Original research

EVALUATING THE EFFECT OF DIFFERENT LASER TYPES ON DENTIN FRACTURE RESISTANCE

ABSTRACT

Objectives: The aim of this in vitro study was to use fracture testing methods to evaluate the impact of the use of different laser types– particularly diode, Nd:YAG and Er:YAG lasers–on dentin fracture resistance.

Materials and Methods: Ninety human maxillary incisors were used. The teeth were divided into three experimental groups and three control groups, each containing 15 samples. The laser treatments were a diode laser for experimental group 1, a Nd:YAG laser for experimental group 2, and an Er:YAG laser for experimental group 3. The teeth were then dried and obturated using the AH-Plus sealer and RevoS AS40 gutta percha (GP). Control group 1 was obturated as in the experimental groups but without laser application; control group 2 was instrumented but not obturated; and negative control group 3 had no procedure performed at all. All samples were fixed in acrylic blocks and were subjected to fracture tests using an Autograph Universal Testing Machine. The results were analysed using IBM SPSS Statistics 22 software, one-way ANOVA test and Tukey's HSD test (to identify groups that cause a difference), with $p<0.05$ indicating statistical significance.

Results: The applied force was significantly lower for control group 2 than for the Er:YAG laser or negative control groups ($p<0.05$). The remaining groups showed no statistically significant differences ($p>0.05$)

Conclusions: The findings presented here support the conclusions that the use of Nd:YAG, Er:YAG and diode lasers in endodontic treatments has no negative impact on dentin fracture resistance and that these lasers can be used safely.

Keywords: Endodontics, laser, fracture resistance, dentin, disinfection.

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INTRODUCTION

The purpose of endodontic treatment is to sustain the function of teeth that have pulpal and/or periapical disease in a biocompatible manner. To succeed in this purpose, irrigation, instrumentation and three-dimensional hermetic obturation, known as the "endodontic triad", should be performed.[1,2]

Irrigation of the root canal system, also called chemo-mechanic preparation, is an important stage of the triad. This stage involves the use of irrigation solutions and medications, in addition to mechanical preparation. The objective of chemo-mechanic preparation is to eliminate microorganisms, vital/necrotic pulp and hard-tissue remains from the root canal system.[3-6] Studies show that, regardless of the method used for chemo-mechanic preparation, complete elimination of all the microorganisms from the system is not possible.[7-9] The reasons for this may be the extremely complicated anatomy of the root canal system or the microorganisms' resistance to traditional disinfecting agents.[10-12] Consequently, the search for a more effective disinfectant continues.

The use of lasers in endodontics, as in many other medical disciplines, has become more popular in recent years, and many studies have been conducted on this subject. Laser systems are now used in disinfection of the root canal system and of root canal instrumentation, as well as in endodontic surgery and endodontic retreatment.[13-21]

One of the commonest failures in endodontically treated teeth is the presence of cracks or fractures. Studies show that the materials and methods used in instrumentation, disinfection and obturation can negatively affect dentin fracture resistance and promote tissue loss on teeth.[22-24] The goal of the present in vitro study was to use fracture-testing methods to evaluate the impact of the use of different laser types, specifically diode, Nd:YAG and Er:YAG lasers, in combination with the traditional irrigation protocols and instrumentation, on dentin fracture resistance.

MATERIALS AND METHODS

This study was evaluated at the meeting numbered 03 in 2014 and approved by the Istanbul University Faculty of Medicine Clinical Research Ethics Committee (2014/277-368).

Ninety recently extracted, caries-free, single-root, single-canal human maxillary incisors were used. The remains of soft tissue were eliminated using a scalpel, and hard tissue was eliminated using a periodontal curette. The teeth were then refrigerated at +4 ºC in distilled water until use.

The anatomy of the root canals and the dimensions of the teeth were determined by cephalometric radiography, viewing all teeth together. Round shaped roots with similar dimensions (in terms of bucco-lingual and mesio-distal dimensions) were selected. For this purpose, the mesio-distal and bucco-lingual widths of the teeth were measured with a digital calliper (Mitutoyo Corp, Tokyo, Japan). Teeth with mesio-distal widths of 11 ± 1 mm and bucco-lingual widths of 10 ± 1 mm teeth were included in the study.

The crowns of the samples were removed and standardised to a 12 mm length at the cemonto-enamel junction. Fifteen of the samples were set aside to serve as a negative control group which received no procedure at all, and the remaining 75 were instrumented and irrigated using the same protocol. The endodontic working length was determined as 1 mm short of the apical foramen. Instrumentation was performed using Revo-S Ni-Ti rotary files (Micro Mega, France) and the X-Smart endo-motor (Dentsply, United Kingdom). Initially, a 3 mm instrumentation of the coronal side was performed using an Endoflare (Micro-Mega, Besancon, France). The roots were kept constantly filled with NaOCl (2.5%) throughout the instrumentation and were irrigated after every instrument using an endodontic irrigation syringe tip (Endo-Eze, Ultradent, South Jordan, UT) and 2 mL of NaOCl (2.5%). Subsequently the SC1, the first instrument of the Revo-S system, was used up to two-thirds of the working length, back and forth, with no pressure applied and with the parameters of 300 rpm and 1.5 Ncm of torque. The instrument was not present in the root canal for more than 10 seconds at a time. Following the use of the SC1, the next instruments (SC2, SU, AS30, AS35 and AS40) were used at the same working length and instrumentation was completed. All the instruments

were used at 300 rpm and 1.5 Ncm of torque in back-and-forth movements of 1–2 mm. The final irrigant was 5 mL of NaOCl (2.5%), followed by EDTA (17%) (Vista Dental, Wisconsin, USA), which was allowed to remain in the root canal system for 1 minute. Finally, 5 mL of NaOCl (2.5%) was again used to neutralise the EDTA. A total irrigant volume of 29 mL was maintained in all the samples. Finally, all the samples were irrigated with 5 mL of distilled water and then incubated at 37 °C in distilled water.

A power calculation was performed using an F test: Fixed effects, one-way analysis (G*Power 3.1 software; Heinrich Heine University, Dusseldorf, Germany), with α = 0.05 for calculating the required sample size. The results indicated that the required sample size for six groups is 90 for an effect size of 0.45 and 0.90 actual power. Therefore, for each subgroup, at least 15 samples were required. Fifteen of the 90 samples received no procedure except the removal of their crowns and were labelled as the negative control group. The remaining 75 were randomly divided into five groups, including three experimental groups and two control groups, based on the procedures performed on them (Table 1).

Table 1: Experimental groups and systems

Groups	Instrumentation	Irrigation	Final Irrigation	Laser	Obturation Technique
Group 1	Revo-S AS40	2.5% NaOCl	17% EDTA 2.5% NaOCl	Diode	Single cone GP
Group 2	Revo-S AS40	2.5% NaOCl	17% EDTA 2.5% NaOCl	Nd:YAG	Single cone GP
Group 3	Revo-S AS40	2.5% NaOCl	17% EDTA 2.5% NaOCl	Er:YAG	Single cone GP
Control 1	Revo-S AS40	2.5% NaOCl	17% EDTA 2.5% NaOCl	Not applied	Single cone GP
Control 2	Revo-S AS40	2.5% NaOCl	17% EDTA 2.5% NaOCl	Not applied	Not applied
Negative Control	No	No	No	Not applied	Not applied

Group 1 (Diode Laser): These samples underwent the diode laser treatment after the final irrigation. The root canal system was filled with distilled water during the laser application. The diode laser (Gigaa Optronics Technology Co. Ltd., China) had a 200 µm fibre-optic tip and was used in continuous mode at 1.5 W and a wavelength of 810 nm. The laser application was performed at one single time from the apical to the coronal areas, with the tip placed at the working length and moved back to the coronal area over the course of 20 seconds. The laser application samples were then obturated with the single-cone gutta-percha method. The root canal system was initially dried using the Revo-S AS40 paper-point (Micro Mega, France). As a sealing agent, resin-based AH-Plus (Dentsply, DeTrey, Germany) was used according to the manufacturer's instructions. A sealer was applied to the root canal system using a Lentulo spiral filler (Pastinject, Micro Mega, France) placed 4 mm shorter than the working length and run at a speed of 500 rpm. For obturation, the Revo-S AS40 gutta percha (Micro Mega, France) was used. The apical 4–5 mm of the gutta percha was smeared with sealing agent and placed in the root canal at the designated working length. Any excess gutta percha was removed using a heated excavator at 1 mm under the canal orifice, and that 1 mm space was then filled with temporary filling material (Coltosol, Coltene; Whaledent Inc., Altstaetten, Switzerland).

Group 2 (Nd:YAG Laser): These samples underwent the Nd:YAG laser treatment (Fotona Laser, Ljubljana Slovenia, EU) after the final irrigation. The root canal system was filled with distilled water during the laser application. The Nd:YAG laser was used at 10 Hz and 1.5 W, with a 200 µm fibre-optic tip moved in a helicoidal fashion. The laser application was performed in the system for four times for 5 seconds at a time at intervals of 20 seconds, for a total of 20 seconds of laser application. The fibre-optic tip was applied from the apical to the coronal areas, at the working

length. The device was activated at the working length. Obturation then was performed as in group 1.

Group 3 (Er:YAG Laser): These samples underwent Er:YAG laser treatment (Fotona Laser, Ljubljana Slovenia, EU) following the final irrigation. The root canal system was filled with distilled water during the laser application. The Er:YAG laser was used at 10 Hz and 1 W with a 400 µm fibre-optic tip (PIPS, Fotona). The fibre-optic tip was placed at the working length and used in helicoidal movements. During the application, the laser was activated five times for 5 seconds at a time at 20 second intervals for a total of 25 seconds of laser application. The device was activated at the working length. Obturation was then performed as in group 1.

Control Group 1 (Obturated Teeth): The samples were obturated as described for experimental groups 1, 2 and 3 but without prior laser application.

Control Group 2 (Instrumented Teeth): The samples were instrumented as in the experimental groups 1, 2, 3 and control group 1 but were not obturated.

Negative Control Group (No procedure): The samples had no procedure performed on them at all. All the samples were incubated for 14 days at 37 °C and 100% humidity.

Preparation of the samples for fracture testing

The samples were placed in acrylic blocks to enable fixing onto the Universal Testing Machine. The periodontal ligament was simulated through this process, as described below.[25,26]

A key model for the acrylic blocks was obtained by preparing model stone blocks of 10 mm× 5 mm×20 mm. C-type silicone impressions were taken of these model stones, and a key model was obtained for the acrylic blocks. All the samples were then covered in a single layer of aluminium foil to create spacing for the silicone material that would be used to simulate the periodontal ligament.[25]

The acrylic resin used in the key model was prepared as instructed by the manufacturer (Imicryl, Konya, Turkey). The samples were then placed in the resin parallel to their vertical root axis, with 5 mm of the root remaining out of the resin. After resin polymerisation, the samples were removed from the resin and the aluminium foil around the tooth was removed. The space remaining within the block was filled with Express XT Light Body Quick (3M ESPE, Germany) impression material using an applicator tip. The samples were placed inside this silicone material and any excess silicone was removed using a spatula.

The samples were fixed after the polymerisation was completed. The silicone material between the sample and the acrylic block served as a simulator for periodontal ligament. The positions of the samples inside the acrylic block were as shown in Figure 1.
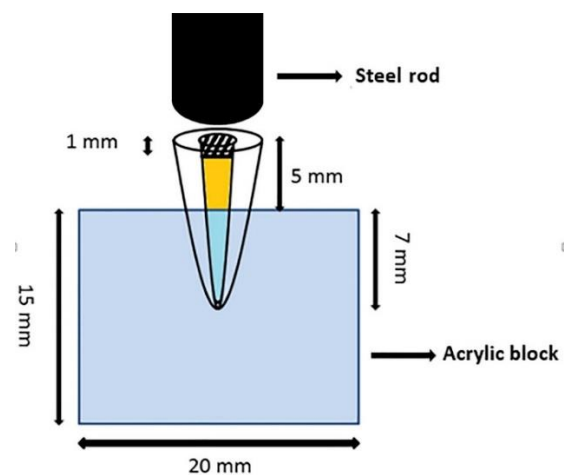

Figure 1. Positions of samples in acrylic block

Fracture Test

Fracture testing was performed using the Universal Testing Machine (Autograph AG-IS; Shimadzu Co., Kyoto, Japan).[27] Force was applied through a steel rod with a 5 mm diameter round tip.[28] Prior to the application of force, the round tip of the steel rod was confirmed to be in full contact with the sample at the centre of the coronal surface, and the steel rod was verified as being perfectly vertical and parallel to the root axis (Figure 2). The exact value of the fracture force was recorded in newtons.

Figure 2. Fitting the acrylic block on the test device

Statistical Analysis

IBM SPSS Statistics 22 software was used to evaluate our findings. The Kolmogorov-Smirnov test was used to evaluate the normal distributions of the study data, and the parameters were confirmed to be normally distributed. A cross-group comparison of the parameters was performed using the one-way ANOVA** test, and the Tukey HDS test was used to determine the group responsible for the difference in the data. The significance was evaluated as $p<0.05$.

RESULTS

The force applied to control group 2 (instrumented, but not obturated) was significantly lower than the force applied to group 3 (Er:YAG laser) ($p<0.05$) and to the negative control (no procedure) ($p=0.011$; $p<0.05$). The remaining groups showed no statistically significant differences (Table 2) ($p>0.05$).

Table 2: Average Force Value(N)

Experimental Groups	Mean±SD	P value*
Diode laser	724.79 ± 170.52	
Er:YAG laser	775.18 ± 190.12	
Nd:YAG laser	719.73 ± 211.14	
Control 1 (obturated teeth)	767.77 ± 140.71	<0.018*
Control 2 (instrumented teeth)	598.84 ± 73.32	
Negative control (no procedure)	808.56 ± 176.16	

* $p<0.05$ **One-way ANOVA Test

DISCUSSION

Previous studies performed to evaluate the success of endodontic treatments have shown that vertical and horizontal fractures are among the most common causes of failure. Two studies determined vertical fracture rates of 8.8% and 13.4% for teeth that had been extracted due to endodontic failures.[29,30] Resistance to dentin fracture is reduced by NaOCl, which dissolves organic tissue.[31,32] For this reason, we treated all samples in all groups with the same volume of NaOCl during irrigation. The currently available treatments using laser systems may assist in endodontic treatments by reducing the number of microorganisms in the root canal system and removing the smear layer.[33-36]

The use of a diode laser at 1.5 W in all operation modes and at 3 W in pulse mode for 20 seconds is safe for endodontic treatments.[37] The 810 nm diode laser is safe to use at a power of up to 3 W even with thin root canal walls.[38] In light of these findings, we used the 810 nm diode laser at 1.5 W power in continuous mode for 20 seconds.

Some researchers have reported that applying a Nd:YAG laser to samples infected with *Enterococcus faecalis* at 1.5 W for 20 or 25 seconds resulted in a statistically significant decrease in the amount of bacteria in the samples. The Nd:YAG laser is also safe to use at 1.5 W power for 20 seconds.[39,40] According to these findings, we used the Nd:YAG at 10 Hz and 1.5 W for 20 seconds.

Studies by Schoop *et al.*[41] demonstrated that the Er:YAG laser need not be used at more than 1 W to eradicate most of the endodontic bacterial species. Furthermore, SEM imaging showed that samples treated with a laser at 1 W laser in the root canal system had clearly observable dentin tubules, while the smear layer was completely removed. The thermal changes caused by the use of lasers at

4 Hz, 6 Hz and 10 Hz frequencies had no negative impact on dentin, and the thermal increase caused by Er:YAG laser was within acceptable limits.[42,43] For these reasons, we used the Er:YAG laser at 10 Hz and 1 W power for a total of 25 seconds.

The findings of the present study revealed no statistically significant differences in the dentin fracture resistance between groups treated with a diode laser, Nd:YAG laser or Er:YAG laser and control group 2 (p>0.05). In parallel with these findings, Braun *et al.*[44] and Faria *et al.*[45] found that laser application with different parameters (970-nm, 1.5 W/100 Hz and 3 W/100 Hz) also had no effect on dentin fracture resistance, even if the irrigation solutions varied. However, opposite results were reported by Karatas *et al.*[46] after the use of a diode laser at 3 W/100 Hz. This result may be related to the presence of EDTA solution in the root canal when the laser was applied. Similar results were observed in the study of Ayrancı *et al.*[47]

In the current study, control group 2 showed significantly lower dentin fracture resistance compared to the negative control group (p<0.05). Control group 1 showed values between control group 2 and the negative control group, but no significant differences were detected between control group 1 and either group (p>0.05). These findings were consistent with those of Sandıkçı and Kaptan,[48] who concluded that instrumentation renders a tooth physically weaker.

The groups that were instrumented and obturated (diode laser, Nd:YAG laser, Er:YAG laser and control group 1) showed no statistically significant difference in their average fracture force values. Conversely, the samples that were obturated and treated with the Er:YAG were significantly more resistant to fracture than were the teeth that were instrumented but not obturated (control group 2) (p<0.05). The studies by Hibst and Keller[49] and by Firoozmand *et al.*[50] concluded that Er:YAG laser application does not cause a thermal increase capable of morphological dentin changes. In the present study, we considered that the cause of this difference might be the obturation in the Er:YAG group, which would increase the fracture resistance over that found in the teeth that were not obturated.

The findings of the current study show that laser systems do not have a negative impact on dentin fracture resistance. This may be related to the fact that lasers do not change the dentin structure if they are not used at a high-power output.

CONCLUSIONS

The findings of this study indicate that the use of lasers (diode, Er:YAG, or Nd:YAG lasers) in endodontic practice, in conjunction with traditional final irrigation protocols to eliminate the smear layer, does not negatively impact dentin fracture resistance. Consequently, these lasers can be used safely. Further study of these lasers in more intense uses, such as instrumentation, would be useful for predicting their effects in other situations.

REFERENCES

1. Siqueira JF, Lima KC, Magalhaes FAC, Lopes HD, de Uzeda M. Mechanical reduction of the bacterial population in the root canal by three instrumentation techniques. J Endod 1999;25:332-335.

2. Pasricha SK, Makkar S, Gupta P. Pressure alteration techniques in endodontics - a review of literature. J Clin Diagn Res 2015;9(3):ZE01.

3. Dahlen G, Bergenholtz G. Endotoxic activity in teeth with necrotic pulps. J Dent Res 1980;59:1033-1040.

4. Byström A, Sundqvist G. Bacteriologic evaluation of the efficacy of mechanical root canal instrumentation in endodontic therapy. Eur J Oral Sci 1981;89:321-328.

5. Vianna ME, Horz HP, Conrads G, Zaia AA, Souza-Filho FJ, Gomes, BPFA. Effect of root canal procedures on endotoxins and endodontic pathogens. Oral Microbiol Immun 2007;22:411-418.

6. Triches TC, Zimmermann GS, de Freitas SFT, Ximenes M, Vieira RS, Cordeiro MMR. Efficacy of a single session protocol for endodontic treatment in primary teeth: in vivo study. Eur Arch Paediatr Dent 2018;19:47-55.

7. Nair PNR, Henry S, Cano V, Vera J. Microbial status of apical root canal system of human mandibular first molars with primary apical periodontitis after 'one-visit' endodontic treatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;99:231-252.

8. Tziafas D, Alraeesi D, Al Hormoodi R, Ataya M, Fezai H, Aga N. Preparation prerequisites for effective irrigation of apical root canal: a critical review. J Clin Exp Dent 2017;9:e1256-e1263.

9. Aveiro E, Chiarelli-Neto VM, de-Jesus-Soares A, Zaia AA, Ferraz CCR, Almeida JFA, Marciano MA, Feres M, Gomes BPFA. Efficacy of reciprocating and ultrasonic activation of 6% sodium hypochlorite in the reduction of microbial content and virulence factors in teeth with primary endodontic infection. Int Endod J 2020;53:604-618.

10. Sundqvist G, Figdor D, Persson S, Sjögren U. Microbiologic analysis of teeth with failed endodontic treatment and the outcome of conservative re-treatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1998;85:86-93.

11. Gergova RT, Gueorgieva T, Dencheva-Garova MS, Krasteva-Panova AZ, Kalchinov V, Mitov I, Kamenoff J. Antimicrobial activity of different disinfection methods against biofilms in root canals. J Investig Clin Dent 2016;7:254-262.

12. Quiram G, Montagner F, Palmer KL, Stefan MC, Washington KE, Rodrigues DC. Novel chlorhexidine-loaded polymeric nanoparticles for root canal treatment. J Funct Biomater. 2018;9:29.

13. Schoop U, Kluger W, Moritz A, Nedjelik N, Georgopoulos A, Sperr W. Bactericidal effect of different laser systems in the deep layers of dentin. Laser Surg Med 2004;35:111-116.

14. Öter B, Topçuoglu N, Tank MK, Çehreli SB. Evaluation of antibacterial efficiency of different root canal disinfection techniques in primary teeth. Photomed Laser Surg 2018;36:179-184.

15. Kokuzawa C, Ebihara A, Watanabe S, Anjo T, Bolortuya G, Saegusa H, Suda H. Shaping of the root canal using ER:YAG laser irradiation. Photomed Laser Surg. 2012;30:367-373.

16. Mohammadi Z, Jafarzadeh H, Shalavi S, Kinoshita JI, Giardino L. Lasers in apicoectomy: a brief review. J Contemp Dent Pract 2017;18:170-173.

17. Zerbinati LPS, Tonietto L, de Moraes JFD, de Oliveira MG. Assessment of marginal adaptation after apicoectomy and apical sealing with Nd:YAG laser. Photomed Laser Surg 2012;30: 444-450.

18. Metin R, Tatli U, Evlice B. Effects of low-level laser therapy on soft and hard tissue healing after endodontic surgery. Lasers Med Sci 2018;33:1699-1706.

19. Vidučić D, Jukić S, Karlović Z, Božić Ž, Miletić I, Anić I. Removal of gutta-percha from root canals using an Nd:YAG laser. Int Endod J 2003;36:670-673.

20. Asnaashari M, Ashraf H, Daghayeghi AH, Mojahedi SM, Azari-Marhabi S. Management of post endodontic retreatment pain with low level laser therapy. J Lasers Med Sci 2017;8:128.

21. Dönmez Özkan H, Kaval ME, Özkan G, Yiğit Özer S. Efficacy of two different nickel-titanium rotary systems in retreatment procedure with or without laser-activated irrigation: an in vitro study. Photobiomodul Photomed Laser Surg 2019;37:495-499.

22. Baechtold M, da Cunha L, Souza E, Gabardo M, de Oliveira K, Baratto-Filho F, Leonardi D. Effect of endodontic irrigation protocols on crown fracture resistance. J Contemp Dent Pract 2018;19:768-772.

23. Khoshbin E, Donyavi Z, Atibeh EA, Roshanaei G, Amani F. The effect of canal preparation with four different rotary systems on formation of dentinal cracks: an in vitro evaluation. Iran Endod J 2018;13:163.

24. Shantiaee Y, Dianat O, Mosayebi G, Namdari M, Tordik P. Effect of root canal preparation techniques on crack formation in root dentin. J Endod 2019;45:447-452.

25. Pişkin B, Aydın B, Sarıkanat M. The effect of spreader size on fracture resistance of maxillary incisor roots. Int Endod J 2008;41:54-59.

26. Lertchirakarn V, Poonkaew A, Messer H. Fracture resistance of roots filled with gutta-percha or RealSeal®. Int Endod J 2011;44:1005-1010.

27. Jamshidi D, Homayouni H, Moradi Majd N, Shahabi S, Arvin A, Ranjbar Omidi B. Impact and fracture strength of simulated immature teeth treated with mineral trioxide aggregate apical plug and fiber post versus revascularization. J Endod 2018;44:1878-1882.

28. Ulusoy ÖİA, Genç Ö, Arslan S, Alaçam T, Görgül G. Fracture resistance of roots obturated with three different materials. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;104:705-708.

29. Zadik Y, Sandler V, Bechor R, Salehrabi R. Analysis of factors related to extraction of endodontically treated teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:e31-e35.

30. Touré B, Faye B, Kane AW, Lo CM, Niang B, Boucher Y. Analysis of reasons for extraction of endodontically treated teeth: a prospective study. J Endod 2011;37:1512-1515.

31. White JD, Lacefield WR, Chavers LS, Eleazer PD. The effect of three commonly used endodontic materials on the strength and hardness of root dentin. J Endod 2002;28:828-830.

32. Gu LS, Huang XQ, Griffin B, Bergeron BR, Pashley DH, Niu LN, Tay FR. Primum non nocere – The effects

of sodium hypochlorite on dentin as used in endodontics. Acta Biomater 2017;61:144-156.

33. Coluzzi DJ. An overview of laser wavelengths used in dentistry. Dent Clin North Am 2000;44:753-761.

34. Gutknecht N, Franzen R, Schippers M, Lampert F. Bactericidal effect of a 980-nm diode laser in the root canal wall dentin of bovine teeth. J Clin Laser Med Surg 2004;22:9-13.

35. Wang X, Sun Y, Kimura Y, Kinoshita J, Ishizaki NT, Matsumoto K. Effects of diode laser irradiation on smear layer removal from root canal walls and apical leakage after obturation. Photom Laser Surg 2005;23:575-581.

36. Dhawan S, Jasuja P, Khurana H, Gakhar E, Singh H. A comparative evaluation of the efficacy of erbium: yttrium-aluminum-garnet and diode lasers in smear layer removal and dentin permeability of root canal after biomechanical preparation - A scanning electron microscopy study. J Indian Soc Pedod Prev Dent 2020;38:64-70.

37. Alfredo E, Marchesan MA, Sousa-Neto MD, Brugnera-Junior A, Silva-Sousa YTC. Temperature variation at the external root surface during 980-nm diode laser irradiation in the root canal. J Dent 2008;36:529-534.

38. Alvarez dFA, Moura-Netto C, Frugoli AD, Fernando C, Aranha ACC, Davidowicz H. Temperature changes on the root surfaces of mandibular incisors after an 810-nm high-intensity intracanal diode laser irradiation. J Biomed Opt 2012;17:0150061-0150063.

39. Bergmans L, Moisiadis P, Teughels W, Van Meerbeek B, Quirynen M, Lambrechts P. Bactericidal effect of Nd:YAG laser irradiation on some endodontic pathogens ex vivo. Int Endod J 2006;39:547-557.

40. Li YG, Wang X, Xie K, Liu D.Temperature variation at the external root surface during Nd:YAG laser irradiation in the root canal in vitro. West China Journal of Stomatology 2014;32:480-483.

41. Schoop U, Moritz A, Kluger W, Patruta S, Goharkhay K, Sperr W, Wernisch J, Gattringer R, Mrass P, Georgopoulos, A. The ER:YAG laser in endodontics: results of an in vitro study. Laser Surg Med 2002;30:360-364.

42. Brandao CB, Contente MMMG, De Lima FA, Galo R, CorrÊA-Afonso AM, Bachmann L, Borsatto MC. Thermal alteration and morphological changes of sound and demineralized primary dentin after ER:YAG laser ablation. Microsc Res Techniq 2012;75:126-132.

43. Raucci-Neto W, dos Santos CR, de Lima FA, Pécora JD, Bachmann L, Palma-Dibb RG. Thermal effects and morphological aspects of varying ER:YAG laser energy on demineralized dentin removal: an in vitro study. Lasers Med Sci 2014:1-6.

44. Braun A, Hagelauer FJ, Wenzler J, Heimer M, Frankenberger R, Stein S. Microcrack analysis of dental hard tissue after root canal irradiation with a 970-nm diode laser. Photomed Laser Surg 2018;36:621-628.

45. Faria MIA, Sousa-Neto MD, Souza-Gabriel AE, Alfredo E, Romeo U, Silva-Sousa YTC. Effects of 980-nm diode laser on the ultrastructure and fracture resistance of dentine. Lasers Med Sci 2013;28:275-280.

46. Karataş E, Arslan H, Topçuoğlu HS, Yılmaz CB, Yeter KY, Ayrancı LB. The effect of diode laser with different parameters on root fracture during irrigation procedure. Artif Organs 2016;40:604-609.

47. Ayrancı F, Ayrancı LB, Özdoğan A, Özkan S, Peker MÖ, Aras MH. Resistance to vertical root fracture of apicoected teeth using different devices during two root canal irrigation procedures. Lasers Med Sci 2018;33:1685-1691.

48. Sandikci T, Kaptan RF. Comparative evaluation of the fracture resistances of endodontically treated teeth filled using five different root canal filling systems. Niger J Clin Pract 2014;17:667-672.

49. Hibst R, Keller U. Experimental studies of the application of the Er:YAG laser on dental hard substances: I. Measurement of the ablation rate. Lasers Surg Med 1989;9:338-344.

50. Firoozmand L, Faria R, Araujo MA, Di Nicoló R, Huthala MF. Temperature rise in cavities prepared by high and low torque handpieces and Er:YAG laser. Br Dent J 2008;205:E1-29.