laser ablation of dental hard tissues. Zhonghua Kou Qiang Yi Xue Za Zhi 2013;48:573–5.

22. Parker S. Surgical lasers and hard dental tissue. Br Dent J 2007;202:445–54.